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FACTORIES AND PLANT

BY

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PREFACE

This volume deals with the provision of 'fixed capital' for munitions production; and it is concerned not only with the supply of new factories, plant and machine tools but also with the use and adaptation of existing factories and plant. The scope and arrangement of this story were limited by two main considerations: the place of this volume in the war production series, and the space available in a single volume of this size. A number of very closely related topics have been almost entirely omitted because they are dealt with in other volumes in this series. The main issues of departmental policy, requirements and production programmes are treated in the introductory volume by Professor Postan; separate volumes have dealt with the administration of war production, the finance of factory premises and plant expansion, the demand and supply of labour for the factories, and the administration of works and buildings. In consequence, many important aspects of the operation of the factories and, even more significant, the background of production programmes, final output and supply, have had to be almost entirely excluded from this volume.

Further limitations were dictated by the nature of the main topic—factories and plant. Many of the factories were the factories of firms and a very large number of the new government factories were managed by industrial firms. Any attempt at an account of so large a number of factories would have been unmanageable; but to single out for separate treatment a few of the private factories would have been wholly undesirable in an official volume. Fortunately, many firms have published full and interesting accounts of their war production and some of them illustrate many of the topics dealt with in this volume.

In preparing this volume it was decided to provide a longer historical perspective than was usual in the official histories. In consequence, in the first chapter, a brief account is given of the development of the modern armament industry, of munitions factories before 1914 and of the provision, of industrial capacity for war production between 1914 and 1918. This provides a comparative approach to the problems of rearmament in 1936 and to war production in 1939. In addition, in most of the later chapters some comparison is made between the industrial resources employed in the two World Wars.

To historians at the end of the century the wars of 1914 and 1939 will no doubt seem very close together, and the First World War will appear as a rehearsal for the Second. This in many ways it proved to be, and nowhere more definitely than in the industrial field. For whereas the Second World War witnessed far reaching changes in strategy and in tactics, the industrial problems in the two World Wars were remarkably similar. This could hardly be otherwise, for although there were developments in the design and effectiveness of some weapons and important additions to war equipment, the basic production problems were generally the same. The same was broadly true of industry; for despite some changes in the balance between the newer and the older industries and some advance in methods of production in some industries, the technology of British industry between the wars remained very much of the same order. Thus the two wars may finally appear as the major military conflicts of an industrial era that has now come to an end with the manufacture of the atomic bomb and the advent of atomic energy.

Though the industrial problems were similar, and although in planning the industrial war potential in 1936, it was possible and useful to draw on the lessons of 1917 and 1918, the scale of the industrial effort after 1939 proved far more extensive. This increase was inevitable; quite apart from other changes, it followed from the full extension of war in the air and from the mechanisation of air and land warfare, in addition to naval warfare. Thus in the Second World War new problems arose regarding the limits and indeed the limitations of the industrial resources for war production. How could three major production programmes—for land, sea and air warfare—be fitted into the industrial structure for war production? How far had the structure to be extended to attain the output of military supplies that was achieved in the United Kingdom?

It is hoped that this volume may help in providing an answer to these questions. Part I of the volume is mainly concerned with the industrial resources brought into action to meet the three main sectors of military requirements—for the Navy, the Army and the Air Force. A good deal of this industrial capacity consisted of new factories specially planned and constructed for military production, or of complete production units installed in existing factories. There were, however, limits to the resources available for the provision of new factories and production units; and in war the need and scope for innovation and for the adaptation of existing capacity increased. An important limitation that had constantly to be taken into account, both in providing new capacity, and in the adaptation of existing capacity, was the supply of machine tools. It was here that the main competition between production programmes occurred. These problems relating to the demand for machine tools and the provisions made for their supply and allocation are dealt with in Part II of the volume.

It will be noted that the discussion of these problems has led to inequality in the space allotted to the work of each supply department. In the main this reflects the range and complexity of their production programmes and the extent of the new capacity that had to be provided. In addition, the Ministry of Supply administration of the Royal Ordnance Factories and of machine tool production has inevitably increased the space devoted to that department.

The preparation of many of the chapters in this volume would not have been possible without the help and information given by production officers in the three production departments. It proved essential and most rewarding to turn aside from the files and the documents in order to learn from the production officers something of the way in which they dealt with their production problems in war-time. My thanks are due to a large number of these officers in all three departments who patiently explained something of the basic production methods employed and the significance of the main requirements for factories and plant. I have also made use of the work of many colleagues with whom I shared the task of preparing narratives on many aspects of war production. I am especially indebted to narratives prepared by Denys Hay, D. Mack Smith, and Mrs. Margaret Dodgson. My research assistant, Mrs. J. M. White, helped with the preliminary research for several chapters, and especially with research into Admiralty production, machine tools and small tools. I am greatly indebted to her for the characteristic willingness with which she tackled any, and often the most unpromising projects for research. Mrs. Margaret Gowing gave invaluable help at a crucial stage in the work of reducing the final draft. Miss Edith Upson helped with the preparation of the typescript. The exacting task of collating the final copy for the printer was undertaken by Miss Hilda Merrifield. Finally, I should like to record my gratitude to Professor Postan; without his patience and encouragement this volume could not have been completed.

WILLIAM HORNBY

London, *July 1957*

ABBREVIATIONS

A.A.	Anti-aircraft
A.D.G.B.	Air Defence of Great Britain
A.D.O.F.	Assistant Director of Ordnance Factories
A.E.C.	The Associated Equipment Company Limited
A.I.D.	Aeronautical Inspection Department
B.S.A.	Birmingham Small Arms Company Limited
B.T.H.	British Thomson-Houston Company Limited
C.M.E.	Chief Mechanical Engineer, Royal Arsenal, Woolwich
C.S.O.F.	Chief Superintendent of Ordnance Factories
D.A.P.	Director of Ammunition Production
D.A.S.	Director of Armament Supply
D.D.G.O.F.	Deputy Director General of Ordnance Factories
D.D.G.O.F. (E)	Deputy Director General of Ordnance Factories (Engineering Factories)
D.D.G.O.F. (F)	Deputy Director General of Ordnance Factories (Filling)
D.D.O.F. (X)	Deputy Director of Ordnance Factories (Explosives)
D.G.F.F.	Director General of Filling Factories
D.G.M.P.	Director General of Munitions Production
D.G.O.F.	Director General of Ordnance Factories
D.G.O.F. (F)	Director General of Ordnance Factories (Filling)
D.G.S.A.A.	Director General Small Arms Ammunition
D.G.X.	Director General of Explosives Production
D.I.P.	Director of Industrial Planning
D.M.T.	Director of Machine Tools
D.O.F.	Director of Ordnance Factories
D.O.F. (E)	Director of Ordnance Factories (Engineering Factories)
D.O.F. (X)	Director of Ordnance Factories (Explosives)
D. of D.	Director of Dockyards
I.C.I.	Imperial Chemical Industries Limited
L.A.P.	London Aircraft Production Group
L.M.S.	London Midland and Scottish Railway
L.P.T.B.	London Passenger Transport Board
M.A.P.	Ministry of Aircraft Production
N.P.L.	National Physical Laboratory
R.F.F.	Royal Filling Factory
R.O.F.	Royal Ordnance Factory
R.S.A.F.	Royal Small Arms Factory
S.A.A.	Small Arms Ammunition
S.B.T.E.	Supply Board Technical Establishment

Part I

CHAPTER I

REHEARSAL AND ANTICIPATION

(i)

Before the Deluge

In the 19th century it gradually became clear that rapid and extensive expansion of armament production was vital to success in war; but it was not until production in the First World War approached its peak that the scale of the industrial problem was adequately understood. What surprised the industrialists and the administrators in 1914 were the difficulties of expansion and the extent of the industrial resources required to wage a modern war. After the event, some blame was attached to armament manufacturers for overestimating their powers of expansion and some war-time administrators felt that more reliance should have been placed on government manufacturing establishments.[1] The truth was that whilst, prior to 1914, the matter had been discussed in general terms no close investigation of capacity had been made; the need for a comprehensive study of industrial capacity for war only gained general acceptance with the unprecedented production problems of the First World War.

Two factors made the ultimate industrial problem inevitable; the increasing size of armies and the increasing use of heavier armament. The effect of the first factor was evident even in the Napoleonic wars but then, as the main difficulties appear to have arisen in the supply of infantry weapons, the problem of industrial expansion was limited. A large holding of these weapons was usual and the rapid expansion of supplies for a mobilisation was not an insuperable difficulty. Nevertheless, difficulties in the supply of personal weapons for the Napoleonic wars resulted in the development of government capacity for the manufacture of small arms. The increasing importance of artillery and heavy guns was painfully demonstrated in the Crimean conflict; an immediate result of this was an increased attention to the design and production of guns and the development of both private and government capacity for their manufacture. The need for an even wider development of heavy armament capacity arose for the provision of armament for the new fleet in 1889. Trial of this capacity as a basis for war supplies came in the South African war. The serious failure in supplies of guns to British land forces revealed the inadequacy of

[1] Royal Commission on the Private Manufacture of and Trading in Arms. Minutes of Evidence 1936; pp. 100-8.

manufacturing capacity to meet an emergency; the superiority of the enemy guns led to an investigation of continental developments in gun design. An immediate result was that improved types of guns were bought from continental arsenals; howitzers manufactured by Skoda at Pilsen and quick firing guns manufactured at Dusseldorf were adopted for the immediate re-equipment of the field artillery.[1]

These developments pointed to a serious deficiency in the evolution of British types. This was not so unexpected as the failure to provide adequate supplies of weapons for the forces in South Africa. After the Crimean War there had been important developments in armament manufacturing capacity, both in private industry and in government establishments. These were now proved inadequate and a policy of placing more orders with the armament firms was adopted to encourage the expansion of capacity in private factories and thus increase the potential capacity for war supplies. The development of improved types of guns capable of satisfactory comparison with continental types was achieved by 1905. In this development, private industry and the gun and carriage factories at Woolwich competed. In general, the designs for the guns were adopted from the armament firms whilst Woolwich contributed mainly to the designs for gun carriages and ancillary equipment. When the re-equipment of the field and horse artillery was undertaken in the years 1904 to 1908 a large part of these orders were placed with private industry.

The introduction of new artillery guns provided little in the way of orders for armament manufacturers except during the years of re-equipment between 1904 and 1908. Both before and after 1900, the major expansion of the private armament factories was mainly to provide supplies for the naval requirement for armour and armament. With the introduction of metal ships and to an even more significant extent with the introduction of armour plate and the consequent competition between gun and armour, the Admiralty requirement presented a demand that could only be met adequately by the combined resources of the heavy metal industry, gun and gun mounting factories and shipbuilding yards. The Royal Arsenal at Woolwich was not equipped to meet the full scope of this demand and could not be expected to compete with the combined resources of the several sections of the heavy engineering industry. Woolwich could and did produce many of the guns for the navy although in years of heavy demand some gun forgings for Woolwich had to be purchased from the trade. But Woolwich did not manufacture the heavy fixed mountings or armour plate. Thus despite the normal allocation to Woolwich of a large part of the requirements of naval guns and ammunition, the only

[1] Maj. Gen. Sir John Headlam, *The History of the Royal Artillery*, Vol. II, (1937).

single capacity capable of meeting the full range of naval armament requirements was in the private armament industry.

To meet the heavy demand for the first modern fleet between 1880 and 1900, industry was encouraged to provide a major share of the new naval guns and mountings. In 1884 it was decided that for heavy gun forgings additional capacity must be found in industry; to ensure this, large orders for gun forgings were offered to Whitworths, Firths, Cammells and Vickers to encourage them to instal plant for forging the heaviest guns. This scheme enabled much larger orders for complete guns to be placed with industry and also for a larger supply of forgings to Woolwich. Thus in the naval building programmes under the Naval Defence Act of 1889 a large share of the very large requirement for guns went to private industry.[1] It had already been decided in 1882 that all capacity for the fixed naval gun mountings—soon to become the main feature of the new fleet — should be with industry and that the Royal Arsenal should not undertake this work.

The naval requirements for British and foreign fleets from 1890 to 1914 account with very few exceptions for the development of the heavy armament industry. These requirements included the whole range of heavy armament manufacture from shipbuilding, guns and mountings, to ammunition and underwater projectiles and craft. The wide scope of this demand, the very close connections both in construction and technique and also the specialised metallurgical basis encouraged the amalgamation of the many sections of the industry into a few firms. So that each firm had capacity for building ships and manufacturing the full range of armament required.[2] The two major amalgamations in this process of vertical integration were both effected in 1897. In that year Armstrongs of Elswick amalgamated with Whitworth of Openshaw. In addition to shipyards on the Tyne, Armstrongs already covered the full range of manufacture essential to naval requirements with the exception of armour plate and certain metallurgical processes. These were provided by the Whitworth capacity at Openshaw which also brought additional highly developed capacity for gun and gun mounting manufacture and one of the most highly developed engineering shops for the manufacture of heavy plant and machine tools including armour plate plant.

In the same year, Vickers & Sons Ltd. of Sheffield acquired the Naval Construction and Armament Co.'s shipyards at Barrow and the

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[1] Responsibility for these decisions rested primarily with the War Office. It was not until 1907 that the Admiralty placed contracts for naval guns. Up to that date responsibility for initiating capacity for guns, ammunition and transferable mountings (but not the fixed mountings) rested with the War Office.

[2] It is of some importance that the Admiralty continued to place orders for ships and armament separately and thus it was the exception that the complete requirements for any naval ship was placed with one firm. The contrary was however usually the procedure with foreign orders.

Maxim Nordenfelt Gun and Ammunition Co.'s works at Erith. Vickers and Sons—up to 1880 primarily steel and steel product manufacturers—had for long had important connections with the heavy armament industry. They produced the large shaftings required for modern ships, and gun forgings which they supplied both to Woolwich and to gun manufacturers. In 1888, they accepted a government contract for the manufacture of complete guns and in the same year successfully produced solid steel armour plate, which was adopted by the Admiralty to replace the steel faced iron plate. With the firms acquired in 1897, Vickers' capacity ranged from shipyards at Barrow to machine guns and quick firing gun and ammunition factories on the Thames. In this one year they achieved a scope similar to that of Armstrong Whitworths in heavy armament and in addition had important capacity for machine guns. Armstrong Whitworths, up to this stage, were much more experienced in ship and armament manufacture; Vickers' main advantage for the future was that they had very extensive metallurgical resources particularly for the all-important armour plate and gun forgings.

The two firms that emerged from the 1897 amalgamations, Armstrong-Whitworth and Vickers each had capacity adequate to construct and equip naval ships. One other firm had similar capacity—Beardmores of Glasgow. There were however other important amalgamations between shipyards and steel and steel product manufacturers. Thus John Brown and Co. steel manufacturers of Sheffield, acquired in 1899 the capacity of the Clydebank Engineering and Shipbuilding Co. Another Sheffield steel firm—Cammells amalgamated with Lairds, shipbuilders of Birkenhead, in 1903. These firms with their steel and shipbuilding resources had facilities for ship construction and the supply of gun forgings but not for the final manufacture of guns and mountings. This deficiency was removed in 1907 when these firms and the Fairfield Shipbuilding Co. formed the Coventry Ordnance Works to manufacture guns and mountings. Thus up to 1914, the basis of the heavy armament industry was the Admiralty requirements together with orders for foreign admiralties; and the structure of the industry was becoming more and more integrated to match the scope of the naval requirement for fully equipped warships.

Manufacturing capacity for small arms developed in almost complete separation from the heavy armament industry. The manufacture of personal weapons and firearms, the musket and the sword, was a very ancient craft. Birmingham early became the most important centre of the craft with London in second place; Birmingham gunsmiths had supplied muskets under standing contracts to the Board of Ordnance continuously for over 100 years before the greatly increased requirements of the Napoleonic wars had to be met. It was not until the serious demands of that conflict developed, that officers of the crown started the assembly of rifles. This was first done at the Tower in 1804 and in the same year at a small factory at Enfield. In 1811, with the continuing demands of the war and the special demands of the Peninsula campaign the Board of Ordnance took over the works at Enfield in an attempt to improve the provision of small arms. These were but the small beginnings of what was to become an important government small arms factory but the dependence on Birmingham was to continue unchallenged until 1855.[1] In the Crimean war the resources at the Enfield factory proved inadequate for war requirements and an important change followed this failure. By 1857, Enfield was equipped with new plant for the mass production of rifles. This was a serious challenge to the master craftsmen of Birmingham where production had been a handcraft for centuries. The challenge was met in 1861 when certain of the leading gunsmiths agreed to form a company for the machine manufacture of small arms. This was the beginning of the Birmingham Small Arms Company and their rifle factory at Birmingham. With these two factories equipped for mass production, the problem of rifle requirements before 1914, except in extreme emergency, was solved.

Up to 1914, the manufacture of machine guns was separate from rifle production and almost entirely with private industry. In 1891, the War Office adopted the Maxim machine gun and in 1897 the manufacturing company was acquired by Vickers. Thus one of the two leading heavy armament firms entered the small arms field but only for automatic weapons, not for rifles. The new interest was maintained and in 1912 a new type of machine gun—the Vickers .303″—was approved by the War Office to replace the Maxim. This was the same calibre as for rifles and there was a consequent close connection in the supply of small arms ammunition. The next machine gun to be adopted—the Lewis—was not finally approved by the War Office until September 1914. Facilities for the development of this machine gun in England had been provided by the B.S.A. Co., and production of the gun had already began in the summer of 1914.

The capacity for gun ammunition had developed in close relation to the manufacture of guns. All the manufacturers of guns also manufactured gun ammunition. With the introduction of rifled weapons, the relation between gun and ammunition became one of ever increasing precision; the use of high explosive and armour piercing shells and of metal cartridge cases introduced important complications in metallurgy and engineering. Armour piercing shot was an important field for metallurgical specialists and early pioneers in this work were

[1] An account of the development of the Birmingham trade is given in *The Other Battle*—a history of B.S.A. Co. Ltd. by D. M. Ward, 1946.

Firths, and Hadfields of Sheffield. These two firms supplied the bulk of this ammunition up to 1914.[1] The principal suppliers of shell in 1900 in addition to the Royal Arsenal were the armament firms—Armstrong-Whitworth, Vickers, Beardmores, Cammel Laird and the steel specialists Hadfields and Thomas Firth. In 1902 a new firm was added—the Projectile Engineering Co. Ltd. Although the main capacity for shell cases and projectiles was with private industry, the filling and final assembly of gun ammunition for British naval and army requirements, prior to 1914, was undertaken at the Royal Arsenal and at naval depots. The Royal Arsenal was extremely important; it dealt with all the army shell and up to 50 per cent. of the naval shell. Most armament firms that manufactured naval shell also undertook the filling and assembly of the loaded shell; but this work was usually for foreign orders. The manufacture of small arms ammunition had also been closely linked with the manufacture of the weapons. Nevertheless by 1900, this connection had been almost completely broken. The B.S.A. Co. had undertaken the manufacture of small arms ammunition but in 1897 their ammunition factory had been sold to Nobel and renamed the Birmingham Metal & Munitions Co. In 1900, most of the principal firms manufacturing small arms ammunition were non-ferrous metal manufacturers, and in the Birmingham area,—the Birmingham Metal & Munitions Co., the Kings Norton Metal Co., Ely Bros. & Kynochs. The one exception was Greenwood & Batley of Leeds, who were also manufacturers of small arms ammunition machinery and plant. In addition, the Royal Arsenal, Woolwich, undertook the manufacture of small arms ammunition on a large scale.

Despite the very large expansion of the armament industry between 1880 and 1914, there were also many major additions made to the manufacturing resources of the three Royal factories—The Royal Arsenal, Woolwich, the Royal Small Arms Factory at Enfield and the Royal Gunpowder Factory at Waltham. Even so, the extension of the government factories might well have been much larger had it not been for the policy of encouraging the peace-time expansion of the armament industry. Paradoxically, although every war in the 19th century in which Britain took part brought a significant increase in the resources of the Royal factories, the inquest on every war after 1850 resulted in a policy in favour of extending the armament industry and limiting, to some degree, the expansion of the government factories. Thus, it was almost true to say that the government factories thrived in war but the armament industry thrived in peace, or on rumours of war.

The first extensive encouragement of the private manufacture of

[1] Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36, Minutes of Evidence, pp. 482-6.

munitions came in the aftermath of the Crimean war. To avoid the difficulties of supply that had been encountered in the Crimean campaigns, it was considered important that the trade manufacture of munitions should be encouraged in peace-time and that available orders should be allocated between trade and government factories so as to encourage trade manufacture. The importance of the trade in stimulating invention and widening the area of production was again endorsed by Lord Morley's committee in 1887. This committee favoured a considerable reliance on the trade and a closer control and limit on the extensions of government factories. Fortunately, both trade and government factories continued to expand and in consequence were in a much better position to meet the very large requirements of the South African war. Even so, the difficulties were sufficient to make it evident that in a war of wider scope in which Admiralty requirements were also included and in which the demands of the artillery would have to be more adequately met, existing capacity would be seriously deficient. Further, the difficulties encountered in the attempt to attain rapid expansion to meet the war requirements, indicated that it was necessary to encourage the development of a larger peace-time capacity. The government factories had been able to expand rapidly because of reserves of unused capacity but in private factories the main reserve plant was for small arms manufacture. It was clear that Government and private factories would be confronted with even greater difficulties in a war involving both naval and army requirements. Reserve capacity at government factories could be further increased but to secure an increase in the peace-time capacity of private firms, larger peace-time orders would be required. In consequence after 1900, a policy was adopted of giving a larger allocation of available orders to private firms.

Almost at the same time it was decided to increase the manufacturing resources of the R.O.Fs. so that the reserve capacity available in emergency would be substantially increased. This process of expansion of capacity which was completed by 1907 emphasised even further the limitation of orders which in the same period had resulted in a considerable reduction of employment. By 1907, the reduction in employment at Woolwich had become very marked and in the protests that were made, the limited allocation of orders to the R.O.Fs. and the exclusion of Woolwich from heavy naval mounting work were very prominent. Even so, the general policy of more limited allocation and the maintenance of reserve capacity was continued, and it was only the increase in naval armament work after 1910 that brought some relief. Before 1900 there had been a more or less equal division of orders between trade and government factories; after 1900 it was proposed that two-thirds of the orders for some requirements should go to the trade factories. In the entire field of naval and army requirements the allocation of orders varied considerably. There were some important stores for which the government factories had no capacity. The most important of these were armour plate, automotive units and machinery for ships and large naval gun mountings. Capacity for naval ship construction was available in the Royal Dockyards but these yards were also used for repair and maintenance work, and were dependent on the trade for materials, armour plate, mountings and engines, and on Woolwich or the trade for guns. Of the other major naval items, the orders for guns in the period 1900 to 1914 were divided about equally between Woolwich and the trade. For naval ammunition the important demand for A.P. shell was met by the steel manufacturers although with very minor exceptions all filling and final assembly was done at Woolwich or at naval depots. The War Office were much less dependent on trade capacity. Almost a full range of armament for the Army was manufactured in government factories and dependence on the trade was mainly for additional quantities only, but in a period of rearmament or in war the dependence on trade capacity for the expansion of supplies was very real.

Despite the very large expansion of the armament industry in the second half of the 19th century and the further expansion up to 1914, the problem of providing an adequate capacity in peace to meet even the immediate requirements of war remained unsolved. The basic difficulty could not be evaded; the peace-time requirements for the land forces and the demand for ammunition of all kinds was so very much less than was required for war. Moreover, throughout the growth of the armament industry, it was the Admiralty demand that dominated the expansion of capacity. This was especially marked in the years 1910 to 1914, when the Admiralty orders to trade firms for guns and ammunition of all kinds was more than double the orders placed by the War Office for armament of all kinds. In addition, the Admiralty orders for ships, armour plate and mountings far exceeded their orders for armament. Indeed, between 1907 and 1914, naval expenditure increased from slightly above army expenditure in 1907 to very nearly double army expenditure in 1913.[1] This rapid increase in the Admiralty demand on specialised industrial resources was the direct result of the rapid expansion of British naval building programmes after 1907 to meet the increased expansion of the German navy. In the same period there was a significant increase in naval construction in the United Kingdom for foreign navies. In consequence, the resources of the heavy armament industry in 1914 were a good deal larger than they had been in 1905 but to an increasing extent the industry was committed to the requirements of naval construction and naval armament.

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[1] Minutes of Evidence, Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36, p. 623.

(ii)

War Production 1914–18

With the outbreak of war in 1914, specialised industrial resources for naval and army munitions were fully committed. The naval construction of the years 1909 to 1914 was the largest so far undertaken but the war years were to see an even greater demand for naval construction and consequent demand for naval armaments. The construction of capital ships was slightly less than in the pre-war years but the construction of all other types was greatly in excess of the pre-war period. In total, 1,040 naval ships were built from 1914 to 1918 and of these only forty-nine were built in government yards.[1] There was some naval armament capacity available from the reduction in foreign orders, but the naval demand on the armament industry was clearly not less than in the pre-war period and in most sections the demand was considerably greater. In consequence, the capacity immediately available for army requirements was seriously restricted by the naval requirements. During the course of the war the abandonment of schemes for army gun production in face of naval demands was not unknown. The War Office had thus to face the problem of expanding capacity to meet the increase in requirements with a large part of the existing resources already committed to naval requirements. This was particularly true of gun production, although the rearmament of the artillery and the competition of the naval armament firms for naval orders had resulted in some increase in the capacity available. In the war period, over 90 per cent. of the supply of guns for the army came from industry and the greater part of the supply came from the armament firms who were also major suppliers for the navy (Armstrong-Whitworth, Vickers, Beardmore and Coventry Ordnance). With the continuous demand on Woolwich for naval guns and for the repair and conversion of all types of guns the supply of new guns for the army from Woolwich was probably not as much as 5 per cent. of the total number of army guns. No other government factory supplied complete guns but in the later stages of the war, National factories at Nottingham and Leeds supplied components and undertook the repair of guns.

The pre-war capacity for rifle production had developed in relation to foreign trade and War Office orders. Here, the War Office had a clear field but the industry had been very inactive in the years preceding 1914. War Office orders had been very few, competition from the continent and from the United States was severe and the total of foreign orders obtained proved very small. In 1912, the War Office had adopted a policy under which R.S.A.F. Enfield supplied all the home

[1] The forty-nine consisted of 6 battleships, 14 light cruisers and 19 submarines. Ibid., p. 631.

service requirements. The trade were thus confined to orders for India and the Colonies. Fortunately the serious fluctuations of the trade had not deterred the main firms from retaining their plant in serviceable condition. Thus with extensive subcontracting of components, the war output of rifles was achieved by expansion of capacity at the three main pre-war suppliers including R.S.A.F. Enfield. For the immediate war requirement the two trade firms—B.S.A. Co. and the London Small Arms Co.—were able to supply over 50 per cent. of the total supplies, with Enfield supplying the remainder. Of the total war production of rifles Enfield supplied with the aid of subcontractors, over 2 million rifles, and the trade firms over 1¾ million. Supplies of rifles from the United States amounted to well over a million. Both the Admiralty and the War Office were interested in the production of machine guns. They were used not only by the land forces and on ships but also in aircraft. War production was notable in that all supplies came from the armament firms. The Maxim and the Vickers machine gun which replaced it were produced entirely by Vickers, the Lewis gun by the B.S.A. Co. and the Hotchkiss gun by the Sociète Hotchkiss in a factory at Coventry. Capacity at Vickers and at B.S.A. factories had to be greatly expanded to obtain an output of at least 1,000 guns a week from both firms. In August 1917, the increased demand for Vickers guns due to the new air-force and for the tank programmes, resulted in a decision to establish a National Machine Gun Factory at Burton-on-Trent, at a cost of £75,000. This was planned to produce 400 guns a week but the factory did not come into production of guns and was only used for repair and overhaul.

The expansion of capacity to meet the war requirements for ammunition proved a more complex and difficult problem. For small arms ammunition specialised plant was required and any expansion of existing capacity outside the established manufacturers was a difficult undertaking. Only one trade firm was added to the pre-war firms in the course of the war. For the first three years, expansion was mainly achieved by extensions to the capacity of the pre-war firms. To meet the large increase in small arms ammunition requirements in 1916, it was decided to provide four more factories—one as an addition to the Royal Arsenal and the other three as National Factories managed by the three specialist firms.

The demand for gun ammunition proved almost insatiable and certainly exceeded even the wildest calculations of the earlier years. The war demand for ammunition was inevitably the one most out of proportion to the existing peace-time capacity. The most that could be expected was that technical knowledge and methods of manufacture for heavy shell would be maintained, in peace-time. On the other hand, light shell machining required only moderate engineering skill and this capacity was indigenous in all engineering areas. This was the basis of the National Shell Factories under local boards of management. They were in most instances new manufacturing units (not necessarily new buildings or plant) in which local engineering skill plant and management were combined. The difficulties in manufacturing heavy shell were more serious and required the resources of a proved manufacturer. Thus the National Projectile Factories were established either with armament firms or with competent heavy engineering firms for management. The necessity for competent technical knowledge and management was even more imperative for explosives factories. In consequence, the nine agency factories were all managed by explosives or chemical manufacturers and by far the greater proportion of new capacity was under the direct control of the explosives division of the Ministry of Munitions. The more dangerous and difficult filling processes brought filling factory development into a similar position, except that it was found practical to establish five factories for simpler filling under local Boards of Management. For only one of these Boards were the members drawn from the trade. The more difficult filling was confined to factories under the direct control of the Ministry of Munitions or to agency factories. The latter were managed by armament or explosives manufacturers but the factories under direct control provided the largest additional capacity.

Thus, a large part of the increased requirements for guns, small arms and small arms ammunition was provided by an expansion of the existing trade and government capacity but in all these stores the stage was reached at which it became necessary to plan further expansion by the provision of what were termed National Factories. These factories proved of limited importance for guns and small arms but were of considerable importance for ammunition. This was indicative of the special position of ammunition in prolonged warfare. The fullest development of National Factories was for the supply of shell ammunition, projectiles and explosives and for the filling of ammunition. There were significant differences in the management employed. Thus for light shell, two of the factories were under direct government control and the rest—more than 40 factories under local boards of management. Similarly, for projectile and heavy shell factories only two were under direct government control and the remainder—thirteen factories—were managed by industrial firms. For explosives and filling factories the situation was very different, twenty of the explosives factories were under direct control of the Ministry of Munitions and nine under agency management. National Filling Factories had all three types of management, eight factories including the largest, were under direct control, six factories were under agency control and five factories were under boards of management.

As a result of this extensive provision of National Factories, a very large part of war capacity was separate from trade capacity. For despite the employment of trade firms as agents to manage some of the National Factories, the trade firms were not financially responsible for these factories; they were not an extension of the firms' industrial capacity. The significance of this additional capacity is best illustrated by the figures shewing the proportion of the peak output which was supplied from the national factories including the pre-war Royal Ordnance Factories and the increase from the 1915 position.

	1915	*Peak*
Empty shell	17%	29%
Filled shell	85%	89%
Filled Mortar shell	63%	100%
S.A.A.	21%	30%
High explosives	22%	65%
Propellant	24%	58%
Rifles	44%	59%

The increase was important for all except the filling factories where the small increase confirms that the already established principle of government filling factories was maintained. For all but empty shell, small arms ammunition, guns and automatic weapons, the output from state owned factories was more than half the peak output but whilst for S.A.A. and guns and small arms a very large part of the capacity outside government factories was with armament firms, a very substantial part of the manufacture of empty gun ammunition—empty shell—was at the peak of war production undertaken in the workshops of a large number of engineering firms outside the armament industry.

The introduction of outside firms was of very great importance in the production of tanks. Indeed, tank production was significant in that although armament firms supplied armour plate and machine guns, the construction and indeed much of the development work were undertaken by outside firms. The two main construction firms were an agricultural tractor manufacturer and a railway carriage and wagon manufacturer. The two other constructors were locomotive builders; many components were obtained from the locomotive industry and from general engineering firms. A matter of great significance was the close link that was necessary with automobile manufacturers, who provided engines and some automative parts and who were already finding a special place in war production with the demand for mechanical transport.

Of even wider significance was the place of the new and immature aircraft industry. The demand for military aircraft had barely begun in 1914 but the two leading armament firms—Vickers and Armstrong-Whitworth already had factories for the development and production of aircraft. But most of the aircraft firms were outside and were to remain outside the armament industry. In war, it was the close link with the growing motor vehicle industry which was to prove the most significant means of expansion. The Royal Aircraft Factory originally established as a balloon factory had from 1912 been devoted to design and erection of airships and aeroplanes for the Navy and the Army, but after 1914 it was mainly used for army aeroplanes. From 1915 to 1918, some 482 aeroplanes were built at the factory and over 2,000 engines repaired but the most important function of the factory was as an experimental establishment. In the war period, a total of over 55,000 planes were produced in the United Kingdom and by far the greater proportion of these came from the new aircraft industry. It was not until 1917 that the decision was taken to supplement output by the provision of national factories. These factories were under agency management and were in operation to some extent by April 1918, but they came too late to make any substantial contribution to war supplies.

The manufacture of tanks, mechanical transport vehicles and above all aircraft, marked the extension of military requirements far beyond the confines of armament manufacture. These were significant portents for the future; but they were quite separate from the solution of the problem of armament manufacture between 1914 and 1918. In this the three Royal Factories for armament production, Woolwich, Enfield and Waltham had a very important part. The advent of the National Factories did not affect the special position of the Royal Factories. With the formation of the Ministry of Munitions the factories became the responsibility of Director General of Munitions Supplies, and subsequently they became the nominal responsibility of a member of the Munitions Council, but production at the factories continued under the direct control of the superintendents and on a greatly expanded scale. The Royal factories remained important key factories, not merely because of their production of a great variety of stores but as centres of important technical and experimental work. The Admiralty had important claims on Woolwich, and in consequence, the claims of the Ministry of Munitions on Woolwich were limited in certain sections, particularly for guns and shell. All the Royal factories were extended in the course of the war; the Royal Arsenal, Woolwich became the largest munitions factory in the world; the Royal Small Arms Factory at Enfield provided over 50 per cent. of the United Kingdom output of rifles and the Royal Gunpowder factory was expanded to more than three times pre-war capacity.

This war-time expansion of the Royal factories was quite contrary to policy before 1914. Similarly the provision of national factories had no place in a pre-war policy, which had placed almost complete reliance on a very large expansion of capacity under the armament firms. Some of the national factories were under the management of the armament firms but many were not; the national factories brought a fairly wide range of firms into armament production but an even wider range of firms undertook munitions production in their own factories. Thus in the First World War there emerged three major methods of expansion which had no place in pre-1914 policy but which were to become an essential part of policy between the wars—the expansion of the Royal Ordnance Factories, the provision of a large number of agency factories and the employment of a large number of engineering firms in their own factories.

(iii)

Industrial Resources and Post-War Demands

The development of new capacity continued right up to the end of the war and several new factories were completed too late to come into production. At the end of the war decisions about disposal or retention had to be taken over the full range of additional capacity. The problem differed in some respects between the different types of factories, but with very few exceptions there proved to be little justification for retention of the additional capacity. The war-time range of factories had presented the possibility of decentralisation and the dispersion of the Woolwich factory units. This problem was examined by the McKinnon Wood committee appointed in 1918. In their report in 1919 the Committee were unanimously in favour of the retention of Woolwich as the arsenal for munition manufacture in peace-time[1] and emphasised the importance of the Royal factories as the essential basis of armament capacity for peace-time requirements. These factories had been considerably expanded but the possible advantage of retaining some of the war-time factories under direct control as reserve capacity for the Royal factories had to be considered. It was eventually decided to retain reserves of plant and machinery in storage at three factories, Birtley, Hereford and Blackpole, but none of these factories were to be kept in operation.

The method of provision of the war-time factories greatly reduced the problems and economic repercussions of disposal. In all the National factories, whether under direct or agency control, the capital assets were government property and consequently their disposal presented no financial problem to the firms who had acted as agents. The position was quite different when the expansion had been undertaken within an existing industrial organisation. Some of this expansion left considerable additional physical assets in the hands of the firms and at

[1] Cmd. 229, March 1919.

some factories plant was purchased at a nominal sum from the government. In general however, financial provisions of varying types had been introduced to prevent the financial position of the firms from suffering because of the war-time provision of these additional assets. Nevertheless, where the firm retained possession after the war, problems of the economic use of the plant might be formidable. The position was much more serious where the expansion had been entirely financed by the firm. Even then, so far as war expansion was concerned, most firms had ample opportunity for recovering the costs of expansions and avoiding any physical or financial burden; it was a situation that required realistic financial adjustment. Nevertheless, the armament firms were confronted with a very formidable problem. This arose mainly from the pre-war expansion of their capacity which had been proceeding for varying periods before 1914. The crux of the problem was that even with the war-time expansion removed, the capacity they had developed up to 1914 was far in excess of the requirements of the post-war decade. Even in the later stages of the war it was clear that government factory capacity would be more than sufficient for the peace-time armament requirements. The matter was put clearly by the McKinnon Wood Committee in their interim report of November 1918.

> Assuming, therefore, that a Government factory is kept in existence, and that the supply of armaments is greatly reduced in quantity, it more or less follows that the present outlay of the larger private firms for armament production will be considerably reduced, and such manufacture will not improbably disappear as a speciality. It is also probable that the country will insist on the production of all armaments being confined to Government factories; nor would the disappearance of the larger armament firms materially handicap production in the event of a serious war, since during the present war a very large number of engineering firms have been educated in armament manufacture, and the basis for armament supply is now so broad that specialising in the future on the part of a limited number of firms will probably not be necessary for the safety of the country.[1]

This opinion presented a very gloomy future for the private armament firms, who might well doubt the correctness of some of the conclusions drawn from war-time experience. Nevertheless, it was clear to the firms that they could not survive if they were to rely on armament manufacture. The balance of the specialist firm's production would have to be very different from what it had been in the pre-war period.

The problem of alternative manufacture was not new. Some alternative had always been necessary to the survival of small arms and

[1] Cmd. 229, p. 8.

small arms ammunition firms; but some heavy armament firms had become increasingly dependent on armament manufacture and naval shipbuilding. In 1920 it was clear that armament production must have a much more limited part in their peace-time activity. One of the first to react was Vickers, who obtained orders for Cunard liners and oil tankers for their Barrow works and increased the diversity of their production interests by control of electrical equipment and oil engine manufacture. By 1925, Armstrong-Whitworth and Vickers had done a good deal to extend their activity by purchasing control in other industrial units. The control of additional industrial units brought diversity and new importance to these firms but it did not solve the problem of utilising existing capacity. Some work was provided for iron and steel manufacturing capacity but little for the actual armament fabrication facilities. The most direct use of specific facilities was the construction of commercial ships in the warship yards; but after the shortlived boom of 1920, orders for commercial ships declined below the pre-war level. Not until 1924 were there any orders for new naval ships and then only sufficient to employ a fraction of the available capacity.

When prices slumped and trade declined the financial structure of the firms, considerably expanded to meet the new activities, was soon found to be in jeopardy. In 1925, Vickers had to adopt a writing down of capital to a third of the nominal value and in 1927 Armstrong-Whitworth were faced with the prospect of liquidation. These financial difficulties were only partly due to lack of employment for the armament capacity,[1] but this factor served to aggravate and bring to notice the unsolved problem of the maintenance of armament capacity. In 1926, an investigation by a joint committee of the two firms of Armstrong-Whitworth and Vickers resulted in a decision to amalgamate the armament capacity of the two firms. The greater part of the capacity including much of the shipbuilding capacity was out of production. It had to be admitted that the armament capacity of the two main armament firms was too large for the exceedingly restricted demand and, as was even more significant, this capacity could not be maintained even by the joint income of these two firms. In the reorganisation of 1926, the armament capacity was separated from the iron and steel manufacturing capacity. The linking of these two had been a source of strength up to 1914; now their separation seemed vital to survival. The complementary process, the amalgamation of the steel interests of the two companies and those of Cammell Laird followed in 1929. The amalgamation was effected by the formation of the English Steel Corporation. This step was in some measure due to the decline in orders for commercial steel production but it also had the advantage

[1] Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36, Minutes of Evidence, p. 363.

of combining the capacity for the production of important primary requirements for armament and warship construction, particularly armour plate production.

The Admiralty demand for ships and armaments had provided a firm basis for the vertical integration of the steel and armament firms. The decline in that demand was now an important factor in the process of disintegration. The example of disintegration and amalgamation set by Vickers and Armstrong-Whitworth was followed in some form by most of the other main Admiralty contractors. Cammell Lairds had included steel, armament, ships and rolling stock in their capacity. By 1930, they were left with shipbuilding capacity only. Steel capacity and with it gun forging capacity, went to the English Steel Corporation and rolling stock capacity to the Metro-Cammell Carriage & Wagon Company, a merger with a Vickers subsidiary. Cammell Lairds participated in all these mergers but only shipbuilding remained entirely under their control. Another disintegration of an Admiralty armament firm occurred in 1931, when the steel and shipbuilding capacity of John Brown & Co. were separated. Shipbuilding remained entirely under John Brown but the steel and gun forging capacity was merged under joint control with that of Thomas Firth. Both firms had manufactured gun forgings and Firths had specialised in armour piercing shell. One further disintegration should be recorded. Just after 1930, Beardmores sold their shipyard and closed their marine engine works. This was the decapitation of a long established armament organisation which had the capacity to provide the full range of the Admiralty requirement. What survived was a valuable steel factory with capacity for armour plate and gun forgings.

In the same period that witnessed the vertical disintegration of the heavy armament firms, there were very important amalgamations in the chemical industry. The foundations of this development had already started during the war and the first major amalgamation was formed in 1918 as the Explosive Trades Ltd. This was an amalgamation of over forty companies headed by Nobels. The companies included with one exception[1] all the small arms ammunition manufacturers, most of the explosives manufacturers and a number of chemical manufacturers. All these firms had been fully employed during the war on ammunition, explosives, or chemical warfare stores. Most of the ammunition manufacturers had important non-ferrous metal capacity and some of the explosive manufacturers had other chemical capacity. The idea of the amalgamation had been encouraged by the war-time co-operation of these firms under the Ministry of Munitions. Advantages claimed for the amalgamation were the pooling of resources and technical knowledge, increased scale of operative unit and the value of a unified commercial unit to deal with

[1] The exception was Greenwood & Batley.

foreign competition organised on similar lines. In addition, there was the general problem of adjusting a large ammunition and explosives capacity to peace-time demand. In the years immediately following the war several other sections of the chemical industry were making trading agreements and examining the prospects for amalgamation.

In 1926, came the formation of Imperial Chemical Industries Ltd. In this the great interests of Nobels, Brunner Mond, Mond Nickel, United Alkali, and the British Dyestuffs Corporation were combined. The amalgamation combined capital of over £56 million. The 1918 Explosives Trades Ltd. formed the basis of the Explosives Division and the Metals Division including the S.A.A. capacity. To these were now added the Alkali, General Chemicals, Fertiliser Divisions and in 1928 by further amalgamation, the Dyestuffs Division. The I.C.I. was an amalgamation of a large part of the chemical and allied industries. The capacity for ammunition and military explosives production was a small section of this vast organisation but this capacity included the major capacity for S.A.A. and explosives production outside the Royal Ordnance Factories. As a result of this amalgamation, the I.C.I. became the largest United Kingdom supplier of synthetic chemicals particularly ammonium nitrate and dyestuffs. The commercial demand for these substances was sufficient to maintain the capacity incorporated and later to be developed in the I.C.I. organisation; but it was inevitable that in any major war the resources of this organisation would be of paramount importance.

In 1914, the aircraft industry of about twelve firms was virtually in the experimental stage and few firms had been in existence more than three years. The 1915 output of less than 2,000 aircraft was expanded by 1918 to an output of over 30,000 aircraft. An important contribution was made by subcontractors and specially organised schemes of component supply but the main impact of the expansion was seen in the expansion of assembly facilities and floor space at the aircraft firms. The post-war decade witnessed a contraction of production to negligible proportions. In 1924 the number of aircraft produced in the United Kingdom was 503 and even in 1930 it was only 1,456. The process of contraction was indeed severe. Fortunately the largely manual methods of assembly made the process financially less severe than it would have been for a mechanised industry. Plant and equipment was a small part of assembly capacity, the main element was floor space, and this had been provided in comparatively simple buildings. More serious than the problem of contraction were the prospects for the industry. An annual total United Kingdom output of 500 or even 1,000 aircraft was an inadequate basis for the existence of even twelve aircraft firms.

Throughout the post-war period the main stay of the industry was the demand for military planes. The Air Ministry orders for aircraft for the six years 1928 to 1933 provided an average annual demand of 612 aircraft and in any year they were always more than 50 per cent. of the total output. With the military element in the exports, the demand for military requirements amounted to at least 75 per cent. of the orders. Without orders for military planes the industry would have had very little justification for existence. The position of the engine manufacturers was in some respects less precarious. Aero-engine production had valuable connections within the motor vehicle industry; war-time expansion had been mainly achieved by expansion within that industry and more than one aero-engine firm had important motor vehicle production. Up to 1919, the airframe firms did not undertake engine manufacture. In that year the Siddeley engine manufacture was brought into an aircraft group but the first engine manufacture by an airframe firm was in 1920 when the Bristol Aeroplane Co. established their own engine production. The only other aircraft firms to follow this precedent and to undertake engine production were de Havilland and Blackburn.

Despite the serious deficiency of orders, there was only one amalgamation in the post-war decade. This was the formation of the Armstrong Whitworth Development Co. in 1919—more appropriately named the Armstrong Siddeley Development Co. in 1927. This amalgamation brought under single financial control the resources of Armstrong Siddeley Motors Ltd. (1906), Armstrong-Whitworth (Aircraft) Ltd. (1913), A. V. Roe & Co. (1913) and Gloster Aircraft Co. (1917). Thus in 1919 the automobile engineering capacity of Armstrong Siddeley was joined to the aircraft manufacturing resources of three aircraft firms. This provided an important link between engine and air-frame production. Historically, it has the added interest of emphasising the continued operation of Armstrong-Whitworth in a new industrial field. This amalgamation was extended in 1935 when the Hawker Siddeley Aircraft Co. was formed to acquire control of the Armstrong Siddeley Development Co. and the Hawker Aircraft Co. the successors of Sopwith Aviation Co. (1911). In these amalgamations the several aircraft firms continued as separate design and manufacturing firms. The continued existence of a comparatively large number of separate design firms resulted in the continuance of competition in design despite infrequent production orders. Within limits of floor space, the operating capacity for construction and assembly could be expanded or reduced; hangars could be used for storage, aerodrome accommodation or assembly. Several firms combined training and instruction schools with their establishments. Thus the technical and design resources were maintained with a minimum of production. The potential capacity of the firms was clearly much greater than their active capacity. This was so much reduced as to raise doubts as to the possibility of expanding the technical and managerial resources to match the potential productive capacity.

The Admiralty demand before 1914 fluctuated but never to the extremes of the War Office demand. Foreign admiralties supplemented the British demand in a very satisfactory manner. This demand for naval construction reached the peak for peace-time in 1911 but the demand was at a very high level throughout most of the period 1901 to 1913. A comparative slackening of Admiralty demand in the middle of the period increased the competition for the available orders. In the same period the output of merchant ships and other types of civil ships reached a pre-war record. The launching of merchant ships for 1913—1,932,000 tons gross—was in fact exceeded by the year 1920 with 2,055,000 tons gross, but naval construction in 1920 was small. Thus in 1914, the shipbuilding capacity of the United Kingdom in terms of tonnage completed was at a peace-time zenith. In 1913 the tonnage of naval construction in government yards also reached a peace-time record. Armour and armament capacity in this period of fairly constant demand had been expanded to match the expansion of shipbuilding capacity.

As a result of the war and the boom that followed, shipbuilding capacity was even further increased.[1] From 1916 to 1921 world construction of merchant ships was more than double pre-war construction but by 1922 the boom was over and even the pre-war levels were not maintained. Despite the record construction of 1920, Great Britain had a much smaller share of the world demand and by 1923 construction had dropped to the lowest recorded output for modern shipbuilding. With the end of the war, Admiralty orders ceased until 1924 when some new cruisers were ordered but these orders were negligible to an industry that had been built on the naval programmes of the pre-war era. Up to 1934, the Admiralty demand remained at a fraction of the pre-war level. The average for these years was less than the tonnage that had been constructed by the government yards alone before 1914. The average active use of the naval capacity was up to 1934 at much less than a quarter of what it had been before 1914. On the other hand merchant shipbuilding, though sadly reduced, was even in 1930 at more than half the 1920 peak activity. After 1930 when the merchant ship construction fell to negligible proportions the active shipbuilding capacity of all kinds was reduced to a level unknown in the annals of British shipbuilding.

[1] See Chapter II p. 38.

The persistent deterioration in the shipbuilding industry and the very limited activity of the aircraft industry were viewed with concern in the Committee of Imperial Defence and in the Principal Supply Officers' Committee[1] but a matter for even greater concern was the general deterioration in the armament industry. By 1930, the decline in armament capacity was very great. The Coventry Ordnance Works which had supplied gun and mountings to several naval shipbuilders as well as to the War Office had gone out of business at the end of the war. John Browns who had supplied gun forgings to Coventry Ordnance had abandoned their gun forging capacity. Beardmores, important both for naval shipbuilding armour and gun manufacture, had disposed of the shipyard and had only limited capacity for gun manufacture. The armament resources of Armstrong-Whitworth, Cammell Laird and Vickers had been amalgamated in Vickers-Armstrongs. This had resulted in considerable reduction of capacity. The great Openshaw works of Whitworth had been largely dismantled and the Erith works of Vickers had been closed. Darlington Forge—important both for ship and gun forgings—had been brought into the English Steel Corporation group and closed though held in reserve. The capacity in private industry for rifle production was reduced to one firm, B.S.A., whose small arms plant had remained idle since 1919.

The situation in the armament industry was well known in government circles. In March 1933, the Prime Minister called for a report on the position of private armament industry in the United Kingdom, in relation to the following aspects.

(1) The position of private armament industry in the system of Imperial Defence.
(2) The position today compared with pre-war.
(3) How far the industry is dependent on foreign orders.
(4) The position of foreign armament industries.

The reports submitted rightly presented a gloomy picture. The importance of the private armament industry in the system of Imperial Defence was by no means diminished. The Admiralty depended very largely on private firms and although much of the peace-time needs of the army could be obtained from the Royal Ordnance Factories, it was clear that private industry would be needed in emergency. There was no doubt that the present state of private armament capacity both as regards the number of firms, factories and shipyards, as well as their reserves for expansion was far inferior to 1914. The general depression in heavy industry had seriously reduced the general resources of the heavy armament industry but there were more specific factors

[1] For an account of this organization of the Principal Supply Officers' Committee and the Supply Board., see J. D. Scott and Richard Hughes *Administration of War Production*, in this series (H.M.S.O. 1956), p. 54ff.

which had brought about the decline in specialised capacity. The limitation of United Kingdom armed forces and the large war surplus of military equipment had reduced the United Kingdom demand to negligible proportions. There was a general lack of foreign orders, and the control exercised by the government on the export of arms from the United Kingdom discouraged and in some instances prevented the acceptance of foreign orders. There had been a large increase in the armament industries of other countries and in many countries these industries were heavily subsidised and were largely sufficient for their own requirements. In addition, they were able to compete successfully for the few foreign orders available, including orders which United Kingdom firms were unable to undertake because of export restrictions.

It had also to be reported that the decline in armament capacity was affecting even the limited programme of naval construction undertaken since 1927. Thus delays in completion of the battleships Rodney and Nelson were caused by deficiency in capacity for design and production of mountings. The continued decline in capacity would further reduce the output which could be provided in an emergency. On every question raised by the Prime Minister's enquiry there was cause for great concern. The armament industry was essential to bridge the gap between the outbreak of war and the mobilisation of general industry for war production. An armament industry maintaining an adequate output of warlike stores as part of its normal peace-time activities was essential to Imperial Defence. The existing resources of the armament and shipbuilding industries were definitely inferior to those existing in 1914 and, in addition, the resources for intermediate products especially in the iron and steel industry had been seriously affected by the decline in heavy engineering after 1920 and subsequently by the general economic depression.

It is clear that it was difficult to exaggerate the extent of deterioration but there was a tendency to underestimate the total potential resources. There were indeed serious difficulties in assessing what was the potential capacity of inactive but partially equipped workshops. Investigation undertaken continuously by a subcommittee of the Committee of Imperial Defence revealed the need for drastic action in almost every sector of munitions production. For some stores, notably explosives and chemical stores, the calculation of resources and deficiency could be precise. Similarly, for these stores, the policy for expansion within the R.O.F. organisation and the I.C.I. was clearly defined. For weapons and ammunition the position was very different. A satisfactory estimate of what capacity could be made active was extremely difficult. The calculation of what resources could be obtained by employment of engineering or other generally suitable firms was not possible without detailed investigation of the firms' equipment and a decision as to the methods of manufacture that might be adopted. One thing was certain; the capacity available at the R.O.Fs and that likely to be available from the armament firms fell far short of what would be required. This was true of all weapons and ammunition with the possible exception of S.A.A. and rifles; it was particularly true of guns, shell, gun carriages, tanks and mountings.

In 1933, confronted with the serious decline in the armament industry and faced with the problem of deciding what policy should be adopted to meet the large deficiency in armament capacity, the Supply Board with the approval of the Committee of Imperial Defence sought the advice of industrialists who were conversant both with the munitions production in the First World War and the general resources of post-war industry. The general problem of organisation of supply for war production and the main difficulties arising in the preparation of plans for war potential were placed before a committee of three industrialists—Lord Weir, Sir Arthur Balfour and Sir James Lithgow. In submitting their report in February 1934, the committee confirmed the serious deficiency in armament production resources and the decline in the armament industry. They were impressed with the favourable situation in countries where standing armies were much larger than in the United Kingdom. As any possibility of a large increase in the peace-time demand for armaments was not to be taken into account, the committee had to base their proposals on improving resources within the existing industrial structure. In their report, three main methods were proposed for the expansion of potential resources of armament manufacture—mainly guns and ammunition at this stage. The first step should be to decide what expansion of the capacity at the Royal Arsenal Woolwich and at Vickers-Armstrongs could be obtained within the factory units at present under their control. After this it should be decided what new capacity could be organised and operated by these two authorities acting as parents to new factory units. Some of the remainder of the capacity required might be provided by smaller armament firms but a large part of the additional capacity would have to be obtained by the introduction of selected engineering firms into armament production. Although the introduction of outside firms was intended to provide capacity for munitions production in war, it was essential that detailed preparations should be made in advance. Firms had to be selected, their plant investigated and if possible, educational orders arranged to ensure that the work could be undertaken effectively in war.

The introduction of outside firms into armament production was immediately described as the formation of a shadow industry. This and the other proposals for expansion of armament capacity were accepted in principle by the Committee of Imperial Defence and in May 1934 the Supply Board was given authority to recruit additional staff and to undertake the investigation of selected firms. A good deal of progress had been made in this work when in February 1936 the Cabinet decided that part of the proposed shadow industry should be brought into operation immediately as it was clear that the rearmament requirements would exceed the resources of the state factories and the armament industry. Several firms were immediately brought into armament work and the shadow industry which had been intended in preparation for war expansion was brought into action for rearmament requirements. Similar immediate action had to be taken in the expansion of aircraft capacity. Though the term was not used in official documents until 1935, a shadow industry scheme for the war-time expansion of the aircraft capacity had been drawn up in the Air Ministry as early as 1927 and approved by the Committee of Imperial Defence. This was a much less general application of the shadow principle; it was confined to selected firms from the motor vehicle industry. In 1936, it was decided that this scheme was needed immediately for the rearmament programme.

From 1936 onwards there was a rapidly increasing introduction of firms for rearmament production and an even larger allocation of firms for possible employment in war production. In the allocation and selection of firms for armament production, there was direct competition between all three departments—particularly between the War Office and the Admiralty—and indeed between production divisions. Thus in rearmament, the shape of the eventual industrial problem in war could be discerned—the division not of a part but of the whole of the engineering resources of the country between the competing demands of production for the three armed forces.

(iv)

The Industrial Problem

In industrial capacity for war production there was a tripartite division which roughly corresponds to the departmental spheres, in the pre-war period of the Admiralty, War Office and Air Ministry, and in war-time of the Admiralty, Ministry of Supply and Ministry of Aircraft Production. Despite the many difficulties of co-ordination, there can be no doubt that the tripartite division of capacity, to a very large extent, corresponded to the physical and industrial facts and that for the greater part, the departmental approach was both inevitable, logical and to a large degree economical and effective. It was indeed the natural force of the essential division which made the co-ordinating work of the Ministry of Production so difficult and in many aspects so limited.

Two of the main divisions correspond to the normal industrial divisions, the shipbuilding and the aircraft industries. Both these industries were well-defined; and although the aircraft industry was very greatly expanded and included many large war-time accretions, the shipbuilding industry remained almost unchanged in structure and physical extent from 1935 to 1945. In contrast, there was in 1935 some doubt as to the very existence of the armament industry. In 1937, there were indeed those who alleged that the government wished it to be understood that the armament industry no longer existed in Great Britain.[1] The life of the shipbuilding and aircraft industries was not without uncertainty, but the great advantage of these industries was the civilian counterpart—the merchant ship and civil aircraft. The armament industry, strictly defined as concerned with weapons of war and ammunition, could have no such peaceful counterpart; the only other outlet was the export market. Between the wars the export trade had a limited effect on military tank production but generally after 1918, it may be said, that with the loss of home and overseas demand, the armament industry reached the verge of extinction. No satisfactory basis had been found for the peace-time existence of the armament industry; quite apart from the effects of disarmament and requirements arising from replacement and modernisation could have only supported an armament industry on a very much smaller scale than in 1913. The armament industry could never enjoy the independent existence which was available to the shipbuilding and the aircraft industry even in times of very limited military demand.

The problem of survival affected the government manufacturing establishments in somewhat different ways. For the Royal Dockyards the problem had already been faced before 1914, when, the need to secure the maintenance of a large naval shipbuilding industry had to some degree threatened the continuance of shipbuilding in the Royal Yards. After 1900, the heavy burden of the repair programme emphasised the importance of the continued operation of Royal Yards; at the same time it was clear that technical knowledge and competence in the Royal Yards could not be maintained without some share in new construction.[2] This policy continued in the inter-war years. After 1920, the Royal Dockyards suffered from the effect of naval disarmament and two dockyards were closed but whilst the fleet remained, the Royal Dockyards had to be retained and their efficiency maintained.

The fate of the Royal Ordnance Factories was somewhat different. Before 1914 the Royal Arsenal at Woolwich was at times drastically affected by the allocation of orders to private industry, and although most of the repair work was undertaken there it was not sufficient to

[1] H. of C. Deb., Vol. 324, Col. 282, 26th May 1937.

[2] See Chapter III, page 65 ff.

fill the gap. Thus the problem remained until 1914, when the war-time requirements brought the expansion of activity and employment at the Royal Arsenal to an all-time record. One important effect of the war was to emphasise the limitations of the armament industry and the necessity of retaining some state manufacture for the more specialised munitions. With the decline in the armament industry after 1918, the three Royal Ordnance Factories—Woolwich, Waltham and Enfield became even more valuable assets. In the preliminary investigation of rearmament problems and even more from 1935 onwards, these three factories came to life again. The expansion of the private armament industry before 1914 had seen a comparative decline in state manufacture; after 1918 the decline in the armament industry brought the state factories into the leading position for planning and for production.

In 1920, the Air Ministry was confronted with the problem of encouraging the growth of the aircraft industry under peace-time conditions. This was an even more delicate situation than had confronted the War Office in the 90's. The position was much more difficult than that of the Royal Dockyards; ships were for the most part built individually and there was no question of quantity production. Hence it was possible to divide even a small naval requirement between the private and the government yards. For aircraft, manufacture in quantity was essential to economical production; but up to 1934 there was barely sufficient to keep the industry alive. With the serious lack of orders, it is not surprising that the Royal Aircraft Factory was renamed the Royal Aircraft Establishment and the production of aircraft confined to private industry. The aircraft industry which had sustained the impact of a war programme whilst still an infant industry showed a remarkable will to persist. The physical structure of capacity was not easily transferred and the manufacturing equipment at this stage was very limited; moreover it was not unreasonable to assume that the day of air travel would eventually arrive. Even so, despite the careful nursing administered by the Air Ministry with a very meagre diet of orders, it was to a large degree the fortitude and determined individuality of the firms that kept them in existence. Up to 1934, their enterprise was shown primarily in the designs which they produced rather than in any organisation for production.

The position of the armament industry was far more uncertain and confused, for as we have seen, the very existence of the industry was in doubt. It was indeed doubtful how far even the basic technical knowledge and the limited stores of reserve plant had been preserved in the few firms who were at all interested in armament production. The most complete conspectus of knowledge and interest was now in the Royal Ordnance Factories. Even though the capacity of the remaining firms could be revived and rehabilitated it would not immediately extend very far. It might be possible to meet a large part of the Admiralty requirements but to do this would leave little for War Office requirements. A lesson of the First World War was that the heavy armament industry even in 1914 was barely sufficient to meet the Admiralty requirement for guns, mountings and ammunition. In war, it had eventually expanded to meet much of the army requirement of guns; but in 1935, it did not seem reasonable to expect such an expansion when the peace-time industry was a mere shadow of the 1914 industry. It was now clear that there should be no limit to the production expected from the state factories—the Royal Ordnance Factories.

Up to 1936, the survival of these three main sectors of munitions capacity appeared as the main problem; but in the same period there were rapid developments in what may be designated a fourth sector of the industrial resources for war production. Briefly, this was the sector of commercial counterparts that developed with the mechanisation and electrification of military equipment. The most notable examples were the complete mechanisation of military land transport and the general employment of radio and other electrical equipment. This development was far from complete even at the outbreak of war, but it was of great significance that there was now a large demand for equipment very similar to the products of large and technically advanced industries, especially the motor vehicle and radio industries. Tanks were in a rather special category; there was no direct commercial counterpart but up to the outbreak of war it was still the general assumption that the heavy vehicle manufacturers, in the locomotive industry, with some assistance from the motor vehicle industry could provide the essential industrial capacity for tank production. The scope of this new development was by no means fully anticipated in the pre-war period; requirements were greatly underestimated. What was readily appreciated was the ease with which these new demands could be met; here at least were military requirements for which there were expanding industries. All the pre-war calculations of war production in this industrial sector showed a good margin of capacity. These new and expanding industries, it was calculated, could offer very large assistance to production in the other three sectors; thus, a large part of the motor industry was earmarked for the expansion of aircraft production.

With the exception of tank production, most of the mechanisation of military equipment was found, as it were, with its own industrial capacity ready and equipped. Up to the outbreak of war it did not seem likely that in this sector of commercial counterparts there would be any significant deficiency. These assumptions were quickly shattered by war requirements. This was due partly to the intensive application of mechanisation but also to the very large expansion in land forces. Thus whilst the war demands on some sectors of armament manufacture were less than anticipated and no more numerically than in 1914–18, the demand on the fourth sector of industrial resources, was very much greater than anticipated. In addition, the comparatively new aircraft sector was also subject to a greatly increased demand. It was in these two sectors—aircraft and the mechanisation of army equipment that the size of the industrial problem in the two world wars proved so very different. This can be seen even from a direct numerical comparison of output.

Output in two World Wars (4½ years)

		First World War (August 1914 to November 1918)	*Second World War (September 1939 to end of 1943)*
Shipbuilding			
Naval ships—number of:		1,661	4,490
(Tonnage Standard Displacement)		1,595,000	1,795,000
Merchant ships (gross tonnage)		3,770,000	4,463,000
All Services			
Filled shell	millions	162	170
S.A.A.	millions	10,500	7,200
Explosives	short tons	560,187	569,000
Propellant	short tons	223,389	285,751
Rifles		3,954,000	1,855,000
Guns (Army only)			
4·5 in. and over		10,913	2,176
Less than 4·5 in.		10,058	106,423
Automatic Small Arms (Army and Air Force)			
·303 Machine guns		240,506	849,923
Carbines		—	3,017,000
20 mm. Cannon		—	117,788
Aircraft bombs filled weight short tons		—	940,000
Tanks		2,619	22,641
Armoured carriers		—	61,076
Wheeled vehicles and motor cycles (Army only)		less than 100,000	717,000
Aircraft		52,027	87,221

In tonnage, the output of shipbuilding was fairly close in the two wars, though the number of ships was considerably larger in the Second World War. Similarly, for many items of armament and ammunition the output was very much the same or even numerically greater between 1914 and 1918; but there were some important additional items and changes in design which at least balanced the tally of production. But even though there were some notable increases, it was in the sector of mechanisation for air and land forces that the very large increase in industrial effort was needed. Numerically, it was very great in the production of tanks and wheeled motor vehicles of all kinds. For aircraft, the difference in the types of aircraft in production makes the numerical comparison a gross underestimate of the large increase in the industrial effort required.

Industrial changes between the wars had an important effect on the industrial problem. Whilst the survival of the shipbuilding and aircraft industries had been beset with uncertainty, other industries had expanded. The two most important were the electrical and the motor vehicle industries and closely related to these was a significant expansion in light engineering, a large part of which was due to the demand for components for the other expanding industries. These were important additions to industrial resources that were quickly included in the pre-war planning of aircraft and armament war potential. But it was by no means a net addition, for military requirements now included a direct demand for the products of these expanding industries. Thus the industrial problems of war production arose not merely in the supply of highly specialised armaments but also in the sphere of fairly close commercial counterparts. The war-time extension of armament production into the field of general engineering had been the essential lesson of the First World War and this was applied widely in the planning of war potential for 1939. Despite the additional demands for the mechanisation of military equipment, there appeared to be a considerable margin of capacity in industry available for other war potential but the demands of war production soon eliminated the margin and forced a very large dependence on imported supplies. In several sectors the available resources were soon fully engaged and from 1940 onwards a persistent problem was what had to remain unplaced or obtained from overseas. War production soon absorbed all the available resources and the major industrial problem was to fit the competing demands for limited capacity into the industrial structure.

All three production departments made separate demands on the resources for armament production; they now made separate demands on the industrial sector for mechanical and electrical equipment. This remained true throughout the war although the Ministry of Supply undertook some common supply; but for mechanisation the only major common supply which covered all three Services completely, was the production of motor vehicles. There was thus a fairly large area of direct competition both for the capacity for armament production and also for mechanical and electrical equipment.

The most direct indication of the division of industrial effort between the departments and between the production of munitions and other equipment is given by the division of the total labour force employed at the peak of war production.

Division of Labour force in Engineering Allied and Shipbuilding Industries[1]

Total employed on service requirements	3,300,000
Division between departments	
Ministry of Supply	1,100,000
M.A.P.	1,400,000
Admiralty	650,000

Division between Sectors of Production

Employed on armaments and munitions (including tanks but excluding aircraft and ships)

Ministry of Supply	660,000
M.A.P.	100,000
Admiralty	250,000
	1,012,000

Employed on products with civilian basis	
Aircraft (excluding armament and radio and radar)	1,200,000
Shipbuilding	272,000
Marine engineering and ships equipment	250,000
Motor transport and wheeled armoured fighting vehicles	160,000
Engineer and signal	100,000
Radio and radar	130,000
Equipment and stores (excluding fabric goods)	60,000
	2,172,000

[1] Excluding manufacture of iron and steel materials, explosives and ammunition filling, textiles, clothing, woodworking, paper, printing, leather, rubber, glass and pottery. The addition of explosives, chemicals and ammunition filling would increase the total for armament and munitions to 1½ million—still about a third of the total capacity (excluding iron and steel materials).

This division of engineering capacity makes clear the broad proportion of munitions production and the large area of capacity for products with a commercial counterpart. Judged by the labour employed, munitions production strictly defined required about a third of the total capacity; products with direct or fairly close commercial counterparts employed about two-thirds. In this sector of commercial counterparts rather more than half is accounted for by aircraft production. Aircraft production was by far the largest single sector of capacity and was at least equal to the total armament and munitions engineering sector. Thus the capacity for service requirements in the engineering and allied industries divides into what are roughly three equal sections. The section for armament and munitions production, excluding aircraft and ships, the sector for aircraft production and the further wide sector of requirements with fairly close commercial counterparts including naval and merchant shipbuilding, motor transport and electrical equipment.

The separate administration of naval requirements and aircraft production was clearly in accordance with the main lines of industrial organisation and secured identification of interest in the departments and in the industrial sector which would have been difficult to achieve by any other method. Armament production was much more widely spread, less unified and much less easy to identify in the industrial capacity. Nevertheless, with the largest requirements for the land forces and with the explosives, filling and small arms ammunition factories almost entirely under the War Office and later under the Ministry of Supply, the co-ordination of this capacity was quite extensive. Scope for competition between the departments in armament production remained; especially for the light weapon production undertaken by all three departments. It was however not so much in the sphere of final manufacture that the dangers of competition arose but in the ancillary capacity for raw materials, components and intermediate products.

Many industries share a common source of raw materials and make use of many of the same firms for intermediate products. Highly specialised industries tend to induce the development of specialised ancillary production. This was particularly true of naval shipbuilding in the 19th century. The close integration with iron and steel production was broken by the new commercial alignments of the 'twenties, but most of the close trading relationships remained. With the general use of light metal alloys in place of wood for aircraft construction, the aircraft industry also became dependent on specialised raw material production and light metal fabrication. For this, close commercial integration with the aircraft industry was not developed and it became one of the primary tasks of the production department to secure the development of an aluminium and light metals industry adequate to meet the demands of the rapidly expanding aircraft capacity. Fortunately, the claims of other war production for light alloys could be reduced to limited proportions. This was by no means true of iron and steel and other metals for shipbuilding; for these there was a large demand for armament production, a demand which was greatly increased by the extended use of tanks and motor vehicles. The problems involved in the allocation of raw materials to the three main industrial sectors of production are dealt with elsewhere.[1] In this analysis of the industrial problem, the most significant aspect of raw material supply is that, whilst the armament and shipbuilding sectors both made large demands on the iron and steel sectors, the aircraft industry was mainly concerned with what was in many ways a new basic industry for non-ferrous alloys.

Much closer to the problems of final manufacture was the supply of components and ancillary equipment. This problem had become even more complex between the wars with the general adoption of mechanisation in all military services and also the increasing use of electrical equipment. Here, there was direct competition between the departments for the supply of automotive parts and components. This was most severe between the demands of aircraft production and the mechanised equipment and fighting vehicles of the land forces. Somewhat similar in effect was the general use of electrical equipment by all three services and the very closely related increasing instrumentation of military equipment. Allocation of final manufacturing resources was adopted but it was much more difficult to avoid direct conflict in the demand for limited supplies of components many of which had to be obtained from the same specialist firms. Some of the most serious shortages occurred in this sphere of component and intermediate product supply. It was in this field more than any other that the three main production departments had to contend for what were often almost identical products from the same firms. The degree of efficient mechanisation in field equipment, the adoption of more efficient wheeled vehicles were often seriously limited by the acute shortages in the common field of component supply. In this sector in peace-time, it was usual to expect the demand to stimulate supply and for capacity to evolve with a number of component manufacturers. The joint demand for some components in war production became so great that special assistance had to be given to obtain further increase in component production. This frequently meant a further increase in the range of firms employed.

This process of the outside purchase of components was typical of the normal industrial organisation, particularly in what may be described as the assembly industries. Much less general for civilian production and indeed, for the most part, exceptional, was extensive

[1] J. Hurstfield, *The Control of Raw Materials*, in this series (H.M.S.O. 1953).

subcontracting of major assembly and sub-assembly work. This was virtually unknown in the shipbuilding industry, and before 1935 in the aircraft industry. Extensive subcontracting of assemblies and sub-assemblies tend to develop only when large scale demand far exceeds the resources of the final assembly firms or when large scale production is established with a definite subdivision of assembly work as an essential feature of the organisation. In the organisation of capacity for rearmament, it was the first situation that frequently applied, but as the planning of war potential and of war production proceeded several large scale subcontracting schemes were adopted, particularly for aircraft production. In these schemes subcontracting was an essential part of the initial organisation.

The general policy of introducing outside firms of many types and sizes into specialised aircraft and armament production, either as contractors or subcontractors, tended to reduce the resources for the production of components and ancillary equipment. At the same time the application of mechanisation to all Services greatly increased the demand for components and automotive parts and fitments. In consequence, the general policy of spreading the load of war production widely over the whole industrial structure created the frequent danger of failing to obtain the essential balance between production and component supply. With the entire industrial structure committed to war production, this division of function became a matter for careful allocation, which could only be assisted to a very limited degree by the importation of components. For the industrial effort to be successful, it was important that the correct balance between capacity for final production and component supply should be attained.

The crux of the industrial problem proved to be substantially the same in most of the major sectors of war production. Despite the existence of an appropriate specialised industry, the capacity available from peace-time activity or preservation was far short of war requirements. The same proved to be true of the industries which, with the general mechanisation and application of electrical and radio technique, had become an essential part of specialised capacity for war requirements. The shipbuilding industry, with very large scope for internal rehabilitation made the smallest demands on general industry and on new capital assets. For aircraft and armament production large increases in capacity were obtained by the provision of new specialised factories but very large additional capacity was obtained by making use of outside firms and their existing factories. In total, outside firms accounted for a large part of the additional capacity for armament production but there was also a large provision of highly specialised factories for some armament production. Some new factories had also to be provided in the sector of commercial counterparts; with the pressure of war requirements, new factory capacity had to be provided for the radio industry and some other highly specialised industries. In contrast, the additional capacity provided for the war production of motor vehicles was negligible. In fact, this was the only major production of vehicles of war which had to be undertaken from a capacity less—a good deal less—than that of the civilian peace-time industry.

Despite the inclusion of virtually every possible scrap of industrial capacity in the resources employed at the peak war production, the statistics of overseas supplies to the United Kingdom indicate that the industrial effort, extensive and intensive as it was, could not reach the level needed to meet the military requirements in full. This was true of most of the major requirements and applied to commercial counterparts like motor vehicles and to the highly specialised requirements like small arms. The size of the total requirement for most equipment depended on the size of the armed forces to be enlisted; and this directly affected the labour force available for production. The total United Kingdom requirement included a good deal that was for the use of Imperial forces; the United Kingdom industrial effort fell short of the total Imperial requirements even when supplemented by production in the Dominions and India. The gap between the United Kingdom output and the requirements for the United Kingdom armed forces alone was a good deal less. Nevertheless, there was a substantial deficiency; and this was particularly marked for aircraft, motor vehicles and tanks.

The industrial capacity in the United Kingdom was thus a good deal less than was needed to equip the armed forces which were enlisted from her own population. When at the peak of the war effort, an increase in the armed forces had to be attained at the expense of the productive labour force, there were many indications that capacity was inadequately manned and that at least some further output might have been obtained with a larger labour force. This was particularly true of aircraft, tanks and motor vehicles. To secure an output approaching the total requirement for United Kingdom forces would have needed a substantial increase in the efficiency of production, as measured by the relation of labour to output. In the production of some stores there was little scope for improvement in efficiency; in the production of explosives and small arms ammunition there was little if any difference between the efficiency of production achieved in the United States and in the United Kingdom. But in the production of some mechanised equipment, particularly aircraft and motor vehicles, had the efficiency in the United Kingdom equalled that attained in the most efficient factories in the United States, the deficiency in supply could have been substantially reduced without any increase in labour force. A very important factor in securing this increased efficiency in production would have been an increase in the scale of manufacture. Indeed, it was found that this factor alone accounted for the bulk of the difference in comparative efficiency in aircraft production in the United Kingdom and the United States.

Yet the scale of manufacture in many United Kingdom factories in war was very much larger than had been usual in peace-time; in 1943 there were more really large factories in the United Kingdom than ever before. Many of the war-time factories in the United Kingdom were very large by British standards and there would have been considerable difficulty in establishing factories of larger size. The policy of spreading the load and of strategic dispersal was an obstacle to an increase in the number of large scale factories. Many that were established were frequently as large and sometimes larger than the supply of labour justified. This problem could often be overcome but there remained the objection that larger factories were extremely vulnerable to enemy attack. The policy of dispersal, which for several war years appeared to be the only means of avoiding real industrial disaster was incompatible with a very large increase in the scale of production. The increasing and extensive use of existing factories and equipment meant a very wide range of size and, in number, a preponderance of the smaller factories.[1]

[1] For further discussion of this topic and for a summary of the expansion of industrial capacity for war productions see Chapter XIV, Section (ii).

CHAPTER II

SHIPBUILDING AND ADMIRALTY PRODUCTION

(i)

The State of the Industry

THE shipbuilding effort was the supreme example of war production achieved without the provision of new capacity. Indeed it was achieved despite the persistent serious decline in the number of slips and berths available in the shipbuilding yards. For war production, naval shipbuilding had the advantage of an industry which had a counterpart in commercial demands; for although the fitting out of a naval vessel is far more complicated than a merchant ship, hull construction of similar sizes is basically the same. But for naval armament—armour plate, guns, mountings and ammunition—it was necessary to create new capacity to meet the requirements for rearmament as well as for war production. Even so, a very small proportion was for the creation of entirely new factory units; the bulk of the building work was needed to increase capacity at a number of firms by providing comparatively small additions to existing buildings. In consequence, the Admiralty expenditure on factory construction and indeed on the provision of manufacturing capacity of all kinds was very much smaller than in the other two production departments. With a very large industrial legacy, the Admiralty found it possible at times to accept the role of the poor relation and to give way to the exceptional demands of the Army and the Air Force.

In the half century before the First World War the expansion of the shipbuilding industry for both naval and merchant vessels was very largely parallel and concurrent. As a result, there were two specialised branches of the industry and though many firms built both naval and merchant vessels, a number did not undertake naval work in peace-time. Naval shipbuilding was the function of a number of firms who devoted a large part of their resources to naval building and for whom a decline in naval building entailed a substantial reduction in activity. The concurrent development of the naval and merchant branches of the industry encouraged each to expand to the fullest extent and was not limited by the possibility of using capacity alternatively for merchant or naval building. The expanded industry flourished by securing a high percentage of world orders for merchant shipping and orders from many foreign admiralties in addition to the requirements of the British Fleet. Any reduction in demand from any of these sources reacted unfavourably on the prosperity of the industry and the effect could be only slightly abated by transfer of capacity between naval and merchant capacity.

In 1914, war came with the shipbuilding industry, at what proved to be the peak of peace-time operation. For in total tonnage of all kinds of vessels launched, the output of 1913 has never been equalled in peace or war. Moreover the output in the two preceding years 1911 and 1912 was not far below the output for the peak year 1913, the average annual tonnage for these three years remains a record.[1] In 1913 the Royal Dockyards produced their highest tonnage of new vessels, and the private naval yards had their highest peace-time output, though the highest launchings for the British Admiralty were in 1911. The launchings in 1913 for foreign admiralties was also a record. This development of output was well founded, for it had been proceeding to this high level through the two preceding decades. In 1901 the output of merchant vessels was over 1½ million gross tons and the combined output of Royal and private naval yards exceeded 210,000 displacement tonnage. Except for the years 1908 and 1909, merchant shipbuilding had been maintained at about 1½ million gross tons. The output of naval vessels had fluctuated but from 1908 onwards there was a fairly steady climb towards the peak in 1913.

In 1934, the situation confronting the Admiralty and the Board of Trade, who were then responsible for merchant shipbuilding capacity, was very different. For, although in the first decade after the war, merchant building had amounted on the average to over 1¼ million tons and in 1929 was 1¼ million tons, the industry failed to revive from the world depression and in 1933 launchings were only 133,000 tons. In 1930 the National Shipbuilders' Security was formed and some yards were purchased and closed down; and in this way capacity for over 1¼ million tons was abolished. Before 1929, the demand for naval vessels had fallen to an even greater extent and several naval yards were closed and dismantled before 1930. In the same period the number of Royal Dockyards was reduced and with the increased size and weight the shipbuilding capacity at the Royal Yards was no longer adequate for the building of the modern battleship or for aircraft carriers. Moreover the First World War had shown that the Royal Yards would be mainly needed for repair.

Despite the effect of the rearmament programme in the naval yards

[1] One and three quarter million tons of merchant ships and a quarter of a million naval displacement tonnage.

and some improvement in merchant shipbuilding after 1935, the output between 1935 and 1939 was far below the output of 1911 to 1913. Signs of revival in merchant shipbuilding did not come until 1935; this coincided with the new naval programme and an increase in orders from foreign admiralties. The increase in the volume of naval construction continued but the orders for merchant ships declined after the spring of 1938. To meet the revival of building, some yards were re-opened although the percentage of capacity in use did not exceed 65 per cent. of the total available

Tonnage in hand 31st December

Year	*Mercantile Tonnage (gross tons)*	*Naval Tonnage (Standard displacement)*	*% of Total capacity*
1936	963,642	375,740	50%
1937	1,125,426	547,014	65%
1938	779,762	544,000	50%

Not all the naval tonnage was for the British Admiralty; between 1938 and 1939 there were cruisers, destroyers, minelayers and submarines building in British yards for several foreign governments. Work in hand in the naval yards was by the spring of 1938 beginning to approach the tonnage but not the number of ships of the 1913 naval construction, but despite the assistance given by the government, the orders for merchant ships was far below the 1913 level.

(ii)
Allocation of Capacity

The expansion of output before 1914, had required a considerable increase in the number of shipbuilding slips, particularly for the larger types of vessels. This increase had continued to some extent during the war but even more rapidly between 1918 and 1920. By 1925 the lower level of demand had resulted in a heavy decline in the number of slips available but the total was still greater than in 1914. After the boom of 1920 the volume of orders for merchant ships was greatly reduced and the average output up to 1929 of about 1,200,000 gross tons a year required little more than a third of the merchant capacity available in 1920. The decline in the number of merchant slips was almost continuous, after 1929 the decline in the number of yards and slips continued. Even with the slips which might be rehabilitated in yards then closed, the total in 1934 was a good deal less than in 1914.

Even so, up to 1939 the accommodation in the yards was not a restrictive factor, although specialised naval capacity for some types was almost fully employed. By far the most serious restrictive factor was the labour force available to construct the ships on hand. As with yard capacity the labour force had been enormously increased in the boom years and suffered a drastic decline in the following years of fluctuation and depression.

	Total number of workers insured under shipbuilding and repairs	*Total Employed*	% *Unemployed*
1920	338,000	320,000	5%
1932	182,000	66,000	64%
1933	169,000	67,000	60%
1935	161,000	93,000	42%
1936	167,000	118,000	29%
1937	178,000	139,000	21%
1938	180,000	143,000	20%
1939	183,000	150,000	18%

In 1930, the total labour force insured in the shipbuilding trade was still over 200,000 although 30 per cent. were registered as unemployed. By 1935 the total had fallen to 161,000 of which 42 per cent. were unemployed. With the short boom in merchant building the total labour force from 1936 onwards increased. In 1938 it had risen to 180,000 although 20 per cent. of the total were unemployed. The load of work at the end of 1937 when 1,125,426 gross tons of merchant shipping and 547,014 tons (standard displacement) of naval shipping were building, approached the maximum which the industry could absorb with the existing labour supply but this output only represented about 65 per cent. of total slip capacity.

It was against this background of a declining industry, losing both capacity and labour, that the Principal Supply Officers' Sub-Committee assisted by the Shipbuilding Consultative Committee, had to investigate the availability of slips and to consider their allocation between naval and merchant orders in the event of an emergency. The purpose of a pre-arranged allocation was primarily to avoid a repetition of the experience in the First World War when the urgent and heavy naval requirements severely reduced the merchant shipbuilding programme until the end of 1916. The Principal Supply Officers' Committee made surveys of the shipbuilding industry in 1930, 1934, and 1939 and estimated the number of slips available in yards which were then regarded as active.

These figures represented the number of slips available for the construction of ships over 2,000 tons, i.e. slips of 250 feet and over, and did not take into account trawler berths, small mercantile yards and boat building yards; all of which had been subject to decline. In addition there was a somewhat uncertain margin of reserve yards. This margin had dwindled from 72 in 1930 to 18 in 1939. Many reserve yards which had formerly been thought capable of re-opening were by 1939 considered to have fallen too far into disuse to be rehabilitated within six months and some of the yards had been closed by the National Shipbuilders' Security.

Slips available for shipbuilding

	1930	*1934*	*1939*
Active Naval	168	158	134
Active Merchant (English) .	127	98	75
Active Merchant (Scottish) .	164	126	57
Total	459	382	266

The allocation of shipbuilding capacity by the Principal Supply Officers' Committee in 1930 and 1934 met the naval requirements in full. In 1930 it was calculated that the remaining capacity would be sufficient for 1,600,000 tons of merchant shipping and in 1934 the remaining capacity was estimated as sufficient for 1,339,000 tons. These calculations related to the allocation of capacity for the current estimate of war-time requirements. When in 1936 plans for naval rearmament were intensified it looked as though the number of slips available for merchant shipbuilding would be far below what was needed. For not only was the total of naval building in war to be higher; the new programmes were to include a much higher proportion of the smaller types of warship which could best be built in merchant berths. The adoption of this naval programme in full would have meant a serious reduction of merchant shipbuilding. By 1939 it was agreed to reduce the number of these smaller naval vessels by 50 per cent. and thus increase the capacity for merchant vessels. There was one basic difficulty which could not be avoided; the actual utilisation of capacity at the outbreak of war might well be at variance with the plans; this proved to be so for smaller vessels. Early in 1939 orders were placed for small naval vessels with merchant yards that might otherwise have been closed; this meant that in September 1939 and for some months afterwards some slips reserved for merchant building were occupied by naval work. It is true that some naval slips were occupied by merchant work but on balance the position was slightly in excess of the naval allocation. The final pre-war allocation provided for an annual output of about 1,200,000 million gross tons of merchant ships and about 370,000 standard displacement tons of naval vessels. This calculation proved remarkably near the mark, for in 1941 the output of merchant shipping launched amounted to 1,156,000 tons and naval vessels to 364,000 standard displacement tons. This excluded mosquito craft and landing craft which come outside the capacity allocated in the pre-war preparations. Indeed throughout the years 1941 and 1944 both the output of merchant and naval vessels was remarkably near the pre-war allocation of possible tonnage.

The substantial allocation to merchant shipbuilding made before the war was largely adhered to throughout the war and the serious fall in merchant construction which occurred between 1914 and 1916 was avoided.[1] Though between 1940 and 1945 the alternative of a serious deficiency in naval vessels was a frequent danger. Despite the rapidly changing strategic situation the use of the building slips shows remarkable consistency until 1944.

Allocation and Employment of Building Slips

Yards	Large Naval		Small Naval		Large Merchant		Small Merchant	
	(N)	(M)	(N)	(M)	(N)	(M)	(N)	(M)
Allocation in 1934	96	49	54	38	21	126	11	13
Allocation 1939	114	21	85	9	5	96	6	13
Usage 1939	81	13	—	21	13	74	6	3
July 1940	102	29	77	5	12	84	9	7
July 1941	103	31	75	10	6	93	4	16
July 1942	106	28	73	11	2	99	2	18
July 1943	104	24	68	12	9	98	5	15
July 1944	102	18	48	32	26	79	5	16

(N) = allocation or use for naval construction.
(M) = allocation or use for merchant construction.

Until 1942 the division of slips between the navy and merchant fleet requirements was approximately adhered to in spite of the naval situation after the fall of France in 1940. Before France fell it had been planned to reduce naval capacity for the benefit of merchant building but the swift change in the situation made it necessary to use the capacity for the rapid production of vitally-needed anti-submarine warships. The first disturbance in the allocation of capacity came in the spring of 1941 when the volume of repair work made it essential to employ labour from new construction to help in reducing the arrears

[1] In February 1940 responsibility for merchant shipbuilding and repairs was transferred from the Ministry of Shipping to the Admiralty. This dual responsibility within the Admiralty no doubt helped to maintain an efficient division of resources and limited the effects of any serious disturbance of the allocation between merchant and naval shipbuilding. For an account of the administration of naval and merchant shipbuilding in the Admiralty, see *Administration of War Production, op. cit.*, Chapter VII.

in repair. But the first major change in the allocation of slips came in 1942 when the attacks from enemy submarines was increasing and the losses of merchant shipping mounted rapidly. These disasters influenced the Cabinet decision to extend the construction of escort vessels. The size of the programme envisaged was such that it became necessary to re-allocate the capacity as a whole. This involved not only a recasting of the allocation of the slips between merchant and naval and, as a result, the transfer of 25 merchant slips to the escort programme but also an attempt, particularly as far as merchant building was concerned, to allocate vacant slips more carefully according to the type of vessel. The previous allocation though by no means haphazard had tended to be uneconomical in the use of slips.

In March 1943, a further expansion in the escort programme was considered highly desirable but it was recognised that this would mean a reduction in the building of other types of warships or merchant ships, or both. Reduction in naval vessel building was unacceptable and merchant building slips had to be made available for the construction of some escort vessels. This diversion of resources to naval construction continued in 1944, a year in which ship production was dominated by preparations for the two great projected operations—the invasion of Europe and the Far Eastern offensive. Even before the end of 1943 naval preparations for the forthcoming operations began to affect the allocation of capacity. It was recognised that there would have to be a marked shift of emphasis from escort vessels to submarines and fleet destroyers; most of the merchant berths borrowed for escort vessels would be returned to the merchant side once the frigate programme had been completed, but some would have to be kept to meet the need for destroyers. More serious however was the diversion of shipyard capacity to the building of tank landing craft. Hitherto these vessels had been fabricated at specially developed sites largely by structural engineering labour and had made no demand on shipyard slips and only a moderate demand upon shipbuilding labour. In November 1943 however the War Cabinet decided that the 75 additional landing craft required for 'Overlord' would have to be built in the normal shipyards. Most of these could be undertaken within the naval allocation but 23 would have to be built on merchant slips, causing a delay of about three months to seven merchant ships. Shortly afterwards there arose a large demand for a new kind of tank landing ship and naval needs encroached further on merchant capacity; but an attempt was made to set right the balance by releasing a few small naval berths to the merchant side for the construction of coasters, tugs, and dredgers.

In 1945 the tank landing ship programme and the demand for the creation of the Fleet Train for Far Eastern operations imposed a heavy load on capacity. So much so that the Prime Minister ruled that the building up of the Fleet Train must take second place to the merchant programme sufficient to ensure a minimum of 24 million tons of imports for 1944 and 1945. Nearly all the ships required for the Fleet Train were to be provided by conversion of existing merchantmen; this resulted in a serious draining away of resources from construction to what was largely conversion work. Moreover seven tramps under construction were earmarked to be converted into repair ships or floating workshops: this change not only involved a gain to naval capacity at the expense of the merchant building but also meant that the vessels would have to stay on the stocks two months longer than normal, thus increasing the delay.

Despite these marginal changes, which were made only under the stress of necessity, the allocation of slips between merchant and naval requirements was remarkably stable. The initial allocation agreed in 1938 persisted until 1942 and the level of output of merchant shipbuilding was generally maintained above 1 million gross tons; the low figure of 810,000 tons in 1940 was due to the difficulties of building up the labour force in the shipyards. The output of merchant building was to remain above one million gross tons for the rest of the war despite the surrender of some slips for naval construction. This achievement was due in part to improved efficiency but this would have been insufficient to compensate for any large scale surrender of capacity to naval requirements. Mainly because of the limitations accepted by the Admiralty in favour of merchant shipbuilding, the number of slips available for naval construction, was never as great as in the First World War nor did any year's output of naval vessels reach the 1916 total of 514,000 tons standard displacement. Even so the average for the other years were remarkably similar in both wars.

All in all, merchant shipbuilding was for most of the war years only slightly affected by the demands of naval shipbuilding. It was not until 1944 that output was affected by as much as 10 per cent. on this account. The output of merchant ships was at times more in danger from the accumulating burden of merchant ship repair and conversion; throughout the war the labour force employed on repair and conversion of merchant ships was a good deal greater than that employed on new merchant ship construction. In most years the labour force on repair and conversion was at least 50 per cent. greater than on new construction. Even so it was only in March 1941 that the large accumulation of damaged merchant ships—over two and a half million tons—led to a reduction in the target for new construction. This arrangement proved abortive; additional labour for repair and for new construction was forthcoming from new recruitment and the level of new construction was generally maintained and at the same time a great improvement in the volume of repair was achieved. Even so, the heavy burden of the repair programme which persisted throughout the war effectively removed any hope of the new construction exceeding the target of

1.25 million tons. Any hope of a higher target was abandoned after the summer of 1940 and more than once the target had to be reduced to 1.1 million tons. The actual output after 1940 was usually between these two.

Merchant Shipbuilding: New Construction and Labour employed

	1940	1941	1942	1943	1944
Tonnage completed					
(thousand gross tons) . .	801	1,156	1,301	1,204	1,014
Numbers employed (thousands)*					
New construction . .	28·8	36·0	38·2	42·0	41·3
Repair and conversion .	44·0	54·5	57·5	62·8	65·2

*Numbers employed in June of each year.

(iii)
Specialisation in the Shipyards

The allocation of shipyard capacity for the naval programme was completed by the Admiralty in the spring of 1939 and shipbuilding firms were given a fairly clear idea of what would be required of them in war. There were of course many factors, particularly labour and armament production, which could seriously upset the effective use of shipyard capacity. But it was essential that the allocation of work to the shipyards should be made so as to ensure the best possible use of the experience, special facilities, slip and fitting out capacity available at the different shipbuilders. A very wide range of different facilities had to be taken into account. Much depended on the size of the slips and the fitting out facilities available. Slips of 900 feet in length which were needed for battleships and aircraft carriers existed only at a few of the large naval shipyards—at Cammell Laird, John Brown, Fairfield, Swan Hunter, Vickers and at Harland and Wolff, Belfast. At only a few of the yards such as Swan Hunter, Vickers (Barrow) and John Brown were some of the slips covered over—a valuable asset in times of blackout. In general, fitting out berths matched the slip capacity for normal peace-time work, when a proportion of merchant ships were also undertaken but in war with the greater work entailed in fitting out warships there was danger of considerable congestion. Vickers had however foreseen the possibility of this at Barrow and had provided for large extensions which would enable them to fit out three liners or aircraft carriers simultaneously. There were also the related problems of shipyard equipment. The fitting out berths of the naval firms were equipped with lifting apparatus suitable for their size and adequate in numbers for peace-time programmes. But most merchant firms, though generally equipped with fitting out facilities and lifting appliances for their normal peace-time activities, were not adequately equipped for dealing with naval vessels, particularly with the more specialised vessels such as submarines and destroyers.

The experience of war-time construction proved, that with few exceptions, the main distinction between the two groups of firms, naval and merchant, was too firmly established to be disturbed. The naval firms were therefore concentrated on the construction of submarines, destroyers, and larger ships driven by turbine machinery and built to the higher naval standards while the merchant yards were confined to building ships designed to commercial specifications and equipped with reciprocating engines. Due, however, to the lengthy fitting out period required for naval vessels compared with the time spent on hull construction, there was a tendency for the balance between the use of slips and the fitting out berths to be uneven. In order to make use of space and to make use of their peace-time experience, some of the principal naval firms continued to build merchantmen on at least some of their slips: Hawthorn Leslie kept two slips occupied by cargo liners, tankers and large tramps; Swan Hunter, Stephens and Vickers had three slips each, Cammell Laird and Denny two slips each, occupied by merchantmen at some time or other. Harland and Wolff's Belfast Yard maintained a large interest in merchant building, reserving eleven slips out of nineteen for this construction. Conversely, merchant specialists built corvettes and frigates. In December 1943, at the peak of activity in the shipyards, twenty frigates and corvettes were in hand on the slips of mercantile building firms. This distinction between naval and merchant firms limited the possibilities of meeting staff requirements, for example, when it was desired to improve the quality of corvettes or when there was a pressing need for more destroyers. So long as naval standards were insisted on for certain classes of ship the distinction was inevitable.

Within the main classifications of naval and merchant firms, specialisation was pushed still further, and it was Admiralty policy that this should be so. In November 1939 the Controller directed that in meeting staff requirements firms should continue to build the types of vessel to which they were accustomed. Again, in 1941, the policy was stated to be to lay down full capacity in all types of ship rather than to meet any one requirement for specific numbers. Particular firms were therefore devoted to the production of one or two types of vessels. Of the main naval yards, White's built scarcely anything but destroyers, at first Hunt and later the 'C' class or 'weapon' class, while Thornycrofts, Denny and Yarrow specialised, as in the First World War, in destroyers and sloops. Among the minor naval yards and merchant yards, Blyth and Hills of Bristol and Robbs concentrated on frigates, Lobnitz on fleet sweepers, and Cook Welton on trawlers, while Cochranes devoted their main effort to trawlers and tugs, Simons to salvage vessels, Ardrossan and Ferguson to boom defence vessels. The same principle of specialisation prompted the rejection in 1943 of a proposal that the fleet destroyers in the programme should give place to frigates and corvettes: it was held that the addition of escort strength would not outweigh the disadvantages of breaking continuity of production.

Specialisation brought significant advantages in the training of labour; unskilled labour entering the industry and put to work after only brief training, was at least able to master the particular problems confined to one class of vessel. By ensuring continuity of production a steady flow of materials and equipment could be arranged to keep pace with hull construction and a constant balance kept between the various types of labour. This applied particularly to the smaller naval classes and those produced in large numbers. On the other hand, there were disadvantages. Specialisation or limitation of types tended to prevent the attainment of higher standards and progress in design. The rate of output under such a system provided a strong incentive for preserving the designs which had been chosen at the outbreak of war: any sudden alterations were resisted by the firms and production departments because of the disorganization which they would cause, not only to the ships immediately affected, but also to subsequent vessels. Capacity too was a check on quality: when designs and new types of ships, such as the twin screw corvette were under consideration, displacement tonnage had to be reduced from the 'ideal' of 1,500 tons to 1,300, and even so the number that could be accommodated on existing slips was strictly limited. Even for most destroyers a limit of 1,900 tons had to be accepted. The number of existing slips suitable for the new motor minesweeper restricted the number that could be built. Except for boat building yards, it was not possible substantially to enlarge existing slips.

An analysis of the output of naval vessels between 1939 and 1945 shows that despite the valuable aid given at times by merchant yards it was from the yards specialising in naval construction that the bulk of the supply came.

*Output of Naval Vessels in United Kingdom 1939–1945**

	No. of Vessels	*Tonnage*
Large Naval Yards	674	1,365,430
Small Naval Yards	590	468,517
Large Merchant Yards	44	60,032
Smaller Merchant Yards	36	26,320

*Excluding vessels build outside the shipyards.

An analysis of the types of vessels built shows that the small naval yards did not build vessels larger than corvettes and frigates. With a solitary exception all the battleships, aircraft carriers, cruisers, destroyers and submarines were built in the large naval yards or in the Royal Dockyards. The large and small merchant yards were limited to a few types but the output of the small naval yards was not only large but covered a wide range of types.

Types of Naval Vessels built in Shipyards

	Large Naval Yards	*Large Merchant Yards*	*Small Naval Yards*	*Small Merchant Yards*
Battleships	5	—	—	—
Aircraft carriers . . .	14	—	—	—
Cruisers and minesweepers .	28	1	—	—
Destroyers	225	—	—	—
Submarines . . .	143	—	—	—
Sloop and minelayers . .	36	2	—	—
Corvettes and frigates . .	55	13	194	8
Fleet minesweepers . .	33	8	41	8
Depot ships and miscellaneous	6	1	66	2
Landing ships . . .	20	4	3	1
Landing craft . . .	39	15	16	—
Coastal forces craft . .	70	—	—	—
Trawlers	—	—	204	15
Boom defence . . .	—	—	55	—
Motor minesweepers . .	—	—	13	—

By far the greater number of the coastal forces craft and the motor minesweepers were built in boat-building yards and the bulk of landing craft were built outside the shipyards. This output is not shown above. In addition three cruisers and fourteen submarines were constructed at the Royal Dockyards.

(iv)

Inland Shipbuilding

The Admiralty had accepted and maintained a principle of utmost rigour in the allocation of capacity; naval requirements were severely curtailed to maintain merchant shipbuilding and the designs of smaller naval vessels were adjusted as far as possible to the type of capacity available. It is not surprising that when confronted with additional requirements for unconventional types of vessels, the Admiralty sought at an early stage to develop capacity outside the shipbuilding industry. In addition, they greatly encouraged methods which enabled outside firms to contribute to construction of major sections of naval and merchant vessels at factories quite unconnected with the shipyards. A major example of these innovations was the development of capacity for tank landing craft. When the first production orders were placed for thirty of these vessels in July 1940 they were all placed with shipbuilding firms. By the end of 1940 it was clear that this type of craft would be needed in large quantities and that capacity must be found outside the shipyards. Even if it had been practicable there was no time to establish new slip capacity to build the landing craft by traditional methods. The Admiralty was therefore obliged to turn elsewhere and was able to take advantage of the modern engineering practice of prefabrication. Various structural engineering firms were approached with a view to prefabricating these craft; the bulk of the work was to be done at inland factories and the sections assembled in yards on the coast. For this assembly work, derelict shipyards at Middlesbrough, Stockton and Glasgow were re-opened and equipped with the necessary plant. By the turn of the year orders were placed for fifteen of the prefabricated type and by the autumn of 1941 the target figure for output was ten tank landing craft per month. At this time deliveries from the structural engineers were only beginning and the figure seemed a little visionary: however, before the end of the year, renewed pressure from the Cabinet stepped the target figure up to twenty a month, and in 1942 the target was raised first to thirty a month and then to forty.

These target figures were based on the development which had by this time been reached in the co-ordination of firms for this production. This was arranged on a group system under which a number of inland firms acting as subcontractors produced all the prefabricated sections and component parts required for the tank landing craft, which were then assembled at the erecting yard. There were three main groups—the Scottish group, the Teeside group and the Stockton group; each group was a self-contained unit. In addition, parts fabricated by certain firms in the Midlands were assembled at Chepstow, while a small proportion of those fabricated in the Tees area were brought to London for erection. When the system was first introduced, the prefabricating firms worked faster than the erecting yards; but the position changed by mid-1943 and subsequently a group of Manchester firms were brought in to prefabricate parts and to increase output. In all there were some twelve firms erecting the hulls (several of these firms also did some prefabricating) and about seventy firms prefabricating. Firms assembling and completing tank landing craft included shipbuilders, ship repairers, constructional and bridge engineering firms.

By the end of the war, over 1,200 tank landing craft had been constructed in the United Kingdom. Of these more than 1,100 had been constructed by groups of engineering firms and this total included all the largest craft designed to carry the heavier tanks. In addition over 3,000 other types of landing craft were produced, mostly lighter craft built mainly of wood, the prototypes and earlier production was undertaken by boatbuilders. A large number of boatbuilders were employed on final production but in addition a large number of firms with woodworking plant and experience were employed. Great economy and efficiency was secured by the Admiralty organisation of the distribution of materials and components.

For ships mainly constructed in wood, particularly of the boat class, there was considerable scope for prefabrication inland by many hundreds of outside firms. In addition, smaller boats could be completely constructed inland. These possibilities were fully exploited by the Admiralty for the manufacture of patrol boats particularly those of the Fairmile design. In 1940, the Admiralty took the unusual step of acquiring the assets of the firm who had designed and organised the construction of these boats. The firm continued to operate as an Admiralty agency and under Admiralty instructions organised a wide spread scheme of subcontracting and mass production, and this made use of a large number of small woodworking firms and boatbuilders.

These schemes show that the Admiralty were determined to make full use of capacity outside the shipyards and that in the main they sought extension of capacity in other industries. Similar methods could be used at least in some measure to aid the construction of ships which had to be built and completed in the shipyards. The tank landing craft production had shown what could be done by prefabrication at inland engineering works. In October 1942, to strengthen protection against the submarine attacks, the Cabinet decided that there should be a programme of 200 more escort vessels to be produced by the end of 1944. It was stipulated that merchant building should not suffer more than 200,000 tons although it was admitted merchant slips would have to be used for many of the corvettes and frigates. In order to reduce the time taken for construction in the shipyard the Admiralty decided to make use of prefabrication methods to manufacture major sections of the hull inland. Success in this undertaking indicated real possibilities for a substantial extension of ship construction without extension of the yards, although it was found that several yards were by no means adequately equipped for the transport of the larger fabricated sections.[1]

This scheme of prefabrication did in fact lead to some extension of active shipyard capacity. The increased output of naval ships led to an increasing shortage of fitting out facilities and berths, and in consequence, in 1942 and 1943, fitting out centres were equipped at several

[1] There were thirteen parent firms undertaking assembly and twenty subcontractors undertaking prefabrication.

derelict yards which were re-opened for this purpose. In all, four yards were opened for this work although a large number of the corvettes and frigates were completed in the existing shipyards. The re-opening of the yards and the equipment required at these yards and at other yards not equipped for naval vessels, involved the Admiralty in some capital expenditure. Thus prefabrication proved to be the major factor in the opening and specialised re-equipment of a number of derelict yards.

(v)
Marine Engineering

Between the wars the marine engineering industry had suffered from the same extremes of demand as the shipbuilding industry. The industry had been subject to a similar process of decline and deterioration but here the decline was less easily reversed. Capacity was dependent on suitably equipped engineering factories and these deteriorated more rapidly than the more structural shipyard facilities. Thus whilst the rearmament programme helped to bring about an improvement of marine engineering for naval vessels, the chronic depression in merchant shipbuilding reduced the marine engineering for merchant ships to a low level of efficiency and equipment. For many of the medium sized vessels—the corvettes, frigates and mine sweepers and trawlers it was the merchant ship type of engine and machinery that was largely required and it proved particularly difficult to provide a sufficient number of these to meet the needs of the construction and repair programmes, both for naval and merchant vessels. Many shipbuilders also undertook the manufacture of main propelling machinery, which at a number of shipyards was undertaken in adjacent workshops. Thus of the fifty-two main shipbuilding firms almost half, including nearly all the larger ones had a marine engineering department of their own and others had connections with firms of marine engineers. Some of the large independent engine works had interests in other branches of engineering. For all major war vessels and a number of smaller vessels such as sloops, repair and depot ships, a few corvettes and frigates, steam turbine engines were required. Capacity available for the production of turbine machinery in the decade before 1935 consisted mainly of fourteen marine engine builders, all of whom had shipyards: of these, seven firms were able to produce high powered turbine machinery and seven were capable of producing turbine machinery of more limited power. In addition there were two independent marine engine firms capable of producing turbine machinery of all powers. Orders from 1925 to 1935 were relatively small and well within this capacity. Although requirements increased from 58 sets of turbine machinery in 1935 to 137 sets in 1939, they could be met easily by the normal suppliers. Even by 1939 little more than 50 per cent. of their work was on Admiralty account. A very great change came with the outbreak of war when requirements increased rapidly: the capacity of the main turbine firms was increased by extending their shop space and machine tool equipments, though this proved to be difficult in some firms because of limited space. The expansion made was however generally sufficient to ensure that with proper planning and progressing of work, the engine production of the firms in question kept pace with hull construction. In consequence, it was only to provide turbine machinery for smaller vessels, particularly for escort vessels of the sloop minesweeper type, that use was made of capacity available in the works of four land turbine builders.

Reciprocating steam engines although used infrequently in peacetime except for slower auxiliary craft such as trawlers, boom defence vessels, minesweepers, tugs etc. were used more extensively during the war and a large number of corvettes, frigates and transport ferries were fitted with reciprocating engines. Up to 1942, increased requirements for reciprocating machinery were met by using the large reserve of capacity at the smaller marine engineering firms equipped to produce similar machinery for small merchant vessels of the tramp whaler, fishing vessel type. But when, early in 1943, a bulk order for 58 corvettes and 112 frigates was placed, it became necessary to find additional capacity for the engines, boilers and auxiliary machinery since the usual marine engineering firms were already working to capacity. The design of the main engines was prepared with this in view and orders were placed with a large number of engineering firms with little or no knowledge of building reciprocating engines of very large horse power. Bulk orders were placed by the Admiralty with 34 engine builders and between 60 and 70 other firms for the supply of main engines, boilers and auxiliary machinery.

The design and construction of submarine main engines was restricted to three firms—Vickers-Armstrongs, Scotts and Cammell Lairds—and the Chatham Royal Dockyard, which also constructed hulls for submarines. Although during the rearmament period requirements increased, they were still within the existing capacity but with the outbreak of war it became necessary to increase the sources of supply. Here again no new capacity was created for it was possible to utilise the manufacturing facilities available in the works of firms normally producing commercial diesel engines. Seven firms mainly situated in the Midlands were selected and designs were produced by the Admiralty in co-operation with Vickers-Armstrongs and one of the selected firms. Additional machine tools were supplied to the firms concerned particularly those engaged on crankshaft production. As a result of these measures to increase and improve capacity, production figures registered a record output. In contrast with the five years from, 1935 to 1939, when 46 engines totalling 53,300 B.H.P. were produced 362 engines totalling 302,200 B.H.P. were produced from 1940 to 1945.

Diesel engines were also required for electric generating machinery and for the propulsion of small craft. Both types were obtained from firms specialising in their manufacture and no difficulty was experienced in satisfying requirements even up to 1939, since service requirements absorbed only a small portion of the total capacity of the diesel engine makers. However from 1935 onwards the need to have a large diesel engine manufacturing capacity available in the event of a war was foreseen and during these years the larger firms such as Ruston and Hornsby, Davey Paxmen and Gardners were encouraged to increase their machine tool equipment and labour force. Early in the war it soon became evident that the capacity of the usual diesel engine builders was insufficient to meet the demands of all the services and the output of the larger firms was put under the control of the Ministry of Supply. Admiralty requirements for diesel generating machinery for the major warships and diesel propulsion machinery for landing craft and for coastal forces craft where large numbers were involved, had to be obtained from the larger diesel firms to ensure uniformity of design. The output of the smaller makers was reserved for other Admiralty requirements such as harbour craft, motor minesweepers, fishing vessels, diesel tugs etc. All available capacity had to be used to meet the demand, and when it proved insufficient, works were extended and additional machine tools installed. Expansion of capacity was however restricted by a shortage of labour, particularly skilled labour. This shortage became acute during 1940–41 and production of hulls for motor minesweepers and fishing vessels and other diesel craft began to outstrip the output of engines and continued to do so throughout the war years. In 1941, requirements for diesel engines had to be supplemented by supplies from America.

There were many items of machinery required including refrigerating and distilling machinery, steam driven fans, a variety of pumps, air conditioning machinery, air compressing machinery, hydraulic pumping machines and steering gear. Although during the rearmament period requirements increased, no difficulties in supply were experienced. The more enterprising firms improved the efficiency of their equipment by the purchase of new tools and also enlarged their factory accommodation. With the outbreak of war quite a few of these firms became wholly engaged on Admiralty work. In spite of extensions of factory space and the installation of additional machine tools, the shortage soon became acute and remained so throughout the war. Additional capacity had therefore to be found outside the usual firms, this was not easy as there were large demands from other Service Departments, whose orders far exceeded the Admiralty requirements.

One of the major difficulties in obtaining new capacity for marine engineering work was that the numbers required of any particular item were usually relatively small and therefore the demand did not encourage mass production methods. There was also the labour shortage: although the yearly shipbuilding programmes were far greater than those in the years preceding the war the labour force increased only 56 per cent. over the three years between 1939 and 1942. Deliveries of auxiliary machinery especially for major war vessels soon began to fall behind schedule, delays were particularly serious in the supply of pumps, electric generating, distilling and refrigerating machinery.

Various measures were adopted by the Admiralty to ensure that the best possible use was being made of existing capacity. Contractors were assisted to overcome difficulties in supply of materials and labour and given orders of priority for the supply of all the principal items of machinery. Attempts were made to augment the source of supply of auxiliary machinery by use of other types, but the machinery for major warships was too specialised to make this practicable. More could be done with minor vessels, for example, it was found possible to accept the normal designs of several firms for such items as pumps for minor vessels, and by this means the source of supply was considerably extended. Further measures adopted included the relaxation of standards of finish below the customary standards, the use of alternative materials e.g. fabricated steel in place of aluminium and gunmetal castings. To ease the production of refrigerator machinery an extensive system of subcontracting had to be instituted. An important factor affecting output of naval machinery was design. For example, during the 10 years before 1939 great advances had been made in improving the efficiency and design of propelling machinery while retaining lightness and compactness in relation to power. But all changes were not towards simplification. The need to design machinery to sustain underwater explosions introduced increased complexity into the designs and required, among other things the replacement of cast iron by steel castings.

In outline the expansion of capacity for engine production proved to be very similar to that for shipbuilding. In the main, the supply of engines for the more specialised and conventional naval ships was attained by increasing the output of the marine engineering firms. A major exception to this was the supply of diesel engines for submarines. As with shipbuilding, it was to a large degree, the special wartime craft and landing craft, minesweepers, and motor patrol boats that made it necessary to go outside the industry and seek the help of land engine manufacturers. Thus despite some production from land engine firms the output of about 900 steam turbines and over 900 steam reciprocating engines came with few exceptions from marine engineering factories. On the other hand a very large part of the supply of many thousands of internal combustion engines both diesel and petrol engines came from land engine firms. Again until the Shipyard Development Schemes of 1942 and 1943 the larger part of capital assistance went to the new sources of supply in outside firms.

(vi)

Shipyard Development

In the first two years of the war the Admiralty had been greatly concerned to adjust their requirements to come within what appeared to be the practical limits of the shipyards. Schemes for expansion of capacity had been mainly contrived to make use of inland engineering firms for the prefabrication of corvettes and landing craft. The programmes of conversion and repair had clearly impeded progress on new ship construction and work on capital ships had to be suspended from time to time to make labour available for urgent conversions or repair. In general, the shipyards had made a commendable recovery from the pre-war period of comparative inactivity; by 1942, the labour force had increased by 100,000 from June 1939 although probably only 25,000 of the addition were employed on naval new construction. With the increase in labour force and some relief from conversion and repair the Admiralty looked for some improvement in the speed of construction of new vessels, but even by the spring of 1942 there appeared to be little indication of significant improvement. Investigations into the problem of labour supply and labour usage in 1942 led on to the problem of plant and equipment. It was indeed clear that the restricted layouts and limited and inefficient equipment at some shipyards made the most efficient use of labour impossible. Direct enquiries from the Admiralty to the shipbuilders for suggestions for improvement met with little response. Arrangements were therefore made for an investigation to be undertaken by the Machine Tool Control into the equipment of the yards and of marine engineering factories.

The Admiralty had been primarily concerned with completion dates for naval vessels. It was significant that the delays were not so frequent in merchant shipbuilding, for the fitting out was a much less onerous task. Even so, the investigation was not confined to naval yards but took in the full range of naval and merchant yards. The report on the major naval shipyards was for the most part favourable. In general their plant and layout was good and it seemed that they had followed a reasonable policy of plant replacement and modernisation. Though not all the firms had reached the same standard. The engine works of some of the firms required considerable modernisation though there were some firms with first-class machines for turbine production. The general requirement of all these firms was for more and larger cranes. The general position at some of the smaller naval yards—where destroyers and sloops were the main speciality—was found to be very similar to the larger yards. They suffered more from congestion and difficulties of layout. Again the main general need was for more and larger cranes and the biggest variation was in the engine shops.

The position was very different at some twenty other yards building smaller naval vessels—corvettes, frigates, minesweepers, trawlers and boom defence ships. Most of these were merchant yards which were not laid out nor specially equipped for naval work; the fitting out facilities at most of these yards were deficient. Even more serious was the very poor state of most of the equipment and plant, much of which had been in use for over fifty years. With one or two exceptions these yards had not had any new plant for many years. Many of them had taken up naval work after a long period of inactivity. The engine works attached to these yards were in a similar condition. In the report it was suggested that there was scarcely one good or new machine in these shipyards or engine works. In addition to machine tools much more than cranage was required to bring these yards and engine works up to a reasonable degree of efficiency. Many of the other merchant shipbuilding yards which were employed almost entirely on merchant shipbuilding, were in a much better state. In the main, although there were deficiencies in plant and in cranage many of the yards were found to be well laid out and fairly well equipped. Again it was in the engine shops that most improvements were needed.

Many of the most serious deficiencies were found in the marine engineering factories operating independently of the shipyards. Inevitably, most of these factories had suffered more inactivity than many of those operating under the shipyards. The existing conditions were persistently regressive. Almost without exception fairly extensive schemes of modernisation were found to be necessary. Many large machines had been installed for twenty or thirty years and were still being fairly effectively used but the intensity of existing work was taking the life out of them. Medium and small sized machine tools were wearing out rapidly owing to the high grade material they were called upon to deal with and to the driving power that was put behind them. It was estimated that within a year many of the machines then serving a useful purpose would begin to fail. Most firms had succeeded in putting in a few machines during the war but these new machines emphasised how very much out of date was the remainder of the plant. The bulk of the machines in some works dated from the First World War or previously and were unsuitable for existing running speeds, and unskilled labour. There was no doubt that at many factories the age of the machines, which in one firm reached seventy years, militated against any attempts to accelerate production. Many factories making ships machinery were in an equally bad condition but there were some notable exceptions which fortunately accounted for a large part of the production.

The essential purpose of the investigation was to discover deficiencies in plant and equipment. The intention and the outcome was to compile lists of machine tools and other equipment which if installed quickly should have definite and immediate effects on production. The introduction of new methods and indeed new types of plant presented many difficulties. The introduction of extensive new methods of construction was often restricted by the layout and physical limits of the smaller yards. Prefabrication on the American scale was not possible in the existing size and layout of the yards. Even so both prefabrication and welding were being used to an increasing extent, indeed, under the guidance of Admiralty welding experts, welding was being introduced almost as fast as was practicable. There were very few new machines available which would reduce the labour required for ship construction but there was a good deal of scope for the introduction of some of these in several yards. It was in marine engineering that the provision of new machines would bring a great saving in labour.

General reorganisation of the layout of the yards and the general replacement of all unsatisfactory equipment and machine tools would have caused serious dislocation and loss of production. For most firms a list of equipment and machine tools which could be installed in the yards and factories without serious dislocation and which could be immediately effective in raising the efficiency of production, was prepared and finally agreed to by the Admiralty and the Machine Tool Control.

Although the investigation had been specifically concerned with equipment and machine tools, including welding equipment and cranage the report also included a good deal of information on the difficulties arising from the layout of the yards. One general problem was the inadequacy of the facilities for fitting out of naval vessels and for handling the prefabricated sections. Several firms had already worked out schemes for improving these facilities but they were unable to finance them. Moreover, the recommendations for additional cranage and for the introduction of welding often involved major alterations in the layout of the shipyard. Jetties had to be provided for the installation and use of the cranes and whilst the introduction of welding meant a great increase in prefabrication, the yards had to be reorganised to provide the necessary space for storage and for the handling of the fabricated material. In order to consider all the proposals for shipyard development and to initiate the necessary action within the Admiralty, a Shipyard Development Committee was formed as a departmental committee at the Admiralty with the Controller of Merchant Shipbuilding and Repairs as chairman. Under the direction of this committee the proposals and schemes for each shipyard were examined and a complete scheme including building work, civil engineering, cranes, welding and shipyard equipment and machine tools, was prepared for each shipyard. Included with these schemes were several for the re-equipment of derelict yards required for erection of tank landing craft and the building of corvettes. Thus whilst most of the schemes arose directly from the special report the 'final' list included all schemes coming within the scope of shipyard development. In addition, the schemes for marine engineering works were also dealt with by this committee but auxiliary machinery was excluded and dealt with separately by the Engineer in Chief. The range of schemes was very wide, from schemes for less than £5,000 to schemes for one shipyard of over £500,000. The main criterion was to decide what could be effectively and quickly provided to improve the output of the yard or shop. After that further schemes were dealt with by the appropriate production department. The total value of the schemes approved by this committee was almost £7 million of which the Admiralty undertook to provide £5 million.

The total cost of the schemes was distributed between firms engaged principally or entirely on naval or merchant building as follows:

	Total Cost £	*Admiralty contribution* £
Naval Schemes		
General development	3,084,618	2,490,482
Welding	1,399,669	916,397
Merchant Schemes		
General development	1,671,599	1,162,956
Welding	776,866	451,781
Total all schemes	6,932,752	5,021,616

Expenditure on welding proved to be a quite substantial part of the total. The work of the Shipyard Development Committee greatly accelerated the introduction of welding into processes which had hitherto been carried out exclusively by riveting. To get the full advantage from this, it was essential that prefabrication either within the yard or in structural steel works should be developed concurrently. Thus there was involved not only the provision of welding plant and often of additional power supply but also a substantial re-organisation of the whole yard so as to provide necessary space for storage and handling of fabricated material and erection of welding shops and cranes. Thus, the main purposes of the survey were achieved; not merely the general replacement and the addition of machine tools, and other mechanical aids to accelerate production; but the adaptation of the layout, and equipment of the yards to make possible the fuller use of welding and the extended employment of other methods which would make the best use of skilled and unskilled labour.

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Factories for Naval Armament

Although it was not until 1942 that the Admiralty became generally committed to schemes to improve the capacity at the shipyards, schemes for the creation and expansion of other essential capacity were extensive and of long standing. By far the largest schemes were for armament supply and for this, very large schemes had been approved in the early stages of rearmament. The provision of armament for warships and particularly for capital ships constitutes a very large part of the total industrial capacity required. The time needed for manufacture of some items, notably heavy gun mountings is often a good deal longer than the period needed for the construction of the hull. Moreover the capacity required is highly specialised and unlike naval shipbuilding there is no comparable commercial requirement. In consequence between the wars, capacity for the production had been reduced to a far greater degree than shipbuilding capacity.

Before 1914, the great extension of naval shipbuilding had been closely matched by extension of capacity for armament capacity. After 1920 there was no work for this very large capacity, which had expanded even further during the war. Many factories were closed and much of the equipment dismantled. The Admiralty felt bound to take some action to ensure that a basis for armament supply remained. For armour plate, out of a total capacity of over 60,000 tons with five firms the Admiralty subsidised the retention of capacity of 18,000 tons with three firms. A monopoly in heavy gun mounting production was given to Vickers-Armstrong to justify the retention of the highly specialised capacity for this production. Some gun manufacturing capacity was retained at Beardmore and Vickers-Armstrong and of course at the Royal Arsenal, Woolwich. The capacity thus retained was only a shadow of the 1913 capacity and was not fully adequate for the limited programme of naval construction in the years before 1934. For the 1934 and subsequent pre-war programmes, this remnant of capacity was woefully inadequate.

To bridge the gap, the Admiralty was heavily dependent on private industry. For although Woolwich had always had an important place in naval gun production, they had never been allowed to produce heavy naval mountings or armour plate. Although in fact Woolwich was able to help in the supply of naval guns it was at one stage assumed that capacity there would be almost entirely devoted to army requirements. This was not so and the Admiralty in addition had some share in one or two of the new gun R.O.Fs that were constructed for rearmament and war production. Nevertheless, the Admiralty had to look to private industry for part of the supply of guns and for the entire supply of armour plate and for many types of the larger mountings. It was for these that the capacity had been developed before. With one or two important exceptions the old factories remained, the problem was to see how far they could be revived. The problem was by no means the same as at the shipyards, there the plant and equipment for the most part remained as the yard space was of no use for any other purpose. In the armament factories, highly specialised plant soon deteriorated and became useless; floor space was often required and in consequence redundant plant sold. In general, the only usable plant was that maintained by subsidy, by other incentive or by the determination of a few firms to retain a minimum of plant.

Whatever the circumstances, it was soon clear that for the construction programme of 1935 to 1939 very substantial expansions of capacity would be necessary. For armour plate the requirement would rise to almost 60,000 in 1939 but capacity proved to be capable of even less than the 18,000 covered by the subsidy. For heavy turreted gun mountings, which took three years to manufacture, capacity was only half what would be required. For the 6 in. turreted gun mountings which had been supplied for the pre-1936 cruiser programme, considerable extensions of capacity at Vickers were necessary. For medium gun mountings an even larger and wider extension capacity was necessary and many firms that had not undertaken gun mounting work had to be brought in. The problem of supply of the large 14 in. and 16 in. guns was very like that of heavy gun mountings. It seemed that the art of manufacture had almost been lost; for all the factories employed, Woolwich, Vickers and Beardmores had real difficulty in bringing production into successful operation. Although some additional plant was required the initial problem was revival and rehabilitation. Delays in gun production would have been serious had not the mountings been delayed at least as much. The requirements for medium guns, 4 in. to 5.25 in., were of course much larger and for this both forging and manufacturing capacity had to be expanded in 1936. It was only for the 6 in. gun where substantial capacity had been retained at Woolwich and at Vickers that there was any immediate prospect in 1936 of an early tally of requirements and deliveries.

The Admiralty programme proceeded mainly by the revival of the old firms and factories, including most of the armament factories of Armstrong-Whitworth and Vickers, Beardmore, the English Steel Corporation which incorporated the great gun forging and armour plate factories of Vickers and Cammell Laird; in addition Harland and

Wolff were still capable of producing gun mountings and guns as well as ships. The factories likewise bore names long familiar to heavy engineering and naval armaments—Barrow, Elswick, Openshaw, Scotswood, Scotstoun, Crayford and outside private industry the Royal Arsenal, Woolwich. But although the Admiralty led the revival of the old guard and although this was the basis for the bulk of pre-war expansion, it was by no means all. Quite apart from subcontracting which many firms found essential in order to tap resources of skilled labour, the Admiralty had from 1935 to introduce new firms into gun mounting work and above all into the production of fire control equipment and ammunition production. In general, it was necessary at this stage to find firms which were not fully employed on other work. In consequence, although additional plant was usually required, the factory accommodation needed was often available and there was little new construction of factory buildings. Thus in the main, the Admiralty in the pre-war period was not concerned with the construction of any large new factories in private industry. The main reason for this was that there was extensive capacity to be obtained by the re-equipment of the heavy armament firms who had always specialised in Admiralty requirements. Even where outside firms had to be introduced extensively, as in ammunition production and fire control, the extent of building work was small, the main expenditure was again for plant and equipment.

The direct responsibility of the Admiralty for the erection of large government factories both agency and R.O.Fs was limited by the fact that many of these factories were shared with the War Office. Thus the Admiralty had a large share in a new cartridge case R.O.F. at Birtley, also in new gun R.O.Fs at Nottingham, Dalmuir and Leeds and in several R.O.F. explosives and ammunition filling factories. The Admiralty also had an interest in the agency factories for cartridge cases and for explosive production with the I.C.I. But the responsibility for construction and operation of all these factories rested with the War Office and later with the Ministry of Supply. In the First World War the advantage of having specialised government owned factories under the direct control of the Admiralty had become apparent. Conflict with War Office demands could be avoided and control of supplies more firmly secured. This principle had indeed already been adopted in regard to torpedoes, for which the Royal Arsenal had prior to 1914 undertaken extensive work. The Royal Naval Torpedo Factory at Greenock had before 1914 largely removed the need for the work at the Royal Arsenal. In 1916 the Admiralty demand for a special type of cordite had led to the construction of the Royal Naval Cordite Factory at Holton Heath. In addition a good deal of special filling and assembly of ammunition had been undertaken at ammunition depots at Admiralty docks. In 1936, the

Admiralty proposed to construct a filling factory specifically for their requirements and under Admiralty control but this proposal had to be abandoned in deference to the ruling that all Royal filling factories should be under the control of the War Office.[1] The Admiralty were however able to extend their capacity for the production of cordite and other propellants in 1938 by the construction of a new Royal Naval Propellant Factory and by the extension of the Royal Naval Cordite Factory. The Admiralty also had factories to supply inspection gauges for the Chief Inspector of Naval Ordnance.

These additional factories were significant but did not amount to a major building programme. Nor did the Admiralty agency factories make a really heavy demand on building resources. At the peak of war production there were only nineteen Admiralty agency factories and most of these were on a comparatively small scale. For the few larger agency factories existing buildings were used and extended. All in all, Admiralty expenditure on factory building was in most years, comparatively negligible, although in 1940 and 1941 expenditure on buildings under private management was about £1 million. Expenditure on plant, was on a much larger scale.

*Admiralty expenditure; plant (and buildings from 1942) for contractors' use (£ thousands)**

	Pre-war	*1939–45*	*Total*
Armament supply	1,002	16,357	17,359
Other production	3,378	13,152	16,530

*In addition there was over £3 million for building prior to 1943 to be allocated between the two groups.

Armament supply—guns, shell, torpedoes, cartridge cases, fuzes and oerlikon guns—accounted for at least half the total expenditure: in war this was significantly in excess of the total expenditure for the other sectors—mountings and fire control, armour plate and shipyard development. By 1944 the expenditure on shipyard development for merchant and naval yards proved to be the largest single item with a combined total of £5 million, but apart from this, for each of the sectors of production mentioned separately above the Admiralty expenditure was a little more or less than £3 million.

In the main the large expenditure for armament capacity reflects the fact that most of this capacity had to be built up from quite inadequate and often token resources. The importance of naval armament in Admiralty production is seen in the annual expenditure on production in the several sectors of naval production.

[1] See Chapter IV, p. 94.

Admiralty expenditure for Naval Shipbuilding and other production (£m)*

	1939	1940	1941	1942	1943	1944
1 Propelling and auxiliary machinery for naval ships	18·6	34·0	35·7	38·7	47·6	51·1
2 Hull building . . .	19·2	36·0	38·1	52·0	63·5	68·9
Total (1 + 2) . .	37·8	70·0	73·8	90·7	111·1	120·0
3 Armour plate . . .	5·3	2·8	1·6	1·0	2·3	3·1
4 Mountings . . .	2·0	11·0	13·5	17·8	21·0	20·3
5 Guns	2·8	5·2	8·0	10·6	9·3	7·2
6 Ammunition . . .	6·3	15·3	22·6	28·6	25·3	15·3
7 Torpedoes and mines .	2·4	18·7	16·6	21·3	24·1	15·9
Total (3 – 7) . .	23·8	53·0	62·3	79·3	82·0	61·8

*Admiralty Appropriation Accounts, 1939–44.

The war-time requirements of ammunition, torpedoes and mines greatly increased the expenditure on armament production and it should be remembered that some of the supplies both of guns and ammunition were required for merchant vessels. On the other hand the cost of armament production including the filling of ammunition undertaken for the Admiralty by the Ministry of Supply is not included in these totals after March 1940; nor is shipbuilding undertaken in the Royal Dockyards included. Whatever qualifications have to be made, the armament sector was a large sector, and expenditure was never less than a third of the total Admiralty expenditure on naval requirements and in more than one year approached half the total expenditure.

Far greater than the Admiralty capital expenditure on contractors' factories and shipyards was the expenditure on Admiralty shore establishments and dockyards in the United Kingdom and aboard. Apart from the few Royal Naval Factories, the main constructional expenditure was for civil engineering in relation to dockyards and docking facilities in the United Kingdom and abroad. The expenditure on this kind of work in naval dockyards averaged over £21 million a year for the years 1940 to 1943, and in addition, plant and machinery to the extent of £2 million a year. The major part of this large expenditure on civil engineering was to provide improved dock and berthing facilities for the fleet in Admiralty dockyards and a large part was for the dockyards overseas. It will be seen that all Admiralty dockyards played some part in the repair of naval ships but the main Admiralty capacity provided for this purpose was in the Royal Dockyards. That it has been possible to give a broad account of naval shipbuilding programmes by referring almost entirely to private industry, reflects the great preponderance of the shipbuilding industry in new construction. But such an account does far less than justice to the importance of the Royal Dockyards in naval engineering and war production. The Royal Dockyards were by far the largest industrial capacity under direct Admiralty management. They were unique not merely in their long history but in their importance in the Admiralty organisation and in the maintenance of the modern fleet.

CHAPTER III

THE ROYAL DOCKYARDS AND REPAIR

(i)

The Royal Dockyards

THE Royal Dockyards can make a very strong claim to be the earliest industrial undertaking under state administration. They had a unique part in the supply of war equipment, centuries before the establishment of the Royal Ordnance factories. Indeed the ancient Royal Dockyard at Woolwich had some part in the beginnings of the Royal Ordnance factories at Woolwich—the Royal Arsenal. For centuries the Royal Dockyards have had an essential place in the construction and maintenance of the Royal Navy. No other government department has had so long and so direct a contact with industrial establishments. Nor has any other service department retained the direct responsibility for the design and development of their main requirement. At the root of a large part of the technical and industrial integration of the Admiralty will be found the Royal Dockyards. The ability of the Admiralty to recruit a large corps of naval constructors who are responsible for the design of all naval craft and from whom are drawn the professional officers required as overseers of naval construction in private yards, derives to a large degree from the unique resources of the Royal Dockyards. No less fundamental has been their part in the technical and industrial developments which over the centuries were the imperative concern of the Navy Board and since 1832 of the Board of Admiralty.

It was not until the second half of the 19th century that private shipyards had a major share in naval ship construction. As late as 1880 more than half the ships in the fleet were built in the Royal Dockyards. Even in 1914 and in 1939, battleships built in the Royal Dockyards formed a large part of the battleships of the fleet. Yet, from at least 1905 onwards the primary responsibility of the Royal Dockyards has been the repair, conversion and refit of ships of the fleet. This work in the modern fleet has an importance and value which at times has exceeded that of new construction. Thus despite the continuance of some new construction in the Royal Dockyards, the work on repair and conversion has become their most important task. In both world wars the programme of repair and conversion far exceeded the capacity of the Royal Dockyards and a very large part had to be undertaken by the shipbuilding industry. But in the extension of repair and conversion work into private industry and in the Admiralty control and direction of the large repair programme, the Royal Dockyards have had the central role. With the growth of a large private naval shipbuilding industry, the importance of the Royal Dockyards has far exceeded their limited share of new construction, and also their share of the programme of repair in war.

The important role of the Royal Dockyards in naval shipbuilding continued throughout the 19th century and indeed through two world wars. It did not come to an end as is sometimes supposed with the supersession of the wooden ships and the development of the modern fleet. Between 1900 and 1914 the position of the Royal Dockyards in new construction was at times uncertain, mainly because of the very heavy programme of repair that had to be undertaken, especially between 1900 and 1905. It is a characteristic of the modern fleet that it is possible and worthwhile to carry out repair and conversion to a degree which had not been practicable with wooden ships. Ships were more frequently damaged than destroyed; with technical innovation the process of conversion and refit has become almost continuous. In 1904, the volume of repair and conversion had become so great that some of the work had to be put out to private yards, but experience with this arrangement reinforced the general policy that repair work should as far as possible be undertaken in the Royal Dockyards. By 1905 it was accepted as axiomatic that the most important function of the Royal Dockyards must be the repair, refit and general upkeep of the Fleet. Even so it was important that the Royal Dockyards should undertake some new construction. This was essential not merely to maintain the Admiralty policy of having a check on contract prices for ship construction but also to give the dockyards experience and knowledge of the latest designs and construction. This was an important factor in maintaining an efficient repair and refit organisation. As a consequence of this policy, the Royal Dockyards in the period up to 1914 were allotted two major warships each year; in addition two light cruisers and some minor vessels were allotted to them between 1907 and 1913. In 1906 it was decided to introduce the construction of submarines at the Royal Dockyards primarily in order to obtain a check on contractor's prices. It was however an important innovation which provided a valuable extension of dockyard experience.

New construction at the Royal Dockyards continued on a substantial scale and as a result more than half the battleships and well over a third of the cruisers in the British Fleet in 1914 had been built in the Royal Dockyards—87 out of a total of 189 battleships and cruisers. New construction at the Royal Dockyards continued in the First World War and six battleships, fourteen cruisers and twentynine submarines

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were completed there.[1] The large repair programme of the turn of the century was dwarfed by the volume of repair that came after 1914. At the outbreak of the First World War the Royal Dockyards were still committed to a fairly large construction programme, although several yards were entirely devoted to repair work. By the end of 1916 with the exception of submarine building the construction work of the Royal Dockyards was completed and all resources were employed on repair and conversion work. Private yards had also to be brought into the repair of naval vessels and the control of all this repair work was under the Director of Dockyards.

At the outbreak of war, in 1914, five Royal Dockyards were engaged in the building of new ships in addition to repair and refit. Three of the dockyards were of very long standing—Chatham, Sheerness and Portsmouth were all founded in Tudor times. Pembroke dock was founded in 1814 and Devonport gradually replaced the Plymouth Royal Dockyard in the 19th century. All these Royal Dockyards had been modernised and extended during the course of the 19th century. As their output of new capital ships and submarines shows they were brought up to the requirements of the modern fleet as it was in 1914. In addition, there was a new dockyard under construction at Rosyth. Construction of this had been started in 1909 and this was primarily intended to provide docking facilities in northern waters and to undertake repair and refit work. It was brought into operation in 1915 and was available for repair work by March 1916, and for the rest of the war was fully occupied with refit and repair work. By 1918 the Royal Dockyards reached the peak of expansion and employment; with seven dockyards the total employment reached 75,000. Over 12,000 of this total was due to expansion at two dockyards—Rosyth and Haulbowline. The other five dockyards—Portsmouth, Devonport, Chatham, Sheerness and Pembroke had employed 33,000 in 1905; by 1914 their total had increased to over 40,000 and by 1918 to 63,000.

For more than two years after 1918 there was a large volume of repair work to be done and employment in the dockyards remained at a high level. When the work declined the building of small merchant vessels was undertaken at two yards. In 1922 at least 10,000 men had to be discharged. In 1926, both Rosyth and Pembroke were placed on a care and maintenance basis and very soon afterwards Pembroke was handed over to the Air Ministry for development as a seaplane base. Until the outbreak of war in 1939 only four Royal Dockyards were in use, Portsmouth, Devonport, Chatham and Sheerness; it was at the first three of these dockyards that new construction was undertaken

[1] Royal Commission on the Private Manufacture of and Trading in Arms, 1935-36, Minutes of Evidence, Table VI, p. 631.

between the wars and in the course of the war. In 1938 the decision was taken to re-open Rosyth and in the first year of war it became available for docking and repair work.

In the main the remaining yards fared well in the lean period following 1927. In 1932, the tonnage of new construction on hand or allocated to the Royal Dockyards was the equivalent of about 70 per cent. of the Admiralty tonnage with the private yards and for the first time included destroyers. With the expansion programmes of 1934 and 1935 the share of the private yards was greatly increased but the Royal Yards were by no means neglected. The Royal Dockyards' share of orders for cruisers and submarines continued to be large and after 1935 several more destroyers were constructed in the Royal Yards. There was however no proposal now that the Royal Dockyards should undertake the construction of battleships, as they had done up to 1916. When in 1937 the building of capital ships was again undertaken all orders were placed with private yards. The size and weight of the new ships were beyond the capacity of the Royal Dockyards slips but none of the new ships were available until well into the war. In consequence of the twelve battleships in the British fleet in 1939, four—Royal Sovereign, Royal Oak, Queen Elizabeth and Warspite—had been built in the Royal Dockyards, and several, during the inter-war years, had been modernised and reconstructed in the Royal Dockyards.

Although between the wars, docking facilities had been improved at the dockyards, no attempt was made to strengthen or enlarge the building slips. Most of the dockyards were also penalised by their very vulnerable position on the southern coastline. Rosyth which was well removed from the southern front was not equipped for construction; it had been built and equipped as a repair dockyard. In the Second World War, the three Royal Dockyards, in the south, constructed three cruisers and fourteen submarines. In addition the Royal Dockyards were able to deal in most years with at least one third of the ships in dock for repair, conversion and refit.[1] As the work undertaken in the Royal Dockyards included a large proportion of the more difficult repairs, it was rather more than a third of the volume of repair that was undertaken in the Royal Dockyards.

The place of the Royal Dockyards organisation in the programme of naval repair was even greater than this. At the outbreak of war, the Emergency Repair Organisation was set up as part of the Dockyard Department of the Admiralty. The task of this organisation, under the immediate direction of the Deputy Director of Dockyards was to organise and supervise the repair and conversion of naval ships in commercial docks and shipyards. To carry out this task, experienced technical officers and men from the Royal Dockyards were stationed at ports and shipyards as overseers. Over 550 of these overseers were

[1] G. A. Bassett, Transactions of the Institution of Naval Architects, Vol. 88.

employed in the United Kingdom. Thus the naval repair programme outside the Royal Dockyards continued to be under the direction and control of the Dockyard Department.

Here it should be noted that something of the Royal Dockyard tradition was carried over into the repair of naval aircraft. When the Admiralty took over the direct control of the Fleet Air Arm in 1939 arrangements had already been made for a Central Repair Establishment for naval aircraft in the Portsmouth area. This was the origin of the Royal Naval Aircraft Repair Yard at Fleetlands. At about the same time preparations were made for a further Aircraft Repair Yard at Donibristle to support the Fleet at Scapa. This northern repair yard was established at the Air Station at Donibristle, which had been transferred from the Royal Air Force to the Navy and had a mixed complement of Service and civilian personnel. But the southern repair yard at Fleetlands, which came into operation in 1940, was manned on Royal Dockyard lines with civilian labour and naval officers. As the burden of repair increased more repair facilities were required and to enable the two Aircraft Repair Yards to concentrate on repair work, four smaller yards called maintenance yards were set up. As with the Royal Dockyards, repair facilities had to be extended to overseas stations and maintenance yards for inspection and for limited repair work were set up in South Africa, Kenya, Egypt, Ceylon, India and Australia. Again, as with the Royal Dockyards, the Admiralty resources were insufficient to meet the war-time volume of repair and in addition arrangements had to be made for industry to undertake a considerable part of the repair of naval aircraft.

(ii)

The Repair Programmes 1939–45

Under the term repair programmes are included not only jobs due to damage caused by enemy action or to accidents resulting from difficult conditions of navigation in war-time, but also the normal refits of the Fleet, schemes of modernisation necessitated by rapidly changing circumstances of war or by technical improvements and conversion for special operational duties. An extensive programme of repair, refit and conversion has become a characteristic of the modern navy. Even in peace-time the process of modernisation and refit is continuous; in war-time the frequency of refitting may be reduced but the amount of repair and conversion work is very greatly increased. In the Second World War, as in the First, the volume of repair and conversion rose to a very high level for both naval and merchant ships.

In the Royal Dockyards, both in 1918 and in 1943, there were never more than a few thousand employed on new construction so that the

Employment on New Construction and Repair (thousands)

	ROYAL DOCKYARDS	PRIVATE YARDS			
		New construction		*Repair and conversion*	
		Naval	*Merchant*	*Naval*	*Merchant*
1940 June	26·4	62·4	28·8	41·5	44·0
1941 June	30·1	73·0	36·0	38·8	54·5
1942 June	35·4	78·2	38·2	40·0	57·5
1943 Sept.	36·7	89·3	42·9	44·1	59·5
1944 June	37·4	88·3	41·3	38·9	65·2
1944 Dec.	37·1	82·7	40·0	47·7	53·1
1945 June	35·7	73·9	42·5	38·8	61·4

bulk of the labour force at the Royal Dockyards should be included under repair and conversions. In the Second World War the Royal Dockyards were fewer and the total employment was only about two thirds of what it had been in 1918. Much more capacity for repairs had to be found in private yards and docks. But from 1941 onwards this loss of capacity for repair was to a large extent offset by the facilities provided for British naval ships in naval dockyards in the United States. These facilities have been estimated as equivalent to two major Royal Dockyards.[1] In addition limited facilities for repair were developed or extended at British naval bases and dockyards overseas. As a result, the total capacity for repair and conversion available to ships of the British fleet was probably no less than it was in 1918.

The tally of total capacity hides an important difficulty due to the change in the size of capital ships. In the inter-war period the size of capital ships had increased beyond that of all but the largest docks.[2] In 1939 in the Royal Dockyards there were available 50 graving docks and five floating docks but of these only seven graving docks and two floating docks were suitable for capital ships. In 1914 there were 25 docks suitable for capital ships and of these 23 were graving docks. By the outbreak of war however the resources of the Royal Dockyards had been increased by the re-opening of Rosyth, which had been on a care and maintenance basis since 1925: much valuable repair work could and was to be carried out at this establishment where numbers employed rose to a peak of over 6,000. The need for more naval repair bases in addition to the Royal Dockyards soon became evident as the burden of work rapidly increased after September 1939. Towards providing this capacity naval repair bases were established at Lyness, at

[1] Journal of Royal United Service Institution, May 1949, No. 574, Vol. XCIV.

[2] For this and the following paragraphs on repair much information has been derived from "*The Repair and Upkeep of H.M. Ships and Vessels in War*" by G. A. Bassett, Vol. 88, Transactions of the Institution of Naval Architects.

Pembroke Dock and at Corpach and Dunstaffnage on the west coast of Scotland. But even so some time had to elapse before either Rosyth or the new bases could be brought into operation: new establishments such as those of the size of Lyness or Dunstaffnage took about eighteen months to build and equip. These docks remained under the direct control of the Admiralty and were treated therefore as additions to the main Royal Dockyards. They were very largely manned by men from the southern dockyards but the total employment was only a few hundred.

Another method of increasing the capacity for repair work was taking over a dock by the Admiralty and the appointment of a specialist repair firm to manage the yard. Thus in 1940 Jarrow Dry Dock and adjacent premises on the north east coast were leased by the Admiralty from the owners who had been forced to close the yard in 1933 by the lack of orders after 90 years of naval shipbuilding. This dock was the largest on that coast and capable of dealing with large naval vessels. The dock gates were repaired and dock pump machinery refitted: several cranes of varying sizes were installed on the sides of the docks and equipment including keel blocks, loose plant and a generating plant and compressor were supplied. The firm had since the closing of the yard concentrated on repair work and therefore took over the management of the yard as agents of the Admiralty. The dock was used extensively from 1942 onwards and 78 vessels mostly naval, were docked there and 45 refits were carried out.

After the fall of France the south coast dockyards were increasingly vulnerable and repair bases in the north had to be used as far as possible especially for large vessels. For this purpose an Admiralty Floating Dock was moved from Devonport to the Clyde and much use was made of this although it was placed in an exposed berth not near a shipyard. From October 1941 when the first ship was dry docked, 71 ships both naval and merchant used the dock. A large floating crane was also transferred to the area to make possible the docking of large warships in the dock. Facilities for repair in the wet docks i.e. Prince's Dock, Queen's Dock, Yorkhill Basin, and Dalmuir Basin were improved by the installation of shore electricity supplies and plant consisting of static and mobile generators etc. A smaller floating dock of 2,200 tons was transferred from Portland to the Clyde in 1941 and extensively used for periodical dockings of submarines. A quay at Gourock Pier was taken over from L.M.S. Railway and sheltered berths in Great Harbour developed for destroyers and escort vessels.

From the first winter of the war Admiralty dockyards and repair facilities were inadequate to handle all the repair work to naval vessels and it became increasingly necessary to seek the assistance of commercial dockyards. A major part of commercial capacity consisted of firms whose sole business was repair work, yards where some berths could be used for repairs if necessary and large commercial docks such as existed at Liverpool and Southampton. To improve the facilities of the private docks, the Admiralty supplied suitable equipment to enable firms to deal with special naval work. An example of this was the submarine repair facilities which were needed increasingly after the grouping of submarines in home waters. The repair yards had to be situated as near as possible to the operational bases of the submarines. In addition to normal docking and repair facilities, special battery sheds with electric charging and lifting arrangements were provided at the yards of three firms in Scotland and two on the north east coast and one on the Thames estuary. None of these firms had previous experience of submarine refit work and Admiralty officials were therefore appointed to assist the firms. The special experience and facilities at the Vickers yard at Barrow were also used for the repair of submarines.

Much use was made of the large commercial docks. Thus the Gladstone Dock at Liverpool was used as a wet berth. The Brocklebank Dock, also at Liverpool, was used as a dry dock for 12 capital ships, for aircraft carriers and for 18 cruisers. To make such work possible the Admiralty supplied at the Gladstone Dock a 50-ton mobile electric crane and workshop, in addition to special machinery and gear required for warship repairs including special dock blocks and dock shores, portable air compressing and welding plants, motor generators and Scotch derricks. Similar assistance was given to enable King George V. Dock at Southampton to be used for larger naval vessels, though with the fall of France the use of the dock for naval vessels was restricted but it was useful for the fabrication of breakwaters for D-day and other large erection jobs. Improvements to other docks were also arranged including provision of adequate electrical supplies. On the South Wales coast two derelict docks in Cardiff and one in Newport were re-opened. Windsor Slipway, Cardiff, was re-conditioned with two new slips and special cradles for repair of landing craft. Special arrangements had to be made to meet the need for repair facilities for landing craft and other naval craft in assault forces for North African landings in late 1942, for Sicily in 1943 and for D-day. Southampton Floating Ferry Slipway at Woolston was requisitioned, dredged, strengthened and fitted with derricks. Two 450-ton concrete floating docks were provided for docking of major landing carft, and additional embarkation facilities were laid down in harbours and sheltered waters in the area. The repair labour for this additional accomodation was provided from local repair firms, increased by about 350 iron workers from local factories. The Royal Dockyards provided the necessary staff to supervise and control the work.

Some relief to the hard pressed capacity at home was given by repair facilities abroad. In 1939 the Admiralty had overseas two graving docks and three floating docks which were suitable for capital ships.

One dock at Gibraltar in 1940 was widened to take the largest warship but even with the addition of four commercial docks the resources abroad were limited. The virtual closing of the Mediterranean for about three years still further reduced the available capacity, which consisted almost entirely of docks in South Africa. Docking facilities on the west and east coasts of Africa were practically non-existent. Certain measures were however undertaken to improve docking facilities especially for the largest naval vessels. Repair bases in the Far East had been seriously reduced by the loss of Hong Kong and Singapore and the Dutch East Indies though some facilities were available in Australia and Ceylon. But as we have seen, important help for repair work to be carried out overseas was given by the United States authorities, especially for the largest vessels of the Royal Navy.

Despite all that was done to provide facilities for repair and conversion outside the shipyards and despite the concentration of the Royal Dockyards on this work, the naval and merchant shipyards had to be drawn into repair work and conversion at all stages of the war. At times it was the volume and urgency of repair which forced the Admiralty to make use of valuable shipyard resources. Often it was the complicated nature of the repair or conversion which made the use of shipyard facilities necessary. Completion of new ships had to be deferred, and vessels deleted from the naval programme, because of the pressing need to allocate capacity to repairs. The Royal Dockyards which were regarded as being available mainly for repairs were from April 1940 to the autumn of 1944 never able to cope with more than 35 per cent. of naval repair and conversion work: the balance was therefore handled by private yards and commercial repair facilities.

(iii)

The Royal Dockyard Organisation

In the Admiralty, the Director of Dockyards is responsible for the control and direction of extensive industrial resources. His position in the department may be compared in some ways with the Director of Ordnance Factories in the War Office and later in the Ministry of Supply.[1] Both posts were founded in the 1880's and by the turn of the century both were adversely affected by the ascendency of the private armament industry. But in this period the post of D. of D. did not, like the D.O.F., fall into abeyance. Indeed the First World War brought a new significance to the position of the D. of D. This process was repeated with equal effect in the Second World War.

The main features of the control and management of the Royal Dockyards are of long standing. The modern structure dates from 1885

[1] See Chapter IV, Section (vi), below.

and although there have been many important technical developments, the main offices and their titles have remained virtually unchanged. When in 1885 the post of Director of Dockyards was created, in place of the existing post of Surveyor of Dockyards, the D. of D. was made responsible to the Controller of the Navy but was given such extended authority and accorded such discretion and power of action as would make him personally responsible for the work at the dockyards. Thus dockyards became a major organisation in their own right directly responsible to the Controller.

Even so, by 1905 and even before, it was clear that the changes of 1885 had by no means solved the problem of adequate control and direction of the dockyards. The difficulties were in part inherent in the system adopted in 1885 and in part due to the very large expansion of the shipbuilding and repair programme during the twenty years. Not merely had the amount of new construction in the dockyards increased but the repair programme and the new construction of private yards had increased to an even greater extent. It is true that in this period the D. of D. was relieved of the work of final provisioning of ships built in private yards but with the very large increase in the work of repair and refit the work of the D. of D. was greatly increased both in the dockyards and for repair in private yards. In the early years of the century there was a very large programme of repair which had to be placed out to contract in private yards. The full weight of this innovation had fallen on the D. of D. and at the same time every increase in responsibilities and in the volume of work undertaken by the dockyards greatly increased the necessity for the D. of D. to give most of his time to related matters requiring his attention at the Admiralty. It thus became clear that as had happened with his predecessor—the Surveyor of Dockyards—the D. of D. had little time left to attend to the local operation and management of the dockyards.

Despite the appointment of a civilian as D. of D. in 1885, the dockyards each remained under the control of a naval officer—the Admiral Superintendent—but a new post of Civil Assistant was created at each dockyard. The civil assistant was intended to provide technical assistance and acting under the authority of the Admiral Superintendent to control and supervise labour and materials and to a large extent the manufacturing programme of the yard. In this it was apparently intended they should be in effect representatives of the D. of D. and exercise a general supervision of industrial activity in the yard on his behalf. It was clear by 1905 that the civil assistants were not undertaking these rather special though no doubt tentative functions which it had been hoped they would develop. Indeed, the appointment of a Director of Dockyards and of civil assistants in the dockyards had failed to secure any substantial change in the organisation of the dockyards.

In 1905, with the Royal Dockyards approaching what proved to be the peak of new construction work and with a large and persistent repair programme, proposals were considered within the Admiralty for a further reorganisation both at the Admiralty and in the dockyards. The proposals were based on what must be accounted an ambitious intention: 'To remodel the whole system of dockyard administration, firstly from the Admiralty, and secondly the local management, so as to bring the latter into line with that obtaining in the best organised private shipbuilding and engineering establishments'. It seemed essential to the Admiralty committee that there should be a firm separation of function between the supervision of the industrial management and organisation of the dockyards and the administration and supervision of work in the dockyards. It was proposed that the first task should be undertaken by an Inspector General of Dockyards who would devote all his time to this, and that the arrangement and examination of work in the dockyards should be the responsibility of a Superintendent of Dockyard Work. These proposals which would have required the abolition of the post of Director of Dockyards, were not adopted. The recommendations for changes in the management at the dockyards were adopted to a very large extent. Thus although the Admiral's Superintendents at each dockyard were to remain the supreme Admiralty representatives, the post of the Civil Assistant was abolished and the industrial management of the yard was placed to a much larger extent under the Chief Constructor and the Chief Engineer, who were renamed Manager Constructive Department and Manager Engineering Department. As a result the industrial management of the yards was improved considerably but the manifold functions of the D. of D. remained.

There were no changes in the Dockyard Administration at the Admiralty until major changes were made in the Controller's Department in the middle of the First World War. These changes arose fairly directly from the special position of the dockyards in the war programme and the responsibility of the D. of D. for repair work in the private yards. In 1916 it was decided to bring all the work of the private yards and the dockyards under the control of a Deputy Controller for Dockyards and Shipbuilding. The wide functions of the Department are clear from the chief officers:

Deputy Controller for Dockyards and Shipbuilding
- Director of Dockyards and Repair
- Deputy Director of Dockyards and Repair
- Director of Warship Construction
- Superintendent of Dockyard Branch

There were now three senior officers concerned with the supervision and administration of the Royal Dockyards. Two of them were also concerned with the large volume of repair undertaken in private yards.

Now the full recognition of the scope of the dockyard responsibility for repair in private yards made it possible to place the Dockyard Branch at the Admiralty under a Superintendent and thus come to a limited extent within the demarcation of responsibilities recommended in 1905. The Director of Dockyards and Repair and his Deputy were now primarily concerned with the administration and direction of the very large programme of repair both in the dockyards and in private yards.

By 1925 the headquarters organisation had returned to something very similar to the pre-war arrangements. The Director of Dockyards again headed a separate department in the Controller's Division but in contrast to the pre-war appointment the post of Director was now held by a naval officer. In consequence the appointment changed every three years from one Vice-Rear Admiral to another. This gave added significance to the perpetuation of the post of Deputy Director, to be held by a civilian. Following the recommendations of a committee appointed by the Admiralty in 1927, significant improvements were made in the financial and costing system and the daily muster and roll call was replaced by 'clocking in'. This committee which included several industrialists as well as Admiralty representatives submitted a majority report which recommended extensive reorganisation of the management and control of the dockyards. These recommendations were not accepted by the Admiralty. Acceptance would have meant the appointment of a civilian as Director of Dockyards and the appointment of a civilian general manager at each dockyard to undertake full responsibility for the management of the dockyard as a productive establishment. These changes would have resulted in a considerable diminution in the powers of the Admiral's Superintendent. The majority of the committee were prepared to recommend the abolition of this post if this should prove necessary to implement the other changes recommended.

It was undoubtedly the intention of the majority of the committee to secure for the dockyards a more adequate industrial organisation and to ensure that equipment and organisation should be more in accord with general industrial standards. It might indeed have been claimed as was later said of the Royal Ordnance Factories that limitations imposed by the departmental organisation and administration were denying the Royal Dockyards the full scope of an industrial organisation. Despite the importance of the Hilton Committee's recommendations it was not until several years after the end of the Second World War that the problem was investigated again.[1] Then, as previously, the Admiralty could present very strong arguments in favour of the large naval element in the technical staff of the Royal Dockyards and in their administration.

[1] Eighth and Ninth Reports from the Select Committee on Estimates, Session 1950–51, *His Majesty's Dockyards*.

Precluded from any major change in organisation, the Royal Dockyards have sustained the demands of two world wars and have proved an invaluable basis for the development of a widespread organisation for repair and conversion. In this they have administered a programme of work requiring capacity more than twice as large as their own industrial resources. The demands of this work resulted in some strengthening of the direction of dockyard work by the appointment of a civilian Deputy Director of Dockyards but changes at the dockyards have been few. In many ways, apart from the volume of very exacting repair and conversion work, the most exceptional contribution of the Royal Dockyards was the supply of the large body of officers who administered and supervised the repair of naval vessels in a very large number of private shipyards and docks. Whatever may be controversial in the industrial organisation, the invaluable characteristics of the Royal Dockyards still persist—the very high standard of the training given and of the work undertaken, and the competence of the men who are trained in the Royal Dockyards.

CHAPTER IV

THE ROYAL ORDNANCE FACTORIES

(i)

Woolwich, Waltham and Enfield

UNTIL 1936, the three historic factories at Woolwich, Enfield and Waltham were the only Royal Ordnance Factories. Despite the long history of these factories and their importance in munitions supply, it was not until 1936 that schemes were approved for additional Royal Ordnance Factories. Although a very large number of the government owned factories provided in the First World War were under private management there were some which were both owned and managed by government under the Ministry of Munitions. Most of the factories under state management were explosives factories; they were given the title of His Majesty's Explosives Factories but these explosives factories were managed directly by the production department of the Ministry of Munitions and were not brought into the Royal Ordnance Factory organisation.[1]

The early history of what may well be called the three historic R.O.Fs might well be considered to be outside the scope of this volume. There was however much in their position up to 1914 which affected their operation in the First World War and this was not without its bearing on the change in policy which came after 1919. When the war came in 1914, Woolwich and Waltham had been firmly established for well over a century and the third factory, the Enfield Small Arms factory could rightly claim to have been initiated during the Napoleonic wars. For several decades before 1914 official policy had sought to strengthen the armament industry and to maintain the R.O.Fs as an immediate but limited reserve capacity. The 1914–18 war had shown that even given preferential treatment, the armament industry could not cope with the extended requirements of modern warfare and that the R.O.Fs were far more important in war production than official policy had assumed. The number of R.O.Fs was not increased but the three existing factories were greatly extended. Woolwich which was in fact a group of several factories became by far the

[1] The Royal Naval Cordite factory at Holton Heath was founded during the First World War and came into production in 1916. This was an Admiralty factory intended as a permanent factory to provide an alternative to the Royal Gunpowder factory at Waltham. It was administered by the Admiralty and was not under R.O.F. administration.

largest factory in the United Kingdom. The importance of the R.O.Fs in the First World War was somewhat obscured for the general observer by the large development of state owned factories under the Ministry of Munitions and by the control of the production at the existing Royal Ordnance Factories by the Ministry of Munitions. For although many of these state owned factories were similar in function to Royal Ordnance Factories, none of them were placed under the R.O.F. organisation. Thus despite their long historic role in munitions supply and their important part in munitions supply in the First World War, it was not until the shadow of the Second World War loomed ahead that the R.O.F. organisation was given the chance to prove the full potentiality of a state factory organisation.

The entry of the state into the manufacture of ordnance and other warlike stores had come gradually and for the most part piecemeal. It was usually undertaken as a matter of convenience or expediency but rarely from any general policy favouring state manufacture. The foundation of the Royal Gun Powder factory at Waltham in 1779 was perhaps the most clearly defined. This came about largely as a result of Admiralty dissatisfaction with the quality of explosives supplied by private manufacturers. The Ordnance Board greatly encouraged by the success of this alternative to private production enlarged the factory several times during the 19th century but with the development of the modern explosives industry Waltham specialised in the development and production of cordite and tended to leave high explosive manufacture to private factories. In consequence, the armed services became dependent again on private manufacture for the supply of almost all types of high explosives, but the technical and research resources available at Waltham prevented a decline into dependence on commercial development and research.

The foundation of the Royal Small Arms Factory at Enfield Lock was a somewhat more evolutionary process. The Enfield factory also owes its origin primarily to the necessity of securing a measure of independence from private manufacture. Here the problem was not so much quality as the difficulty of obtaining sufficient supplies without dependence on private manufacture and design. The first state manufacture of small arms was undertaken in the Tower of London and in a musket factory at Lewisham but in 1811 the enterprise was moved to Enfield Lock where a small factory was taken over and extended. It was not until the crisis of supplies in the Crimean war and the decision in 1851 to introduce rifles to replace the smooth bore muskets that a modern factory was established. Difficulties in obtaining supplies of the new rifle from private manufacture encouraged the policy of undertaking manufacture at Enfield. The new problems of rifled barrel manufacture and the use of machinery in the United States in place of craft methods, as well as the general opposition of private manufacturers to the adoption of machine production, led to the decision in 1855 to equip Enfield with American rifle plant, and thus to establish the first factory in the United Kingdom for the mechanised manufacture of small arms. The mission which went from Enfield in 1854 to study the methods and plant for rifle manufacture in the factories in the United States was one of the earliest productivity teams to cross the Atlantic to the United States. The result was the purchase there of much of the plant to equip the Enfield factory for machine produotion of the complete rifle. This was a remarkable achievement in government manufacture and indeed in parliamentary control for it was a select committee which had recommended that this important change in manufacture should be undertaken. The Enfield factory within a few years became the undoubted leader of small arms manufacture in the United Kingdom. This position of pre-eminence has been maintained in many respects up to the present day; an apprenticeship at Enfield remains a much coveted training.

The Royal Arsenal at Woolwich was much more diverse in origin and was more directly challenged by the growth of the private armament industry in the second half of the 19th century. The earliest manufacturing for the Crown in the Woolwich district was at the Royal Dockyard and at the adjacent workshops for the manufacture of ancillary stores for the wooden ships of the Royal Navy. Long before the manufacture of ordnance stores began there, Woolwich had become the official residence of the Master of Ordnance, the Master Gunner of England and the Proof Master, who like their predecessors made use of the adjacent marshes for the proving of ordnance. Woolwich was thus connected with the trial, storage and eventually the repair of ordnance before any manufacture was established there. Probably the earliest Royal Ordnance Factory was the Royal Laboratory founded at Greenwich for the manufacture of ammunition and removed to Woolwich in 1695. The manufacture of guns was soon to follow; in 1716 a serious explosion at a private gun foundry led to the decision that the government should for the first time have a brass foundry for the casting of guns. The modern history of the Arsenal may well be dated from the construction of the gun foundry in 1717. This together with the carriage factory and the Royal Laboratory enabled Woolwich to provide at least part of the demand for ordnance and ammunition throughout the 18th century. The growth of the Arsenal, particularly apparent by the end of the century was a natural concomitant of successive wars. In the American War of Independence the 43 acres were increased to 100 acres. In the Napoleonic wars 2,500 people were employed in factories stretching over 140 acres, using in the carriage shop the latest devices of Bentham and Brunel and in the Royal Laboratory new designs for ammunition which bear a modern nomenclature—time fuzes, rockets, land mines and shrapnel shell. Woolwich was thus able to supply a wide range of ordnance for what is usually accounted the first modern European war. With full justification what had generally been known as Woolwich Warren was in 1805 by royal decree given the designation of the Royal Arsenal.

The industrial revolution came slowly to the engineering industry and it came even more slowly to Woolwich, removed as it was from the main sources of natural and artificial power. The impact of the Crimean war was felt throughout the manufacture, design and administration of ordnance supplies. It brought the industrial revolution into the private and state manufacture of arms; it brought the full impact of continental designs to emphasise the inadequacy of the British weapons. Further, it placed the main responsibility for the manufacture and development of naval and army ordnance and ammunition on the War Department in which the Board of Ordnance was incorporated in 1855. Very important changes were to follow in the second half of the century especially in the development of guns and ammunition for both the Army and the Navy. The Royal Arsenal had a very important part in all these developments not merely in production but also in design and research. By the end of the century the peace-time employment was about 10,000.

The state manufacture of armaments had been founded before the development of large private armament factories. In the second half of the 19th century however the private armament industry was growing rapidly. It was in this period that most of the modern private armament factories were founded and a large armament industry developed. The first of the large private ordnance factories—the Armstrong Ordnance works at Elswick—was not started until 1847 and Joseph Whitworth, whose works at Openshaw were subsequently to be merged with those of Armstrong did not concern himself with ordnance until 1854. It was not until 1888 that Vickers—the Sheffield firm of iron and steel forgemasters who were already manufacturing gun forgings—agreed to instal plant for the manufacture of complete guns and equipment, and this they did in response to a direct approach from the War Office.[1] The entry of these three firms and their factories into armament production greatly affected the position of the Royal Arsenal, for after 1880 the expansion of the private factories was assiduously encouraged by the government. The immediate reason for this was to obtain the large supplies of armament and armour required for the new modern fleet which was constructed under the Naval Defence Act of 1885 and later additions. Since the foundation of the Gun Factory at Woolwich, the Royal Arsenal had been the major supplier of naval

[1] Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36, Minutes of Evidence, p. 348.

ordnance, but the immediate demand of 1885 was far beyond the existing capacity of that factory. To have expanded the factory to meet the immediate demand would have required a very large accession of plant and equipment. Already the work of Armstrong and Whitworth had added much to the design and to the technique of manufacture and since metallurgical problems were increasing it was not unreasonable to look to the forgemaster to undertake not merely the production of forgings but also the manufacture of guns.

The creation of extensive capacity in private factories removed the necessity for large expansion of state factories, and also brought with it the problem of the maintenance of that capacity. Thus whilst the difficulties of supply in the Crimean War led to an expansion of state factories, the difficulties of bringing the armament firms into action for the South African War led to the general conclusion that the armament firms should receive more orders to keep them as active as possible and that the government factories should be relied on mainly to provide a rapid expansion of supplies at the outbreak of war. The equipment at the Royal Ordnance Factories was to be improved so as to increase the potential capacity but the peace-time employment and operation there were to be restricted to the minimum required to ensure immediate war-time full scale operation. Although production at Woolwich was restricted after 1900 some additional capacity was provided there and the attempt to eliminate redundant plant had not proceeded to any serious extent by 1914.

The Royal Small Arms Factory at Enfield and the Royal Gun Powder Factory at Waltham were less directly affected by the policy of minimum operation. The demand for rifles fluctuated with the military situation and the periodic decisions to adopt new types of weapons. Enfield had it is true often to operate a good deal below maximum capacity but in general the orders given to private industry represented the quantity over and above the amount Enfield could supply in the time allocated for the total requirements. The chief private manufacturer--the B.S.A. Co.—had been driven by the instability of demand to undertake the manufacture of other products; indeed the B.S.A. cycle was to become as famous as the B.S.A. rifle and justifiably bore the sign of stacked arms—a significant sign of suspended animation in armament capacity. The growth of the modern explosives industry and the manufacture of gunpowder and cordite by several firms led to the greater use of industrial firms for military requirements. By 1900, Waltham had become important mainly for development and the initial production of new propellants. There had been no restriction on development work and Waltham had been foremost in the introduction of many new propellants. There was, however, no expansion of the factory to meet the increasing demand for explosives.

Despite the pre-war policy of restriction, the demand placed on the Royal Arsenal by all services during the First World War resulted in a continuous expansion of capacity and employment at Woolwich. The demands placed on Woolwich by the Admiralty alone would have brought the factory to a scale reached by few other munitions factories. With the combined demand of the army and the navy the Royal Arsenal expanded to a scale and scope never equalled by any armament factory in the Western Hemisphere; in 1917 it employed over 70,000, a record for long unequalled by any factory of any kind in any country. Contrary to all expectations the building of additional factories started at Woolwich with the first month of war; and continued throughout the war. By far the largest additions were for shell and small arms ammunition but more than a quarter of the new factory space was for gun and carriage production. Throughout the First World War the importance of the Royal Arsenal increased and new advantages were discovered. Both the Admiralty and War Office found the Royal Arsenal invaluable as a factory to which they could go with the most difficult and urgent orders. It was a factory prepared and indeed required by the exigencies of state service to undertake the most difficult and unrewarding tasks. Seventy-five per cent. of the naval ammunition was filled and completed at Woolwich and by far the greater part of new gun production at Woolwich was on behalf of the Navy. So much so that the War Office from time to time began to feel the need of a gun factory of their own, and the Ministry of Munitions looked primarily to the expansion of the armament firms to provide the additional guns required for the Army. Expansion of capacity at Waltham and at Enfield was no less significant although on a smaller scale than at Woolwich.

Although the importance of the three Ordnance Factories soon became apparent, no other Ordnance Factories were constructed nor was the existing factory organisation given any special responsibility in the Ministry of Munitions. By 1916, Waltham and Enfield were administered by the production branches in the Ministry of Munitions concerned with explosives and small arms. Woolwich continued after 1916 to operate very largely as it had done in peace-time, with the Chief Superintendent primarily responsible for relations with Whitehall. An earlier attempt at a common central administration with a Management Committee in the Ministry of Munitions proved abortive and the later arrangement under which a Munitions Council member was given responsibility for general oversight of matters relating to the Royal Arsenal, proved unsatisfactory. So much so that early in 1918 the council member recommended that there was a need for a Controller of Ordnance factories to undertake the primary responsibility for the three Royal Factories.

(ii)

The Royal Ordnance Factories 1920–39

It was not until the last year of war that the overcrowding of the Royal Arsenal led to consideration of the possibility of dispersing some capacity to the National Factories. With the end of the war this became a post war problem which became linked with the future of the Royal Ordnance Factories and the National Factories. For two or three years after 1918 there were proposals that one or all of the three historic R.O.Fs should be replaced by state factories that had been constructed during the war. Waltham was in the greatest danger, for it was strongly recommended that the National Propellant factory at Gretna should be retained in preference to Waltham. There was no National factory that had facilities comparable with Enfield and to replace Woolwich several factories would have been needed. In the end these proposals came to naught and the three historic R.O.Fs remained the key factories. All that was retained of the 250 National factories was a filling factory at Hereford, part of the armament factory at Birtley and the explosives factory at Irvine. These factories were retained merely as reserve factories which could be rehabilitated if needed. They were in fact, in 1936 and 1937, to become the first of the new R.O.Fs. Before 1936 the only active factories were Woolwich, Waltham and Enfield. At all these factories work and employment was greatly reduced; in most years up to the end of 1934 Woolwich employed about 7,000, Enfield usually less than 1,000 and Waltham only a few hundred. With continued disarmament it was extremely difficult to find work for the minimum labour force which was considered essential in order to make any subsequent expansion possible.

Despite the difficulties, there was never any doubt as to the necessity of keeping the three factories as the basis for any production and any expansion which might prove necessary. The effect of disarmament on the resources of the few remaining armament firms made the continued existence of the three R.O.Fs more important than it had ever been. This situation had been clearly foreseen by the McKinnon Wood Committee in 1919, which had stressed the need for the retention of the R.O.Fs as key factories and the probable ascendancy of state factories.[1] In 1926 with the appointment of a Director of Ordnance Factories, the position of the R.O.Fs in the administration of the War Office was greatly improved. In many ways this was a return to the position which had been lost in 1899.[2] The D.O.F. was directly responsible to the Master General of Ordnance for the operation of the factories but

[1] See p. 15 above.

[2] Between 1887 and 1889 there was a Director General of Ordnance Factories responsible to the Financial Secretary. The post was abolished in 1899.

he was also the main technical adviser on matters of production. In the period of investigation and planning which ensued between 1927 and 1935 this was his most important function.

In the War Office, D.O.F. shared these functions with the Director of Army Contracts, who was responsible for information regarding suitable capacity in industry. With the formation of the Supply Board the work of D.O.F. was greatly increased; he was brought in to provide technical data for many investigations and when the Supply Board Technical Establishment (S.B.T.E.) was formed, it was staffed largely from D.O.F. personnel and directed by an A.D.O.F. The S.B.T.E. was charged with the preparation of manufacturing plans for accelerating and increasing the supply of warlike stores on mobilisation and thus D.O.F's concern with industrial production was greatly extended. In the ten years of planning between 1926 and 1936, D.O.F. was the only general authority for munitions production and planning. When in 1936 the duality of D.O.F's work was recognised by placing the planning of industrial capacity and the mobilisation of industry under a Director of Industrial Planning, many of the technical blueprints had already been prepared by the staff of D.O.F. Indeed, not merely was the work of D.I.P. in many ways a continuation of the functions previously undertaken by D.O.F. but the D.I.P. and his senior staff were in fact officers who had worked under D.O.F. The contribution of the Royal Ordnance Factory resources to the preliminary planning and to pre-war preparation was clearly fundamental and continuous.

Before 1935 the actual manufacturing activity of the three R.O.Fs was very small. Their real value at this stage was in the technical knowledge of munitions, the processes of manufacture and plant. Unlike industrial firms, their sole justification for existence and their only real interest was in the design and manufacture of munitions. Significant as were the deficiencies in equipment and organisation for mass production, it was the only organisation which had a working knowledge of most types of munitions. No less important, it was the only organisation which could be expected to undertake without question the investigation and experiments essential to the introduction of any type of store. As will be seen later the contribution of many firms and not merely the armament firms, to this work was to become highly important, but in the long process of initiation which goes with all technical planning and particularly with the tentative planning that was so often a characteristic of pre-war programmes, the value of a government establishment devoted to munitions production was proved beyond all doubt.

It was clear to those who had been concerned with the problem of expansion in the First World War, that for another major conflict the fullest possible expansion of the R.O.F. organisation and of the existing armament firms would be necessary. The panel of industrialists in

1934 recommended that the first stage in expansion of capacity should be at the existing R.O.Fs and at the armament firms and that this should be followed by additional factories, some under the management of the R.O.Fs and some under the armament firms.[1] This was indeed the first time that the general expansion of the R.O.F. organisation by the addition of new factories had been recommended. In 1934, there was no longer any necessity to withhold expansion in favour of the armament firms for the few remaining firms were not in any case disposed to expand to any great extent without government assistance and approval. The fullest expansion of the R.O.F. factory organisation was from 1935 an essential part of the War Office programme and indeed of government policy. As a result, the part of the R.O.Fs was crucial in all major sectors of production. For most major production the part of the R.O.Fs was never less than that of the armament industry—sometimes there was a remarkably parallel and equal development of the R.O.Fs and the industry—while for several large sections of production the part of the R.O.Fs was far greater than that of the armament industry and for some production almost exclusive. The expansion of the R.O.F. organisation in all major munitions production was unequalled in its long history.

The beginnings of this expansion of R.O.F. organisation came at a time when there was a very strong current of opinion openly expressed against the private manufacture of arms. As so often happens the investigation of the activities of the giant colussus came after it had fallen into decline. In 1935, the Royal Commission on the Private Manufacture of and Trading in Arms had to consider the practicability and desirability of a prohibition of the private manufacture of and trading in arms and munitions of war and the institution of a state monopoly in this manufacture and trade. This gave an opportunity to many witnesses to advocate the state manufacture of arms to the exclusion of private industry. Most who advocated this course were concerned to take the manufacture of arms out of the sphere of private gain but some of the arguments were based on the difficulties in 1914 of securing an adequate response from the armament firms.[2] On this ground it could at least be argued that there was a definite need for a larger state owned capacity to meet war requirements.

The findings of the Commission and the government's decision on policy were somewhat at variance. The Commission, whilst rejecting any proposal for state monopoly in the manufacture of arms, did strongly recommend that 'government manufacturing establishments should be fully equipped for the production in some measure of naval,

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[1] See above, Chapter I, p. 23.

[2] Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36, Minutes of Evidence.

military and air armaments of all types.'[1] Taken literally this was a particularly drastic proposal. It implied that the government factories should not merely extend the scope of their manufacture in naval and military armament but what was more significant, that they should undertake the manufacture of aircraft. The government were not prepared to accept this proposal for the extension of government manufacture to all types of armaments.[2] For some munitions, the government gave specific objections which were to prevail over any use of fully fledged state factories. The proposal to extend state manufacture to the production of aircraft was contrary to the policy of encouraging the aircraft industry to provide constant improvements in aircraft by general competition within the industry. Moreover it was felt that, even in war time, the establishment of shadow factories for aircraft manufacture would go a long way to meet the aims which the commission had in mind. For these factories although managed by industrial firms were owned and equipped by the state. This form of state factory—the agency factory—was to remain the only type of state factory provided for aircraft production. The agency factory was also to be extensively adopted for many types of munitions production. Here agency factories, although at first conceived as an alternative to the expansion of private firms, were often the direct alternative to the Royal Ordnance Factory, for although they were under private management the factory and equipment was state property. Moreover, as the manufacture to be undertaken at these factories was under the direct control of the government department concerned, these factories were to prove that it was possible to employ industrial firms for management and yet avoid the private manufacture of arms.

Armour plate and large fixed gun mountings for the Admiralty were other munitions for which the government were not disposed to accept state manufacture. Unlike aircraft, this production had never been undertaken in a state factory; the government were anxious to encourage the maintenance and use of suitable plant in private firms and to avoid the duplication which would result if government factories were to undertake this type of manufacture. The manufacture of armour plate was of course closely related to commercial metallurgical manufacture but the exclusion of Woolwich from heavy naval mounting production in the 1890's was a deliberate restriction which with the decline of the munitions industry brought real disadvantages. For had Woolwich been allowed to develop capacity for these heavy gun mountings, as they did for naval guns, some of the difficulties of naval rearmament in the years 1935–39 would have been greatly lessened. Thus although the government stated that they were not opposed in

[1] Cmd. 5292, 1936 Report of Royal Commission, Pt. VIII, Ch. XII, Summary of conclusions and recommendations.

[2] Cmd. 5451, 1937 Statement relating to Report of the Royal Commission on the Private Manufacture of and Trading in Arms, 1935–36.

principle to extending the range of government manufacture, it was clear that they were not prepared to extend the government manufacture of arms to what were in fact the main types already excluded. Whilst they were prepared to consider any proposed extension of the range of manufacture the government statement did not mention any new products which were likely to be adopted for government manufacture. Throughout the period of war and of rearmament despite the very large expansion of Royal Ordnance Factories both in number and in capacity there was no significant extension of the range of products. Indeed in one important field--tank production—the activities of the R.O.Fs ceased during the rearmament period and were not re-instated until 1943.

The exclusion of Woolwich from tank production in the rearmament period came rather by default than from any deliberate choice. War Office policy had been to maintain activity at Vickers-Armstrongs although a large part of their manufacture of tanks up to 1934 had been for export. Up to 1936 the manufacture of tanks which was on a very small scale came almost entirely from Vickers-Armstrongs. Manufacture at Woolwich was largely of experimental models and was maintained mainly to provide a vestige of competition in development. When the problem of production for rearmament had to be faced the possibility of putting the Woolwich tank section on a production basis does not appear to have been considered. In the 1930's it was the automative problems that were uppermost in tank development, and Morris Commercial, an important War Office vehicle contractor, collaborated with the War Office in following up foreign tank development. The eventual outcome of this was the Nuffield Mechanisation factory for tank production. In addition, the War Office encouraged the introduction of heavy engineering firms particularly locomotive and heavy vehicle manufacturers. Thus, as with aircraft, the policy of encouraging the private manufacture of the tank was accompanied by the exclusion of government manufacture. Later the exclusion of R.O.Fs from tank production was to be abandoned; but this did not happen until the second half of the war. Thus the great expansion of R.O.F. capacity was not by an increase in the range of products but by a great increase in the number of factories for the manufacture of the staple products—above all for guns, small arms, small arms ammunition, explosives and filling, and the final assembly of ammunition of all kinds—the products for which the three historic R.O.Fs had been founded.

In 1936 and in the following years, the state of opinion and the political climate were favourable to a considerable increase in the state manufacture of arms but it is doubtful whether this had any substantial effect on War Office policy. There were indeed many good reasons for a policy favourable to a general extension of R.O.F. capacity. The

D.O.F. organisation provided a nucleus of industrial and technical resources for munition production which it was a clear advantage to expand and which could be expanded rapidly. The introduction of general engineering firms into highly specialised munitions production was by no means easily or quickly achieved under peace-time conditions. Except for some stores such as shells and fuzes where specialised units could be fitted into existing factories in emergency, the main demands were more easily and more speedily achieved by specialised state factories entirely devoted to armament production. The opinion of the committee of industrialists confirmed this view. Though they recommended the introduction of carefully selected firms they clearly held that to attempt any general introduction of highly specialised munitions manufacture into industry in peace-time would be difficult and the balance of advantage was definitely in the fullest expansion of existing specialised factory organisations—the armament industry and the R.O.Fs. The indirect effects of the general opinion favourable to state manufacture of arms, were however important, in that they brought the choice between private and state manufacture sharply into focus and made it difficult to disregard the advantages to be obtained from the expansion of state factories. This facilitated the full and increasing use and provision of state managed factories and made any artificial limitation of the expansion of R.O.F. organisation quite out of date.

From 1934 until the formation of D.I.P. in 1936, the D.O.F. was responsible both for planning the expansion of R.O.F. capacity and investigating the possible expansion in industry. From 1936 D.O.F. had to give most of his attention to the now urgent problem of the planning and construction of the new R.O.Fs. At the D.O.F. level the main direct responsibility was the determination of size and capacity and siting of the new factories. D.O.F's main task was to advise D.G.M.P. on these problems. The detailed planning and for some factories the construction, was the task of officers operating under C.S.O.F. Woolwich or the superintendent at Waltham. As will be seen later the greater part of this work apart from propellant factories was the immediate responsibility of the C.M.E. Woolwich. Throughout the period of rearmament the D.O.F. and the senior staff at Woolwich and Waltham were fully occupied in the planning of new factories. A committee of technical staff were in more or less continuous session dealing with the plans for the new filling factories; there was another group responsible for the planning and equipment of all the new engineering R.O.Fs and also for the construction of most of these factories. At the Royal Gunpowder factory at Waltham a technical committee was formed in 1936 and was in continuous session to deal with the planning of new explosives and propellant factories. Only a few of the types required had been produced previously; many in 1936 had not even reached the pilot production stage. Valuable collaboration was given by I.C.I. but for the greater number of products the technical committee was responsible for the process of production, design and the general lay-out of the plan. New large scale processes had to be planned for some explosives already established, even for T.N.T. For the propellant factories, the processes and plant for a wide range of products had to be worked out.

From 1936 up to the beginning of 1939, ten new Royal Ordnance Factories were approved in addition to the expansion of the reserve factories. Even so, the number and the size of the factories was less than had been originally contemplated. But when in 1939 the Cabinet increased the War Office programme to rather more than had been proposed in 1935, the earlier factory programme and more was required. Thus immediately before the outbreak of war a further large addition to the number of R.O.Fs was planned. By the end of 1939 the total number of new R.O.Fs approved in 1939 was fourteen—eight engineering factories, three filling and three explosives factories. The work of D.O.F. thus increased to formidable proportions. He had to deal to some extent with the problems relating to the site, planning, construction and equipment of a very wide range of factories. Superintendents and senior staff had to be appointed for all the new factories and the many problems of preparing for the operation of a very large factory capacity dealt with and indeed anticipated. As a result a large part of the technical and administrative resources of the three older factories were employed in the planning, construction and starting up of the new factories. When the Ministry of Supply was formed, the Royal Ordnance Factories and the D.O.F. organisation were transferred to the new Ministry. For the first six months the Directorate continued under the general control of D.G.M.P. but with the large scope of its activities it is not surprising that in March 1940 the D.O.F. became Director General of Ordnance Factories. This attainment of a title and status that had been lost in 1899 was not merely a matter of historic interest. By this change the Royal Ordnance Factories became a division for munitions production in their own right.

By the end of 1940, 25 factories were in operation employing over 110,000. By March 1942, when all but one of the new factories were in operation there were more than forty factories employing over 300,000. Broadly, half of the total number of new factories may be considered as part of the pre-war preparations, and the other half as approved for war-time requirements. There were three major groups of factories—filling, explosives and engineering factories; but the third group which includes all R.O.Fs where engineering processes are the basis of manufacture, should be divided into several sub-groups.

*Peak employment at Royal Ordnance Factories**

	No.		*Labour*
Filling Factories . . .	10	—	153,081
Explosives Factories			
(including Waltham) . .	9	—	41,351
Engineering Factories			
Gun and carriage† . .	10	—	27,449
Small arms (including Enfield)	4	—	21,727
Small arms ammunition .	5	—	33,487
Gun ammunition . . .	5	—	18,849

* Excluding Woolwich.

† Including Dalmuir. This factory was operated as an Agency from August 1941 to November 1944.

Most sectors of manufacture at Woolwich were after 1940 replaced by new factories but even after 1941 there was never less than 20,000 employed there on munitions production. Guns, small arms, shell and small arms ammunition, explosives and the filling and assembling of ammunition—these are the main sections of specialised armament production. This appears to have required the employment of rather more than 1 million at the peak of munitions production in 1942 and of these the R.O.Fs employed over 300,000 or 30 per cent. As the 1 million includes subcontractors, the share of the R.O.Fs in the final factory manufacture was much greater. Not merely were the R.O.Fs the largest group of factories but they included more than half of the few really large factories in the United Kingdom. Even at the peak of war production there were probably not more than twelve factories in the United Kingdom employing more than 19,000 and of these, seven were R.O.Fs. Thus there were more really large scale factories under the administration of the R.O.F. organisation than under any other organisation. It is true that at least six of the large R.O.Fs were operating on a three shift system but this in itself provided many problems with which very few private firms had to contend and none on so large a scale. With more than forty factories and an employment of over 300,000 the R.O.F. organisation was the largest munitions undertaking in industrial history.

This large and unique industrial organisation of over 40 factories developed into an industrial undertaking for the most part unnoticed. There was little time to stand back and take stock; there was no annual meeting of shareholders at which the progress of the undertaking was declared. Most of the factories were approved and constructed as the solution of a specific problem and the sum total went for long unassessed. The early factories were approved either as replacements of the older factories, which were all at one time or another condemned as too old and in too vulnerable a position, or as expansions of R.O.F. capacity only existing previously at Woolwich or Enfield. It was only as the early factories came into production that their individuality became established. The size of the undertaking grew gradually and the full impact was not felt until 1941 when most of the factories were coming into production. In the two years from December 1939 to December 1941, 29 new R.O.F.s came into operation and

	New Royal Ordnance Factories		*Total Labour Force*
	Approved	*In operation*	
March 1938 .	10	5	28,479
March 1939 .	16	9	32,794
December 1939.	29	10	54,249
December 1940.	38	31	112,268
December 1941.	41	39	276,760
March 1942 .	41	40	311,932

over 200,000 workers were added to the R.O.F. employment. This expansion was the equivalent of the creation of a new major industrial sector. It was a transformation which would normally be achieved only over a long period of years. It would not be surprising if the resources and facilities of the D.G.O.F. organisation hardly seemed to keep pace with the expansion of the industrial sector it had brought into operation.

(iii)
The Royal Filling Factories[1]

The filling of shell ammunition and bombs is a very hazardous and exacting process. From the early days of the 19th century the responsibility for the filling of the ammunition for all armed forces in peacetime had been largely confined to the Royal Filling Factory at Woolwich Arsenal. Before 1914 the naval armament firms developed some filling capacity but primarily for the ammunition they supplied with the ships which they built or equipped for foreign governments. By 1930, Vickers-Armstrongs alone still retained some of this capacity and were thus able to make a small but useful contribution in the filling of

[1] Of the new R.O.Fs the filling factories were the only factories to have a specific designation—Royal Filling Factories. The official title for the other new factories, whatever their production—explosives, guns, small arms or ammunition—remained Royal Ordnance Factory. This term was also often used generally as in the preceeding pages to include the Royal Filling Factories.

some calibres of shell. The Admiralty also undertook some filling at ammunition depots and in the pre-war period had contemplated erecting an Admiralty filling factory to provide for a much larger share of their requirements. This proposal had to be abandoned when it was decided in 1936 that as a matter of policy all new filling capacity should be within the Royal Filling Factory organisation and at that time under control of the War Office.

The prerogative of the Royal Filling Factories was substantially maintained throughout the Second World War. Eight large new Royal Filling Factories were approved between 1937 and 1940. It is true that some additions were made to the capacity at Vickers and there was some increase in filling at Admiralty naval depots but the only real exceptions were the six small filling factories finally approved in 1941 as government agency factories to be managed by commercial firms. Even so, these factories together with the capacity at Vickers and some small units established in a few other factories, did not account for more than 10 per cent. of the capacity employed on filling in January 1943. Thus, even when these factories were in operation at least 90 per cent. of the capacity was in the Royal Filling Factories. This extension of filling factory capacity almost entirely under Royal Ordnance Factory control was in striking contrast to the procedure that was adopted in the First World War. Then, at least 75 per cent. of the total filling was done outside Woolwich which remained throughout the war the only Royal Filling Factory. It was a mark of the ascendancy of the R.O.F. organisation that most of the new filling factories in the Second World War were under R.O.F. management and control. Woolwich, which until the bombing in 1940 was employing over 8,000 on shell filling, was completely overshadowed by the large new Royal Filling Factories, which in 1943 had a total employment of more than 150,000.

In addition to gun ammunition, three of the Royal Filling Factories undertook the filling and loading of small arms ammunition. This work absorbed a large part of the total labour force employed at these factories and was an important addition to the traditional role of the filling factories. An even larger addition to the general burden of filling work was the filling of aircraft bombs. Eventually this was undertaken at all but two factories and absorbed by far the largest amount of explosive for any class of store. The increasing size of bombs, whilst it reduced the labour force required, increased the amount of explosive to be used and stored. Filling factories were in many ways the most exceptional of all the war production factories. In other sectors of production there were usually some industrial factories either in the engineering, chemical or explosives industry which in civilian production employed broadly similar processes and technique. To appreciate the peculiarities of these factories and the exceptional precautions that had to be taken both in construction and in operation, a detailed description of their production and organisation would be necessary. Fortunately the largest filling factory in operation in the Second World War is fully described elsewhere.[1]

Although the term filling is used in a general way to cover all the work undertaken in the filling factories there are two distinct main processes. One of these is technically known as filling, the other as loading. Strictly, filling relates only to the filling of components other than the main charge. The components, range from detonators and fuzes to the projectile, i.e. the shell or bullet which is finally required to reach the target. Projectiles ranged in size from the large naval shells to the 2 pdr. and the 20 mm. shells, bullets and up to 15 mm. A wide range of the projectiles were solid. In the Second World War there was a large demand for solid armour piercing shot for tank warfare, but there was also an increasing tendency for more and more projectiles to be filled e.g. the incendiary and tracer bullets. As a result, there was an increasing variety in the filling required. Detonators and fuzes are small but extremely difficult and hazardous components to fill. The loading of the charge—usually the cartridge case is often the simplest process but often involves a large quantity of high explosive. The third main task is the assembly of all components into a complete round of ammunition, or where the projectile and charge are stored separately, the assembly of these two parts. All this work—filling, loading and assembly is usually undertaken at the filling factory.

Between the wars, the problems of planning filling factory capacity had greatly increased in complexity. Many new types of ammunition had to be dealt with including the bombs required for air warfare and there was a large increase in filled components and important developments in detonators and fuzes which had to be filled with an ever widening variety of complex explosive substances. Most of these changes had the result of greatly increasing the possible hazards of filling factory work. The disasters and loss of life in filling factories in the First World War had led to more stringent regulations to be observed in construction of factories using explosive materials and this was a large factor affecting the cost and time taken in construction. When to these inherent difficulties were added uncertainties and sudden changes in ammunition requirements both in the pre-war and above all in the war period, it is not surprising that the filling factory programme was marked by great difficulties and sudden changes of plans, nor that in the end, it was found to have the largest margin for contingencies of any factory programme.

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[1] *R.O.F.: The Story of the Royal Ordnance Factories 1939–48*, Ian Hay, (H.M.S.O. 1949)

Proposals for the construction of new filling factories were under discussion before the advent of the rearmament programme. These proposals arose from the Cabinet decision in July 1935 to replace the Woolwich filling factory by a new factory on a less vulnerable site. This decision to replace the Woolwich Filling Factory also largely determined the scale and scope of the initial planning for the new factory. The Woolwich factory had employed 20,000 workers on filling in 1917 and provisional plans for the new factory were intended to provide about the same volume of output as Woolwich and to employ rather more than 20,000. A site for the new factory was chosen at Chorley in Lancashire. This brought disappointment to many who had hoped to obtain some relief for the acute unemployment in South Wales. In December 1935, it was agreed that in addition to the new factory, to replace Woolwich, the filling requirements for a five contingent army would require the construction of at least a second new filling factory. In March 1936 it was announced that this new factory would be in South Wales.[1] In addition, the Admiralty proposal to have a filling factory specialising in naval filling to replace the naval filling section at Woolwich led to the proposal for a third filling factory. This project was set back by the decision of the Minister for Co-ordination of Defence who ruled that apart from the filling at Admiralty depots all naval filling should be under War Office administration. Even so the possibility of having a filling factory specialising in naval ammunition, although under the War Office control, was attractive and in many ways desirable. The exploratory planning and examination of possible sites was therefore not entirely abandoned; and in July 1937 a third new filling factory was approved mainly for naval requirements.

The calculation of capacity for filling factories was, of course, based not on the production of filled ammunition in the rearmament period but on the estimated requirements for the first year of war and preferably on the maximum requirements for that year. This basis was particularly important for filling factories, which were difficult to construct and in which exceptional difficulties and dangers might occur in making extensions while the factory was in use. Despite this, it was only possible to obtain financial approval for the three new filling factories on condition that building work was strictly limited to the immediate war requirements of the current expansion programme. It was indeed fortunate that through all these uncertainties Woolwich was available to undertake the bulk of the current rearmament requirements for filled ammunition. It was not entirely alone in this, for as early as 1932 a National filling factory at Hereford which had been retained by the War Office in 1918 mainly as a storage depot was used on a limited scale as a supplementary filling factory. With the

[1] H. of C. Deb. Vol. 309, Col. 1040.

delays and uncertainties of the new construction programme the importance of this factory was greatly increased and in 1937 a major extension and modernisation was decided upon. Hereford was to be of great value for some time to come, for at the outbreak of war it had the largest labour force employed on filling outside Woolwich.

Planning and construction of filling factories up to the spring of 1939 was thus confined to the rehabilitation of Hereford and the limited construction of the three new factories, Chorley, Bridgend and Glascoed. Three of the factories were planned to a fair degree of specialisation though it was also arranged that not more than 75 per cent. of any one type of ammunition should be concentrated at any one factory, but Chorley which was intended to replace Woolwich was to have a wide range of capacity. It was still assumed that the Woolwich Filling Factory would eventually cease to operate and that even in peace the four factories would share the orders arising from current requirements. All additions to the Army requirements up to March 1939 were fitted into this scheme. But in the spring of 1939 the revival of the earlier Army programme and the further expansion of Air Force requirements made several more filling factories an immediate necessity.

In planning the new Royal Filling Factories in 1939 and 1940 some reduction in size was achieved. Already in April 1939, D.G.M.P. had formed the view that filling factories on the scale of Chorley were definitely on the large size. There were good reasons why filling factories should cover a larger area than in the First World War but the factory area and capacity at Chorley had grown beyond what was at first intended. The first proposal in 1935 was to provide a factory with the same capacity as the R.F.F. at Woolwich but to do this strictly in accordance with the statutory regulations relating to distances for buildings in which explosives were handled or stored. This meant that a factory site would need to be considerably larger than the 500 acres of the R.F.F. at Woolwich where the distances were far less than required. In the search for a site of at least 700 acres the site finally chosen as suitable included 900 acres. As the total filling capacity which D.O.F. was instructed to provide for even in 1935 was considerably in excess of the Woolwich capacity it was decided to provide at Chorley the maximum capacity possible within the area of the site. Thus from as early as the end of 1935, Chorley was planned to have a capacity approaching 1½ times the capacity of R.F.F. Woolwich. In 1918 Woolwich R.F.F. had employed over 20,000, so the new factory could be expected to employ over 30,000. For the two other filling factories under construction—Bridgend and Glascoed—sites even larger than at Chorley had been acquired but this was mainly due to geographical factors. There was never any intention to make the built-up area larger than at Chorley.

The inclusion of S.A.A. filling in the first filling factory approved in 1939 meant there could be no substantial reduction in size; and a site of 1,000 acres in Staffordshire was selected. It was not until two further factories were approved in August 1939 that factories sites of a good deal less than 1,000 acres could be used. At the outbreak of war the location of these two factories was undecided. Sites were eventually decided upon some fifteen miles apart with one factory in Lancashire and the other just over the county boundary, in Cheshire. By December 1939 the provision of three more filling factories had to be dealt with. By February 1940, sites had been decided on for two of these factories. The third factory which would have brought the total, excluding Hereford, up to nine new filling factories was never approved.[1]

Throughout 1940 the filling factory programme suffered from a serious phase of uncertainty. It was caught up in the conflict of policy and conjecture regarding the ultimate level of the gun ammunition requirements for the Army.[2] At the same time the number of additional filling factories needed was greatly increased by the decision to plan future filling factories on a very much smaller size than previously. There were several reasons for the change. Chorley had been found to be almost uneconomical in size and even the somewhat smaller factories approved earlier in the year were likely to have serious difficulties in obtaining sufficient labour not merely for production but also for their construction. A more widely dispersed set of factories of much smaller size would greatly facilitate the solution of these problems and afford better security from air attack and would also facilitate the finding of suitable sites. It would also be possible for the smaller factories to specialise in a limited range of stores; the size of factories would vary according to the quantity and type of ammunition—a few might employ 10,000 and more but others only 5,000 or even less. Based on the planning of smaller factories it was calculated that ten additional factories would be required to meet the requirement for 36 divisions. In December 1940 the Ministry of Supply calculated that to bridge the gap between the 36 and 55 divisions and to meet the increasing requirements of the Royal Air Force and the Navy and for new types of ammunition, a further sixteen small factories would be needed. This meant twenty-six small factories in all.

In 1941, a rapid succession of changes in requirements and in the operation of the existing factories made possible a very large reduction in the factory programme. By May 1941 the annual requirement for army gun ammunition had been reduced from 155 million rounds to

[1] A ninth Royal Filling Factory was in fact approved at Healey Hall but this was a small factory—a converted mill which may well be classed as ancillary to Chorley.

[2] cf. M. M. Postan, *British War Production*, in this series (H.M.S.O. 1952), pp 133, 134.

less than 100 million rounds.[1] Despite the continuing increase in naval and air force requirements, this reduction greatly reduced the number of new filling factories now required. In the same period it became possible to count on a much larger output from the existing factories and from any new factories because of the introduction of three-shift working in all filling factories in place of the existing two shifts. This it was computed would increase output by at least a third. As a result of the large reduction in requirements and of the increased output to be expected from each factory, the proposal for 26 additional small factories was reduced to six. Even this reduction left a margin of capacity over the requirements; but it was not practicable to assume that the optimum labour force could be attained at all the factories. The difficulties of reaching full strength at the existing factories were proving very great indeed. In addition, the possible effect of enemy bombing was all too obvious and this it was calculated might at any time result in a loss of 20 per cent. of the available capacity.

In reviewing the position before the final reduction to six additional factories a further factor had also been taken into consideration. This was the rapidly increasing efficiency of labour which, as will be shown later, was partly due to the recent adoption of various efficiency systems. Whilst this had some bearing on the planning of the new factories it had no very great effect on the number of factories required. Indeed the main change produced by this factor was to reduce the labour force in the nine large factories. It was now possible to obtain the same output with a smaller labour force but it was not usually possible to increase the output beyond the planned capacity of the factory; there were limiting factors in the form of special storage for explosives and components and finally in the total effective labour force that could be attained. Increased efficiency led to a fairly immediate reduction of the labour force required at each of the factories. Thus the major part of the filling programme was undertaken by the eight large new Royal Filling Factories and Hereford. For after 1940 the Woolwich employment on filling fell to 5,000 and the total for the six agency filling factories was little more than 10,000. Of the eight new Royal Filling Factories, five had peak employment of over 19,000 each, and all but one had over 10,000 employed. The rehabilitated factory at Hereford employed over 7,000. Chorley and Bridgend, the first two of the new factories, employed over 20,000 for at least two years and both exceeded 28,000 at the peak of employment.

Specialisation was less than had at first been intended, for with the reduction in number of factories it was necessary to add to the range of ammunition dealt with by most of the factories. More than half the National filling factories of the First World War were engaged on a

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[1] This was mainly as a result of the Prime Minister's directive on the role and scale of the Army. See *British War Production*, *op. cit.*, pp. 127 and 134.

very limited range of ammunition or more often of small components. In the Second World War all the Royal Filling Factories undertook the filling of a wide range of ammunition. Only in the six agency filling factories was there narrow specialisation; most of these factories dealt only with one or two products and one factory was confined entirely to the filling of aircraft bombs. Although the planning, provision and operation of the filling factories was the responsibility of the War Office and in war-time of the Ministry of Supply, the filling factories served all three Services. The work of the filling factories ranged from S.A.A. for the three Services to shell of all sizes for the Army and Navy, mines and torpedoes for the Navy to bombs of all sizes for the Royal Air Force. The demands for S.A.A. on the filling factories affected the distribution of capacity between the three Services, assessed on the basis of labour employed.

Percentage of Total Filling Labour Force employed for the three Services

	Excluding S.A.A.			*Including S.A.A.*		
	Army	*Navy*	*R.A.F.*	*Army*	*Navy*	*R.A.F.*
January 1943 . . .	83	13	4	68	15	17
October 1943 . . .	68	22	10	49	29	22
January 1944. . .	61	24	15	53	27	19
May 1944 . . .	60	25	15	54	26	19

Filling factories, both in their planning and construction, were quite unlike any other type of factory. Superficially, most of them appeared as a very large area enclosed by a formidable fence and populated with relatively small buildings, carefully spaced and constructed to reduce the effect of explosions. For the most part all the Royal Filling Factories had to deal with a wide range of ammunition and to hold stocks of a wide range of explosives, propellants and components. In consequence they had to be specially constructed to secure both the most favourable structures and arrangements for the work of the factory and for the storage of ammunition. Some of the new factories consisted of more than a thousand buildings scattered over more than 1,000 acres. Within this area was a whole range of special services and facilities including at the largest factory more than 50 miles of light railway and double that length of special foot and vehicle tracks. Apart from the locomotive sheds and general engineering shops there was a textile factory to supply the textiles required and power stations and boiler houses to serve a vast heating system with 30 to 40 miles of steam piping. In addition there had to be storage accommodation for explosives, components and filled ammunition equivalent to several weeks output. The need for large earthworks and underground storage dumps and the necessity for levelling out of the site meant that an enormous amount of heavy civil engineeri-- work was a very large part of the factory construction.

The arrangement of the buildings and services had to be worked out in very careful manner. Not merely was it necessary to secure the best safety precautions possible but it was necessary to provide for the movement and final assembly of up to 40 different types of components which might have to be incorporated into one round of ammunition. The effect of this on the arrangement of groups of building was highly complex. In 1936 there was a very limited knowledge of the most suitable structures and arrangements for a modern filling factory. The factory at Woolwich was basically too old an establishment to form a direct guide. The experience of the First World War could not be taken as a general guide as there were many important changes both in ammunition and in the explosives and also in the regulations governing the spacing of buildings. Indeed the experience of disastrous explosions at factories in the First World War led to extreme care and extensive changes in planning the factories. Explosives were more dangerous to handle and safety precautions and the distance between buildings had to be increased. There was a much greater variety of ammunition to fill. The experience of 1914–18 filling factories did however indicate that there could be more standardisation in filling factory buildings even for different types of ammunition.

The difficulties arising from the size of the filling factories affected planning from the start; it greatly increased the difficulties of finding suitable sites. The strategic and economic policies which largely dictated factory location in the pre-war period greatly added to these difficulties and are dealt with in a later chapter.[1] The difficulties of finding a site usually of at least 1,000 acres within the regions prescribed under that policy or, indeed, in any region, were very great. Not merely was a very large open site required of the kind which were in increasing demand for airfield construction but the site had to have geological and other physical characteristics not available in many regions. Thus the need for a level and at most, gently undulating area with good drainage not liable to flooding ruled out many parts of the otherwise desirable areas in Westmorland and South Wales. Similarly many comparatively level tracts of land were found on investigation to have subsoil which would have required extensive draining and pile construction for foundations. This was a defect in the Chorley site which despite all the normal investigations was not discovered until construction had been started.

Apart from these physical characteristics, the site had to be well removed from any large urban centre, also from airfields, but had nevertheless to have an ample supply of water and electricity and an

[1] Chapter IX below.

adequate railway service. It is not surprising that with these many exacting requirements, some sites had perforce to be adopted in localities where there was no housing accommodation or transport facilities for either the construction or factory workers. From 1939 onwards it was possible to choose sites in much less isolated positions. This was due in part to some relaxation in the policy of strategic location and also to the construction of the factories as temporary filling factories and on a somewhat smaller scale. Even so the size of the site required for some of these factories still greatly restricted choice of site and brought with it many problems of staffing and transport. It was only for the smaller factories that the problem of size came down to manageable proportions.

The immense scale of most of the filling factories not merely complicated computation and planning of capacity but also the estimate of the time needed for the construction of the factories. In 1936, the planning staff at Woolwich had stated that 3 years would be required for the construction of Chorley, of this 6 months would be for preliminary work, 2 years for construction up to occupation and 6 months to complete. This estimate of 3 years caused much concern and contributed in no small degree to the decision in August 1936 to transfer responsibility for construction to the Office of Works and confine Woolwich to the technical planning. This decision, needless to say, was not popular at Woolwich, and became even less so when it was clear that the change brought no reduction in the period of construction. Comparisons with the rapid construction of temporary filling factories in the First World War were very misleading; the Woolwich estimate of three years proved to be all too true. Chorley, for which the estimate was given, although in use for limited production from early in 1939 was not substantially complete, quite apart from later extensions, until the spring of 1940. For neither of the other 1937 factories, Bridgend and Glascoed, was the period of three years reduced. Even for the 1939 and 1940 factories which were constructed as short term war-time factories the construction period did not fall below two years. In all these factories special provision had been made to facilitate the starting of production in sections of the factory before completion. At most factories the labour force for the operation of the factory had reached half peak strength before the constructional work was complete. This was usually at least 12 months after some kind of production had been started.

There was no doubt that fundamentally the construction of these factories was a very large undertaking which required a lengthy period both for preparation and for construction. It was in fact their size which made it extremely difficult to achieve any drastic reduction in time even by additional expenditure on acceleration which was approved after Munich. There were, of course many unforeseen factors which increased the difficulties. Unexpected geological formations affected the work on foundations at some sites and the rigours of the first winter of the war greatly reduced construction work. Even so, the fundamental problem was the size, the complexity and the variety of the constructional work to be done. The filling factory construction programme included at least three factories which required by far the largest factory construction work of the war. In cost of building and civil engineering work they dwarfed the largest factories which were constructed for aircraft production—the Rolls-Royce engine factory at Glasgow and the Castle Bromwich aircraft factory. Indeed, their cost was several times that of the aircraft factories although the size of their peak labour force was almost the same.

Cost of Construction of Royal Filling Factories

	Final Cost (£m)	*Approximate Cost per 1,000 workers* £
Chorley	13·14	487
Bridgend	9·58	334
Glascoed	6·30	514
Swynnerton	13·60	680
Risley	13·39	610
Kirby	8·63	436
Thorpe Arch	5·95	672
Aycliffe	6·64	455

The differences in total cost and in cost per 1,000 workers were due to a number of factors. The types of ammunition to be filled affected the types and construction of buildings but probably the most important factor affecting the cost per worker was the different extent to which the factories came within reach of their optimum labour capacity. Thus Bridgend was not merely a cheaper factory for its size but it came nearer than any other factory to the optimum labour strength.

The constructional labour force employed on each of the eight Royal Filling factories ran into many thousands. The employment of large armies of constructional labour on these very extensive sites, presented serious problems of control and direction. It was rarely possible to obtain the maximum effort from so large a labour force but the numbers employed on construction rarely reached the maximum that could be employed on the sites. These problems were aggravated by the comparative isolation of many of the sites. In consequence it was necessary at many sites to build hostels to house the constructional labour and at all sites to provide special transport facilities. Despite all the efforts made, it was not possible to reduce the time from approval to completion of construction to less than two years and the construction of the first three factories took a full three years. It was indeed fortunate that this protracted period of construction did not have the serious consequences in munitions supply that were often anticipated. This was due largely to fortuitous circumstances, the military inactivity in the first winter of the war and the continued operation of the Woolwich Filling Factory. In addition, the policy of bringing the new factories into operation in sections made it possible to obtain considerable production from the factory long before construction was complete. In all factories there was about twelve months overlap between the start of production and the completion of construction.

The difficulties of bringing the factories into substantial operation proved no less than the difficulties of approval and construction. To a large extent the difficulties arose from the same causes—the size of the factories and frequent changes in the range and volume of requirements. The problem of recruiting the large labour force required constituted a major operation and to do this within a short period was even more difficult. The location of most of the factories greatly added to these difficulties and when sufficient labour was available within a reasonable distance for travelling to and from the factory, it was not always possible to increase the transport to cope with the rapid increase in the labour force. Although other considerations were very important the supply of labour had often been the deciding factor between alternative locations in the pre-war period. In war-time even more weight was given to this factor. Unfortunately the supply of labour, which in the pre-war period meant the number available from the unemployed, usually changed substantially in the course of preparation and construction of the factory. In some areas the unemployed were absorbed fairly rapidly even before 1939 and before the factory was ready to recruit the main labour force. It was significant that the Bridgend factory located in South Wales where unemployment persisted even in 1940, had the least difficulty in recruiting labour, even though transport in that area was very difficult. On the other hand the filling factories in the north west area were seriously affected by the rapid absorption of labour into the engineering and aircraft factories in 1939 and 1940. It was not until the concentration of the textile industry and the mobilisation of women in 1941 that recruitment for these factories approached a reasonable level.

The work at filling factories was after all by no means attractive. It was both dangerous and exacting and could be injurious to health. Even when more labour did become available the comparatively isolated position of some of the factories made it difficult to attract and to transport the workers. This and the necessity of recruiting labour from even farther afield led to the general policy in 1940 of providing hostel and housing accommodation. The extent of this accommodation varied considerably between the factories. The uncertainties that had to be assessed were indeed reflected in the outcome which showed a very limited use of hostels at some factories. It is not within the scope of this volume to enter into details of the labour problems. It is, however, important to emphasise that labour supply was a major factor affecting the operation and output of these factories. It also had an important bearing on the proposals for the additional factories on a smaller scale proposed in 1940 and 1941. The number of these was reduced, as we have seen, to six factories but had it been feasible to assume that the larger factories could be staffed to their maximum complement on three-shift working, only two of the six additional factories would have been necessary and then only for special ammunition.

Had it not been for the successful adoption of the three-shift system of work at all the new filling factories, these factories would have operated at a lower level of capacity. The three-shift system, decided upon at the end of 1940, was brought into operation remarkably quickly in the first half of 1941. In May 1941 the Minister of Supply could report that the three-shift system was in operation in all the Royal Filling Factories with the exception of Hereford. It was by no means an easy innovation. Very considerable expansion of storage and other facilities were necessary at these factories at an aggregate cost of about £3 million but the advantages far outweighed the difficulties and additional expenditure. The two-shift system with a 100 hour week had been very difficult to maintain and absenteeism was very high. The three-shift system with reduced shift hours was, despite the disadvantages of an all night shift, much more attractive and less arduous. With the three-shift system the factories operated at about 75 per cent. of their maximum capacity. The same labour force employed on the two-shift system would not have achieved more than 60 per cent. of the maximum. The result of the operation of the three-shift system was to increase the output more than 25 per cent. above the output that was likely under the two-shift system.

In the second half of 1941 the operation of the factories was moving very rapidly to the peak. Very rapidly indeed, for in the twelve months from March 1941 to March 1942 the operation of the factories in terms of employment more than doubled and the output increased even more than that. In March 1941 only two factories were anywhere near their peak—Hereford with 91 per cent. and Glascoed with 72 per cent. of their peak labour force. Aycliffe and Thorp Arch had not come into operation and most of the other factories were well below the halfway mark. Even Chorley, the first of the new factories, had a bare 60 per cent. of the peak employment and little more than a third of the full complement of 35,000, which was never attained. The large increase in the total strength in 1941 was, of course, greatly facilitated by the occupation of the new factories at Aycliffe and Thorpe in the spring of 1941 and the rapid expansion of production at these factories and at the three new factories which came into production in the second half of 1940. But more than half the increased operation was at the Chorley, Bridgend and Glascoed; two of these were by March 1942 approaching the 30,000 employment mark. Output from the filling factories in 1942 reached a level equivalent to more than 100 million rounds of ammunition a year. This, whatever difficulties remained on special types, was the volume of output required after the revision of programme in 1941. It is clear that this output could have been exceeded had it been necessary. Indeed this level of output was maintained throughout 1942 with a declining labour force; a further indication of improved efficiency and also of the possibility of further expansion of output.

It was the fate of the filling factories in the period of achievement to be both the object of criticism and to bear the immediate effects of the reduction in the ammunition requirements. In the spring of 1942 as the factories approached peak operation, the members of the Select Committee on National Expenditure found much cause for criticism.[1] It was in fact to a large degree the measure and method of success which made criticism possible, for the most important points of the Select Committee's criticism were first, that there was a substantial excess of capacity at the filling factories—surplus labour of several thousands at some factories—and secondly, that the principles of time and motion study, which were a large factor in success, should have been applied at a much earlier stage. It was indeed ironical that these criticisms should have been made at the very point of achievement. There were, of course, some grounds for comment. The position at some of the factories was, superficially at least, very much against the Ministry of Supply. But to judge by appearances at this stage was, to say the least, misleading. The surplus labour was being rapidly dismissed; it was to a large extent due to the improved efficiency and was not much in excess of the normal wastage in so large a labour force. The Ministry of Supply in reply to the Committee's criticism denied that the margin of capacity was excessive. The Ministry considered that in view of the risk of loss of capacity due to explosions and enemy action and the need to provide for frequent changes in the type of ammunition, the margin of capacity was not unreasonable.[2] As we have seen, the margin of capacity was in fact larger than had been proposed in planning for these contingencies but the increase in the margin had been largely incidental to the three-shift system and

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[1] Eleventh Report from the Select Committee on National Expenditure, Session 1941–42.

[2] Second Report from the Select Committee on National Expenditure, Session 1942–43.

improved efficiency, but to some extent it was due to the difficulties of operating the larger factories at full strength.

The Select Committee's criticism of the late introduction of time and motion study seemed at first sight more valid, particularly in view of the striking improvements achieved within eighteen months. It is true that some study of efficiency bonus systems might well have been made as part of pre-war planning; in particular the application of the system in 1917 in the National filling factories might have been investigated. But the scope for introducing these methods in peace-time was small. For the main task of the R.O.Fs in peace-time was to undertake experimental and pioneer work rather than flow production; the filling factory at Woolwich in particular had become the home of odd batches and small quantities. Moreover in peace-time there had been very strong opposition to efficiency systems. In war-time it was easy to overstress the importance of efficiency systems in increasing output per worker in new factories and to assume that they could be introduced immediately production had started. In the early months of the war new workers were recruited in vast numbers; for example between June and August 1940 more than 80,000 new workers had been taken on at the filling factories and at some factories nearly 2,000 new workers were taken on each month. The time needed for training these workers was fairly short but all the same their efficiency was bound to increase for some time after training. Some improvements in efficiency were due to the introduction of three-shift working. Efficiency bonus systems brought further improvements in output per man hour but they could not be usefully applied until most workers had attained a fairly high degree of efficiency. The first efficiency engineer was appointed in the summer of 1940 to apply efficiency systems at Chorley. From that time onwards more officers were appointed and more factories were brought into the scheme although shortage of trained officers to organise the schemes restricted progress. As it was schemes were introduced in most of the factories a good deal less than 12 months from the start of major production; with entirely inexperienced workers and supervisory staff the schemes could hardly have been introduced earlier, except possibly at Chorley.

Closely related to efficiency was the problem of mechanisation. The difficulties here were very real, for quite apart from the danger of adopting methods which might engender explosions, many of the methods and machines were made obsolete by the frequent changes in type of ammunition required. Thus in November 1942, a Ministry of Production investigator reported that if all processes had been fully mechanised 12 months previously, changes in design would have rendered the assembly and filling shops 70 per cent. ineffective and the fuze shops 50 per cent. ineffective. During 1941 the mechanisation of processes for filling and loading S.A.A. and 20 mm. ammunition had been consistently adopted but the Ministry of Supply were not convinced of the possibility of a more general application of mechanisation. The Ministry of Production report tended to support this view. For all calibres above 20 mm. increased efficiency in manual operations and in organisation of the work remained the general policy.

It was the fate of the filling factories to have to prepare for decline almost as soon as the peak requirement had been matched. The peak output was maintained over the twelve months from March 1942 to March 1943, but in September 1942 preparations had to be made to reduce output. The expenditure of shell ammunition had fallen far below even the revised expectations of early 1941 and stocks were mounting rapidly. Even though the peak output was maintained into the first quarter of 1943, the labour force employed in the Royal Filling Factories was substantially reduced from the peak total of 153,000. By the summer of 1943 the reduction amounted to 25 per cent. and more than half of the reduction was attributed to the decline in requirements.[1] By December 1943 the reduction amounted to more than 30 per cent. Thereafter there was no further drastic decline until the second quarter of 1945. The reduction in operation affected some factories much less than others. In general it was the largest factories which were affected most. This was not merely because of their size but to a very large extent because they were not concerned with S.A.A. filling and only to a limited extent with naval and bomb filling. Whilst by December 1943, at least four factories were down to nearly half their peak strength, other factories were only just below peak strength. The position of the six smaller factories, which were operated as agency factories was also affected by these changes; most of these factories came into production in the spring of 1942, just as the Royal Filling Factories were reaching their peak. At three of the new small factories production was coming to an end within not much more than twelve months of the start of production, but the output at three of the factories remained of vital importance throughout 1943, and at one factory up to the end of the war.

The provision of ammunition presented in the most acute form the problem which dominated much of the Ministry of Supply planning—the problem of achieving the peak requirement without creating capacity the usefulness of which would be short-lived. In all the circumstances it might well be argued that vigilance on the part of all concerned had kept the margin of capacity within reasonable limits. Even so, the margin of capacity in the filling factories proved somewhat larger than had been intended. The contingencies for which the

[1] Seventh Report from the Select Committee on National Expenditure, Session 1942–43.

margin had been provided—factory explosions, bombing of the factories and loss of imports did not affect supplies to any serious extent. The filling factories were attacked from the air but never in any major attack. Explosions occurred at several of the factories and some resulted in heavy loss of life.[1] Even so, there were no heavy demands on the margin of capacity. The worst explosions occurred in the later stages of the war, after the peak demand was well passed. The provision against failure in overseas supplies proved equally unnecessary and with the reduction in requirements in 1943, considerable cuts had to be made in overseas supplies.

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The Explosives Factories

In the First World War a very large part of the production of explosives and propellants came from National factories most of which were under the direct control of the Ministry of Munitions. By 1918 the proportion coming from these factories was about 60 per cent. of the total production and for the whole of the period 1914–18 it exceeded 40 per cent. A very large part of the output which came from the trade firms was from plant supplied at government expense. The activities of the War Office and later of the Ministry of Munitions in this field were direct and extensive. They were responsible for the development of at least 75 per cent. of the capacity in use. Many now famous factories had their initiation under the Ministry of Munitions or the War Office. The T.N.T. factory at Gretna was for long a byword in war production and the now famous factory at Billingham, though constructed by private enterprise after 1918, was provisionally planned in the Ministry of Munitions.

As many of the National factories for explosives manufacture were under the direct management of the Ministry of Munitions, they were given the title of His Majesty's Explosives Factories. This was the one sphere in which there was in effect an extension of the Royal Ordnance Factory principle although not under the R.O.F. organisation. The Royal Gun Powder Factory at Waltham was expanded, but was confined to the manufacture of propellants. The problem of expansion of propellant production proved even more difficult than for explosives and a much larger part of the supply had to be imported. One result of these difficulties was the Admiralty decision in 1915 to construct a Royal Naval Cordite Factory at Holton Heath. This was to prove both a permanent addition to the Royal Factories and to Admiralty policy in cordite production. The output of explosives and propellants by

[1] For an account of the explosions and of the meritorious conduct of all concerned see Ian Hay, *R.O.F: The Story of the Royal Ordnance Factories, 1939–48*, H.M.S.O., Chapter X.

1918 had reached a scale quite unprecedented in this manufacture; the production of raw materials, some of which had important industrial uses, was quite beyond the scale required for peace-time use. After the war, all the National factories were closed and most of the sites and plants sold. Several firms, important both for the manufacture of explosives and primary raw materials remained outside the I.C.I. but their capacity for specialised military requirements was very small. Up to 1934, the main interest and activities in relation to military explosives and propellants was centred at the Royal Naval Cordite Factory, at the Royal Gunpowder Factory at Waltham and at the Research Department, Woolwich.

By 1934, several new explosives and propellants had reached or were soon to reach the stage of production technique. This constant development of new types greatly increased the problems of planning new capacity and factories. Explosives were much less affected than propellants; the introduction of new explosives did not substantially displace the two explosives which had been the mainstay of production in 1917—T.N.T. and ammonium nitrate. As will be seen, factory planning for explosives was able to proceed from 1935 on an extensive scale without fear of over provision. The new explosives were for the most part more difficult to manufacture and the factory plant more expensive. It was thus fortunate that the preponderance of T.N.T. and ammonium nitrate persisted throughout the war. For propellants the range of types was more significant; with the technical development of the inter-war years and during the war, there tended to be different types of cordite suitable for the different weapons and different functions. Thus, the type of cordite which had been the main propellant in the First World War was replaced by a range of propellants corresponding to the main groups of weapons from the rifle to the coastal defence and naval guns. The equipment for the manufacture of these propellants had to be constructed in specialised units which could not usually be adapted to manufacture of other types. Moreover the raw materials were usually different and required the provision of further specialised manufacturing units. The selection of types for particular weapons was not quickly settled and both in the pre-war period and during the war, these uncertainties and the anticipation of improved types under development, led to many delays in the finalisation of factory planning.

Despite the growth of the chemical industry, the problem of providing additional capacity for the essential raw materials was no less in 1936 than it had been in 1914. The new explosives and propellants often required several new chemical materials involving specialised capacity and the demand for materials for T.N.T. and ammonium nitrate was as heavy as in the First World War. Between the wars there were important additions to capacity for the production of ammonia and ammonium nitrate but a large part of these resources were required for industrial and even more for agricultural use. Moreover, it was decided in 1935 that because of the vulnerable location of Billingham on the north east coast, no reliance should be placed on that factory in war-time for military requirements. Thus, the prospect for raw material supplies was certainly no better than it had been in 1914, when a very large expansion of constituent materials had to be provided. In 1935 the capacity for the final manufacture of explosives and propellants was a good deal less than had been available in 1914. Then there had been a number of firms engaged in the manufacture of propellants and explosives for naval requirements. In 1935, the Royal Naval Cordite Factory was available for naval cordite requirements, but for most other demands, there was only the long established but almost outmoded Royal Gunpowder Factory at Waltham and the remnant of specialised capacity which was concentrated at the I.C.I. factory at Ardeer. Here indeed was a section of munitions production where sheer inactivity had reduced specialised capacity to a more or less token existence.

The total peak output to be achieved in the two wars proved very similar. The peak output of 230,000 tons of explosives in 1917 was slightly in excess of the peak output of 220,000 tons in 1943 but the peak output of 112,000 tons of propellants in 1942 exceeded the peak output of 97,000 tons in 1917.[1] The main difference was that the maximum output had to be maintained for a longer period in the Second World War.

United Kingdom output in short tons

	Explosives	*Propellants*		*Explosives*	*Propellants*
1914	..	..	1939	21,255	23,989
1915	16,923	12,438	1940	74,206	30,513
1916	109,578	29,617	1941	112,558	58,525
1917	230,140	98,778	1942	190,562	112,442
1918	203,109	77,258	1943	220,717	89,222
—	—	—	1944	206,648	61,668

The expansion from almost negligible resources to large scale output was achieved in 1914 and, after 1936, almost entirely by the construction of new specialised factories. But between 1936 and 1939 with the advantage of the rearmament programme, the policy regarding the new factories was carefully worked out and a close integration between Royal Explosives Factories and agency factories was secured. The ultimate outcome was that the burden of expansion was divided almost equally between the Royal factories and the agency factories

[1] The effect of imports was to bring the peak supply of both explosives and propellants in the two wars from all sources to almost identical quantities.

managed by trade firms of which I.C.I. had by far the greatest number. On a planned tonnage basis the Royal factories undertook rather more than half the propellant and somewhat less than half the explosives production.

Explosives and propellant factories like filling factories were an integral part of the ammunition programme. They had to meet the demands of the filling factories for the explosive content, not merely for shell ammunition but also for aircraft bombs and for small arms ammunition. Even so the explosives factory programme was not beset by the wide fluctuations of the filling factory programme. There were several reasons for this. For the most part, production from the start was largely determined by the use of continuous process plant operating on a three-shift system. In consequence, the scale of factory construction for most products could be precisely determined. Even more important, the burden of inflated requirements was largely borne by overseas factories. When in 1940 the planning of filling factories was subject to wide fluctuation in requirements, most of the additional requirements for explosives and propellant were placed overseas. This resulted in the construction of many new factories in North America but as these were available for, and to a large extent subsequently taken over by, the United States authorities, they were never in danger of constituting surplus capacity.

The provision of capacity for propellants was at all times the most complex part of this factory programme. The range of types was ever increasing, the methods of manufacture were much more difficult to establish and the factories took much longer to construct than for explosives. Despite this, the pre-war planning was seriously delayed and restricted by financial limits. In the summer of 1935 the Cabinet had agreed that the Royal Gun Powder Factory at Waltham should be replaced, but it was not until January 1937 that approval was given for construction to proceed at the new factory site, which had been chosen at Bishopton near Glasgow. Even then construction was limited to one unit instead of the three units initially planned. That it was allowed to proceed at all was mainly due to the declared policy of replacing Waltham and of maintaining the long established place of the R.O.Fs in propellant production and their function as a check on trade production prices. Thus, Bishopton which had been planned as a modern and permanent propellant factory was only approved piecemeal and it was not until January 1939 that a second unit was approved.

By then the increased demands for Air Defence had brought requirements beyond the available capacity and the first unit under construction at Bishopton. The needs of the Admiralty had also increased and approval was given in January 1939 for a new Royal Naval Propellant Factory. For the army expansion approved in March and April 1939 and for the increased requirements for S.A.A. the propellant factory programme had to be trebled within a matter of months. It was indeed not until August and September 1939 that the schemes for three new factories were finally approved. Only one, but the largest, of these factories was to be an R.O.F., the other two were to operate as agency factories under I.C.I. management. This arrangement, however, still left rather more than half of the propellant capacity within the R.O.F. organisation.

Before the outbreak of war the position of the Royal Gun Powder Factory at Waltham had to be reconsidered. It was then providing the entire R.O.F. contribution to the supply of propellants and was to continue in this position until the starting up of the first unit at Bishopton in June 1940. In addition it was from Waltham that the planning of most of the new propellant and explosives factories under R.O.F. control had been directed. There was no opportunity for closing and abandoning what had been described in 1934 as old-fashioned and strategically misplaced. In fact, not until 1943 was any reduction in the operation of Waltham possible. The factories approved up to October 1939 were barely sufficient to provide for the requirements of the 36 divisions programme and provided little scope for the introduction of further new types of propellants. Nevertheless these factories proved to be almost the last propellant factories to be constructed in the United Kingdom. In 1940, the requirement for propellants continued to increase as the full needs of the 55 divisions were calculated. There were urgent needs for several new types of propellant for almost all types of ammunition. Almost without exception the whole of these additional requirements were sought from overseas factories. It was not until February 1941 that the third and last new factory in the United Kingdom for propellant production was approved.

The explosives factory programme proceeded with much less difficulty. The need for additional supplies for rearmament led to the approval of one R.O.F. for T.N.T. in 1936. The importance of reserve capacity and the difficulties of obtaining supplies of specialised plant led to the approval of a second factory in 1937 and a third factory for T.N.T. was approved in the summer of 1939. By this time the first factory was in operation and the second was to start up by the end of the year. In 1940 the policy of seeking overseas supplies led to the construction of several T.N.T. factories in North America but in 1941 when the plans for the expansion of the heavy bomber force were adopted it was decided to meet the major part of the very large increase in T.N.T. requirements by the construction of two new factories in the United Kingdom. These were the only T.N.T. factories to be approved after 1939. One was an R.O.F. at Sellafield, but the other, an agency factory under I.C.I. management, was the first and only agency factory to manufacture T.N.T. The factory programme for the manufacture of ammonium nitrate and for the essential ingredient—ammonia—followed a very similar course. As early as 1936, the Committee of Imperial Defence were impressed by the necessity of avoiding reliance on Billingham; the approval of a series of factories proposed for this purpose was obtained without great difficulty. In contrast to T.N.T. the knowledge and experience for large scale production of these products was with the chemical industry and especially with I.C.I. In consequence, with one exception, all the factories provided were agency factories under the management of I.C.I.[1] The one exception was the plant for the production of ammonium nitrate which was erected at R.O.F. Pembrey in 1938 and operated in conjunction with the T.N.T. plant erected at the same site.

T.N.T. and ammonium nitrate were in bulk by far the largest part of the explosives production. In addition to several agency factories these two explosives accounted for four new R.O.Fs, three of which were exclusively for T.N.T. production. There was only one other explosives R.O.F. but this factory approved in June 1939 was of special significance. It was the only factory in the United Kingdom to be planned and constructed specifically to produce a new type of explosive—R.D.X. Approval for the construction of a two unit R.O.F. at Bridgwater for the manufacture of R.D.X. was given in June 1939. One of the units came into production in August 1941 but the second unit, on which work was suspended in order to erect at the same factory a unit for the manufacture of tetryl, did not come into operation until 1942. Until the first unit came into operation the only supplies of R.D.X. were from the pilot plant at Waltham. As a result supplies up to the autumn of 1941 were at the low rate of only a few hundred tons a year. This against an R.A.F. demand of 'as much as possible' in 1941 and 13,000 tons a quarter in 1942. Even as late as 1944 there was very large dependence on supplies from North America. Fortunately, by then a new mixture of explosives had been found which was, it was calculated, even more effective than R.D.X. This new mixture finally adopted by the R.A.F. in 1944 in preference to R.D.X. consisted largely of ammonium nitrate and T.N.T. which fortunately at this time were at peak supply. There were several other explosives with special devastation and demolition properties which were developed between 1936 and 1945. None of these were in very large demand and capacity for the production was in the main grafted on to existing R.O.F. or agency factories. Of the explosives factory programme it may be said that it was broadly based on T.N.T. and ammonium nitrate as the main agents of explosive power. As the history of the requirement for R.D.X. shows, this proved to be a wise choice.

[1] See Chapter V.

At the end of 1939 the building programme for explosives and propellant factories presented a formidable task. A large part of Bishopton had yet to be constructed and in addition work on most of the ten factories—R.O.Fs and agency—approved in 1939 had barely begun. Apart from the difficulties of making any further demands on building resources, the prospect of obtaining plant for any additional factories was far from encouraging. It was at this stage that the decision was taken to promote the construction of explosives and propellant factories overseas and thus avoid further major additions to the already formidable factory programme in the United Kingdom.[1] The aid provided by the overseas factories varied in volume with the differing conditions of the total supplies and requirements for the separate products. For many products the importance of overseas supplies continued until 1944 but for a few, including T.N.T. and ammonium nitrate the importance of these supplies was most marked in the first half of the war before the second range of United Kingdom factories had come into operation.

The large provision of overseas factories in 1940 meant that the provision of factories in the United Kingdom was mainly in 1939 and earlier.

New capacity planned and approved for Explosives and Propellants

	Short tons per month				
	Before 1939	*1939*	*1940*	*1941*	*1942*
In United Kingdom					
R.O.F. . .	8,540	6,030	1,189	1,600	—
Agency and trade	5,940	1,165	1,152	4,940	30
In North America	—		12,800	—	1,300

Viewed in perspective, the provision made in schemes approved before 1939 looms very large. For the R.O.Fs it was as large as the 1939 and war-time provision combined; for agency trade factories it was a good deal less. Even more significant, but for the large provision of overseas factories the United Kingdom factory programme in 1940 and 1941 would have had to be trebled. Further, this would have meant that with the rapid fall in requirements in 1942 there would have been a serious surplus of factory capacity in the United Kingdom.

Strategic and economic policies affected the location of explosives and propellant factories no less than filling factories. The very large labour

[1] The story of overseas supplies is told elsewhere. H. Duncan Hall, *North American Supply*, in this series (H.M.S.O. 1955) and H. Duncan Hall and C. C. Wrigley, *Studies of Overseas Supply*, in this series (H.M.S.O. 1956).

force required for propellant factories made the location of these factories the centre of political and economic consideration which at times led to much conflict of opinion. This was particularly true of Bishopton—the largest of the factories.[1] The supply of labour—the main economic consideration for propellant factories—was not a very serious problem for explosives factories, where less than 2,000 workers was sufficient at most factories. Size of site affected both explosives and propellant factories but again it was the propellant factories which were seriously affected. The large area required for propellant factories was particularly difficult to find in combination with the many other essential qualities. Gretna in the last war had extended over nine square miles. In 1934 the extent of the new propellant factory was estimated at 700 acres, in 1935 at twice this amount, and finally, 1,950 acres had to be bought to fit in the necessary safety distances between buildings. Before long, an even larger size proved desirable, for not only were extensions to be expected but part of each site was almost bound to turn out unusable for heavy construction. At Bishopton, where the late discovery of peat made the purchase of a further 300 acres necessary, the final figure was nearer 2,500 acres, although the area within the factory fence was slightly under 2,000 acres. For none of the other factories was so large a site required. At the Wrexham factory the site was 1,400 acres and at Ranskill less than 1,000 acres. For T.N.T. factories a site of less than 300 acres was adequate. Even at Pembrey, which included T.N.T. and ammonium nitrate, 500 acres was sufficient. Bridgwater with a site of over 700 acres was the largest of the explosives factories.

Suitable soil and geological formation were even more important than for filling factories. Drigg and Sellafield were thus found to be the only open sites over a large area of Cumberland where there were no coal mines to cause any danger of surface subsidence, and this same point came up also in the choice of the Marchwiel district of Wrexham. It was not only the need for firm foundations, but the heavy traffic of building operations in winter which churned up the ground and made deeper foundations necessary. The marshy surface over all the Bridgwater site resulted in much expense in money and time to provide piled foundations there. At Bridgwater it was clearly a mistake to select land that was partly under sea level, but a low altitude was essential for cordite manufacture. An elevated site might bring dangerously cold temperature in winter, with great risks in manufacture and transport, and the likelihood of incorrect ballistics from the finished product. For these reasons climatic tests had to be taken, and it was important that Bishopton in Scotland, with an average elevation of 27 feet, was found to possess a more equable climate even than Waltham in Essex.

[1] Chapter IX.

One of the greatest difficulties in finding suitable sites of the size required was the need for a generally level site. Swiftly changing contours would lower efficiency of working and raise the time and cost of construction and greatly effect the problem of the extensive internal transport. This fact greatly restricted choice especially in view of the large acreage involved, and the fact that the three or four areas to which search was limited were hilly above the average. In the Glasgow area it was not easy to find 2,500 consecutive acres with a maximum height of 150 feet as at Bishopton. Yet at the same time some variation in contours would be a help. One advantage foreseen at Pembrey was that sand dunes were available there to make easier the construction of magazines. In cordite factories an occasional gradient saved a great deal of time in the construction of nitroglycerine hills, just as the intelligent use of different levels helped in the manufacturing processes of nitrocellulose and acid. Hills and woodland also had the effect of aiding camouflage and of breaking up detonation waves in an explosion.

Another aspect of the importance in contours and altitudes was their effect on drainage. Efficient drainage and water supply were of paramount importance in factories through which up to 10 million gallons of water might pass each day, and from which noxious effluents had to be dispersed. This latter point led to an important distinction being made between the placing of each class of factory. With all high explosives factories it made a seaside site almost essential, and the exception made at Bridgwater was soon regretted when expensive pumping and drainage works had to be put in. From cordite factories, on the other hand, the effluent could be released into inland waterways without elaborate treatment; it had no effect on taste or fitness for consumption.

The provision of great quantities of water, like that of power, was by no means easy to secure. At Pembrey it was decisive that water works built for the 1914 war factory had been taken over by the town of Llanelly and still existed, and yet difficulties in water supply were to hold up production there. At Drigg it was a considerable disadvantage that supplies had to be specially laid on from Wastwater six miles off, and similar difficulties arose at Bridgwater. In 1936, the 12 months' delay while layouts were devised for the alternative site at Gretna had their origin in just this deficiency of Bishopton, where the water was described to be of unsuitable quality, scarce and expensive. Although other considerations overruled this objection, it was only the unexpectedly protracted time spent in building the factory which prevented this deficiency of water holding up production while reservoirs were constructed.

The reconciliation of all these essential requirements was a matter of great difficulty and was usually achieved only after prolonged search and investigation. Many authorities and departments had a right to be consulted and this consultation often greatly prolonged the period of investigation. Even so, the technical necessities for production and construction and the supply of labour were for most factories the decisive considerations. The eventual location of the factories as seen on the map suggests an obvious selection which belies the very extensive discussions and investigations which finally resulted in the choice of each of the sites. The explosive factories with the exception of Bridgwater were all on the west coast—one on the coast of Ayrshire, two on the coast of Cumberland and one on the coast of South Wales. Similarly, with one exception the propellant factories were located not far inland from the western littoral.

The construction of T.N.T. factories had the advantage of a standardised plant and size. The factories were all planned to have the same maximum output and although some improvements were introduced into the two war-time factories, all the R.O.F. factories for T.N.T. manufacture were constructed to a largely standardised pattern and plan. This was worked out for the construction of the first of the factories at Irvine, and the planning of this factory was followed for the later factories. The re-development of the continuous process of manufacture which had been used in the First World War was technically completed by 1936 and the responsibilities for final planning of the factories was handed over to C.M.E. Woolwich. Inevitably, there was much to be learnt in detail in the construction of Irvine and this factory was only half complete when the construction of the second T.N.T. factory, at Pembrey, had to be started. From the date of approval, almost 2½ years was needed before the first production began and three years before the factories were in full operation. There was much preliminary delay at both sites before construction could be started and production was in fact achieved at Irvine in 18 months from the start of construction and at Pembrey in slightly less than that. For both the war-time Royal Ordnance factories for T.N.T. the time taken from the start of construction to the first production was just under eighteen months and indeed only about eighteen months after definite financial approval.

In time taken for construction and in total cost, the record of the T.N.T. factories proved highly consistent. With the exception of Drigg at which there were exceptional difficulties the cost of each of these factories did not exceed £2½ million. Both in time and cost of construction the Royal Ordnance factories for T.N.T. were as economical as T.N.T. factories under commercial management. The same was true of the Royal Ordnance factory for ammonium nitrate production for which the planning and installation of plant was undertaken by I.C.I. For the main new explosive, R.D.X., progress was much more difficult. Technical uncertainties and problems of siting delayed the start of factory construction for at least six months. Concentration on one unit at a time speeded up construction but this was largely offset by technical difficulties. The construction of the second unit was further delayed by the need to use some of the constructional labour for the operation of the first unit and by the introduction of another type of explosive at the same factory. The first unit did not come into production until June 1941, and the second in July 1942, although approval for the factory had been given in August 1939.

The construction of propellant R.O.Fs presents a far less satisfactory picture; though the longest shadow is cast by the pre-war factory at Bishopton. This factory did not get into production until June 1940. This was 3½ years after the approval to proceed with the construction and five years after the Cabinet had given their approval for a new R.O.F. to replace the Royal Gunpowder Factory at Waltham Abbey. When the technical planning of Bishopton began at Waltham early in 1936 the work was hampered by several uncertainties; the type of cordite to be produced was not yet definitely decided, the most likely was a new type which was only emerging from the development stage. Preliminary work by contractors began during 1937 but almost in all directions there were false starts and sudden difficulties. Bishopton got off to a thoroughly bad start, and the Office of Works certainly found their new responsibility both formidable and exceedingly difficult to direct.

Part of what began to appear as the problem of interminable construction of the first unit at Bishopton, was due to the sheer physical size and difficulties of the task. To this must be added the many technical and engineering uncertainties which prevailed throughout and even after 1937. The construction of Bishopton was, quite apart from the construction of buildings and erection of plant, a civil engineering work of really major proportions. So many different tasks were included, from the construction of a power station, railways and roads, to the construction of the factory buildings and the foundations of the process plants, that only exceptional measures would have been likely to secure rapid development and construction. It was pointed out by an independent investigation in 1940 that the failure of the Office of Works to place the direction of the work under the charge of a Civil Engineer showed a lack of appreciation of the large proportion of civil engineering work and this had contributed substantially to the delays in construction. It is however, doubtful whether under more favourable circumstances the construction of the first unit at Bishopton could have been completed in under two and a half years.

Fortunately the delays and the physical difficulties at Bishopton proved exceptional. The Wrexham cordite factory approved in July 1939 was in production by February 1941, in just over twelve months from the start of construction and in 18 months from the financial approval of the scheme. Similarly, Ranskill which was not approved until the last few days of 1940 was in production by March 1942. This drastic reduction in time for construction emphasises the tremendous delay at Bishopton and also points to some of the special difficulties there. Both of the two later factories were on a smaller scale and were more fortunate in the physical circumstances of the sites which made an even smaller total area possible. The size of site was further reduced by the reduction in safety distances allowed for war-time construction.

Very different in size, the three propellant factories had corresponding differences in cost and peak employment, with the exception of Bridgwater the explosives factories made much smaller demands on all resources.

Explosives and Propellant R.O.Fs.

	Final Cost £m	*Date of first production*	
Propellant Factories			
Bishopton	17·1	June	1940
Wrexham	10·9	March	1941
Ranskill	4·4	March	1942
Explosive Factories			
Irvine	2·1	March	1939
Pembrey	2·9	November	1939
Drigg	2·5	April	1941
Sellafield	2·5	March	1943
Bridgwater	5·7	August	1941

In bringing the explosives factories up to maximum production no exceptional difficulties were encountered. The total number of workers required was not so very large. It was found possible to reach maximum production on the T.N.T. plants with a labour force of just over 1,200. At Pembrey where ammonium nitrate and tetryl were produced in addition to the T.N.T. the total labour force only just reached 3,000. It was essential to the operation of process plant that the labour force should be built up rapidly and this proved possible at most of these factories. Indeed within six months of starting to take workers at the T.N.T. plants, the labour force was sufficient to approach maximum working. At the composite factories, Pembrey and Bridgwater, the operation of the separate units was brought up to maximum within about the same period but the expansion of the total labour force was inevitably more protracted. At the propellent factories the size of the problem was very different. Both Bishopton and Wrexham were planned in the form of three main production units and it was possible to concentrate on the starting up of each unit in turn. Even so, with

4,000 workers required for each manufacturing unit the problem of effective operation at the propellant factories was a matter of some difficulty.

At Wrexham when the construction of the first unit was completed at the beginning of 1941, the need to bring this into production immediately led to the employment of constructional labour as factory operatives with consequent delay in the completion of the second unit. At Bishopton with three cordite units and two smaller units for other production, the gross labour force on the factory books, reached 20,000 in March 1942 but the effective employment was stabilised at about 17,000. Ranskill which was a single unit factory had to reach about 4,000 to obtain maximum production. Nevertheless, recruitment at these factories was on the whole fairly rapid. At Bishopton and Wrexham it proved possible to approach maximum strength for one unit within nine months, at Ranskill it took more than twelve months but at Wrexham final expansion was achieved within eighteen months of starting up. At Bishopton the expansion was much slower. More than two years elapsed before the maximum labour force was reached; though this was partly due to the delays in starting and completing the construction of the second and third units.

In the period of expansion attention was concentrated on getting the plants into full production. This inevitably meant building up a labour force somewhat in excess of the number eventually required. At this stage, maximum output was imperative; when this had been reached, the problem of increasing efficiency and reducing the total labour force was tackled. At all factories it was found possible to make an appreciable reduction in the total labour force and yet maintain maximum production. This was indeed characteristic of the operation of process factories expanded under a general drive for immediate and maximum production. From the beginning of 1942 there was a persistent and methodical drive for increased efficiency and for the reduction of labour employed. The direction of this investigation came from the Director General of Explosives Production, who from 1941 was in charge of production not only at the R.O.Fs but also at the agency factories for explosives and propellant production. Direct comparison between R.O.Fs and agency explosive factories immediately showed the much higher percentage of non-process workers employed at the R.O.Fs. It was subsequently possible to show that this made the overhead costs at some R.O.Fs very much higher and that this was the main element in the higher total costs at R.O.Fs.

Many factors of organisation not merely at the factories but also at the headquarters affected the position. Local factors also operated as the proportion differed considerably between different R.O.Fs employed on the same work. There was however no doubt that the number of non-process workers per ton produced was generally substantially higher in the R.O.Fs. The main groups causing these differences were management control (including bookkeepers, work takers, laboratory assistants), engineering and building maintenance and the security police. Some of these differences in non-process employment were no doubt largely due to the customary arrangements for the upkeep of a government establishment. A similar trend was discernible in the general and administrative overheads, but as most of the R.O.Fs had a somewhat larger output than the agency factories the amount of overheads per ton was not always so very different. There were a number of special charges which reflected the special provisions either arising from the location of the factory or from government policy. Thus many R.O.Fs had a large account for assisted travel. Holiday, sickness and injury pay was usually a larger item than in other factories, as were also internal transport, land and building maintenance, and the War Department constabulary.

The concentration of attention on the differences in non-process labour and overhead costs, emphasised the fact that in the efficiency of manufacturing there was little cause for comment. The R.O.Fs were the leaders for some processes of manufacture, the agency factories for others; in the end there was very little difference in the economy of manufacture. In initiation and development the R.O.Fs held a fully acknowledged place. Alternative processes were often used by the agency factories and particularly in North America. Thus the process for the manufacture of R.D.X. developed at Woolwich and established at Bridgwater was not generally adopted in North America, there an alternative method was very soon developed and adopted for the later North American factories. It is of some historical interest that the R.O.F. continuous process for the manufacture of T.N.T., which had been first developed for the 1914–18 National factories and which had then been by far the most efficient, lost this unchallenged position in the course of the Second World War. The batch method of manufacture which was used by the trade firms in both wars and by the agency factories both in the United Kingdom and in North America was subject to many improvements on both sides of the Atlantic, with the result that the batch process in North America was more economic than the R.O.F. continuous process. Supplies rather than costs were of supreme importance; the R.O.Fs for T.N.T. production showed a remarkable power of exceeding their nominal capacity and gave proof of this in the uncertain months before V.E.-day when the rapid expansion of supplies was a matter of extreme urgency.

(v)

The Engineering Royal Ordnance Factories

That the R.O.Fs should take so large a part in the manufacture of military explosives and in the filling of ammunition, is readily understood, it is not always so readily accepted that a large number of R.O.Fs were needed to undertake manufacture based on engineering processes. At the peak of war production there were 24 new engineering R.O.Fs employing nearly 100,000. They are classified as engineering R.O.Fs because although most of them were mainly concerned with one range of production—either guns, shell, small arms, small arms ammunition, cartridge cases or fuzes—the basic processes employed in all these factories were metal engineering processes. It might well be argued that with a large and highly skilled engineering industry, there was no need for so large an extension of state manufacture.

The part played by the engineering industry in war production is well known. Firms of all types and sizes were fully employed in war production of some kind or another. It might be thought that this sector of industry employing over 1½ million in 1940 could readily have accommodated the production which in the engineering R.O.Fs only employed 100,000. An analysis of the industrial sector shows that the engineering sector includes a very wide range of specialised industries as well as a large number of small firms of very limited capacity. To meet the demands of war production several highly specialised industries employed their capacity on products very similar to their normal production. Indeed, never before had so many specialised firms been required to use their capacity so directly for war requirements. A very large part of the expansion and advance in the engineering sector had taken place in industries whose capacity was required en bloc for war production. Thus many of the leading industries using engineering processes were not generally available for armament production. This was true to a large extent of the motor vehicle industry, and of course, the aircraft industry. In addition, in the pre-war allocation of capacity, tank production claimed a large part of the locomotive industry and several firms in the heavy electrical industry.

Thus the scope left for placing orders for armament manufacture was very limited. This was true for war potential planning and the position was even more limited for pre-war orders where interference with industrial activity was a further limitation. Under the war potential allocation the few major engineering firms at least partially available for armament production were for the most part heavy electrical engineering firms and locomotive builders. Apart from these firms there remained a large number of firms generally classed as in the mechanical engineering industry. These included machine tool firms; they would clearly be required to concentrate on the manufacture of machine tools. Some other manufacturers of specialised manufacturing plant, particularly chemical and light alloy plant would be needed to follow their normal production. In the pre-war period with the general revival of industry the demand for manufacturing plant was at a fairly high level and although some manufacture could be expected to cease in war-time, the scope for pre-war orders even in this sector was limited to relatively depressed firms—notably makers of textile manufacturing machinery. Many of the firms in the mechanical engineering section were small firms and though many were highly skilled in their own trade and could assist in a wide scheme of manufacture they were not of the size or strength to initiate major armament production.

In the pre-war period the number of firms that the War Office could contemplate introducing to major armament production, was very small. It was even smaller when the claims of the Admiralty to the use of engineering firms for armament production had to be taken into account. It is not surprising that many firms then introduced were in the heavy electrical industry and in the textile machinery manufacturing industry. The immediate prospect in war was already substantially determined by pre-war allocation of some sectors of the engineering industry to other production. It was only under the increasing pressure of war and the reduction of civilian production that the general entry of firms from these sectors into armament production became possible. The margin of the engineering industry remaining for armament production was thus always narrow and included a large proportion of smaller firms often of high skill but usually of limited technical and managerial resources. There was thus never any doubt in the War Office in the rearmament period, nor in the Ministry of Supply in the early years of the war, that despite the existence of a large engineering industry, the fullest use must be made of the expansion of R.O.Fs for armament production. This indeed had been the recommendation of the Weir Committee in 1935 with their intimate knowledge of the capacity of industry for war production.

The policy in favour of the expansion of engineering R.O.Fs was not merely based on the narrow margin of industrial capacity available. There were also many obstacles to the successful introduction of armament production into the factories of industrial firms. Very few armaments could be economically manufactured entirely on the firm's existing plant. Some could be manufactured economically when the plant had been balanced with additional machines but other requirements could only be economically dealt with on a completely specialised unit of plant. Some of these specialised units could be installed in engineering factories and operated successfully by fairly small firms but other production required the provision of self-contained factories limited to the manufacture of one type of munition e.g. small arms ammunition. Other armament production e.g. gun manufacture, whilst combining general engineering processes with highly specialised processes could be undertaken by a few competent engineering firms with good technical resources but for the successful employment of smaller firms the manufacture had to be extensively subdivided.

For almost every major store there was either the technical necessity of a self-contained specialised factory or sufficient difficulties in the way of the general use of existing factories, to warrant the provision of an R.O.F. Small arms ammunition required self-contained specialised factories and almost all the factories were either R.O.Fs or managed by armament firms. The same was true of small arms weapons production until the middle of the war. Cartridge case production required large scale specialised plant—the largest cartridge case factory was an R.O.F. Very few firms could undertake the more difficult parts of gun production, and the number available for this work was even fewer. Thus despite the subdivision of the work to enable a wide range of firms to enter gun production after 1939, the advantages of specialised factory production resulted in the provision of over ten new gun R.O.Fs. This had the further advantage that it left a large number of firms available for the complementary requirements of gun carriage production, which was more readily fitted into the capacity of general engineering firms. Even for gun ammunition which was planned from 1935 as a task to be undertaken by a large number of firms provided with units of special plant, there was considerable advantage in securing several large scale factory units. As we have seen, in most sections of engineering armament production the war requirements were a good deal larger than ever before. This in itself was a very significant reason for providing many engineering R.O.Fs to secure a greatly increased output. This also explains why a large increase in the Royal Ordnance Factories was necessary as well as the intensive mobilisation of the engineering industry.

The exclusion of the R.O.Fs from tank production until almost the last year of the war emphasised the dangers of neglecting the advantages to be gained by the employment of the Royal Ordnance Factories. It was then seen that despite the excellent work which had been done in tank production by many leading engineering firms, a great deal had been lost by excluding the R.O.Fs from the production. Subsequently, the result of R.O.F. work on tank production in the final stages of the war confirmed that the participation of the Royal Ordnance Factories in all major armament manufacture brought very substantial advantages. No doubt the engineering sector was the most difficult in which to achieve the right choice of alternatives and the most advantageous balance between Royal Ordnance Factories and outside capacity. With the possible exception of tanks, the results of war-time production confirmed that in the main the general line of policy had achieved the most favourable balance between R.O.Fs and the resources of the engineering industry.

The largest group of new engineering R.O.Fs were the ten gun factories. Three of the new factories were approved before the outbreak of war; the others were approved in the early months of war. As a result, Royal Ordnance Factory production accounted for more than half the total ouput of army guns between 1936 and 1945; there was in fact no type of army gun that was not manufactured in the R.O.Fs. There was never any doubt about the need for this large extension under R.O.F. organisation. From the start of rearmament it was essential to make full use of the technical resources of the R.O.F. organisation for gun production. This meant that orders for new guns were divided about equally between the R.O.Fs and the armament firms. As it had already been agreed that the Woolwich gun factory should be replaced, a new gun R.O.F. was included in the 1936 factory programme and rapid progress with this factory proved that the extension of gun capacity under R.O.F. organisation was at this stage the quickest method of securing additional gun production. Two more new gun R.O.Fs were approved in 1938 and early in 1939. Immediately after the outbreak of war, five more factories were approved and in February 1940 two factories completed the final total of ten new R.O.Fs which were concerned with gun production.

Many sections of gun manufacture were highly specialised engineering processes. In the First World War the bulk of gun manufacture had been confined to the armament firms and to Woolwich. The requirement of army guns in the Second World War was about five times greater but there was a much higher proportion of smaller types of guns. This demand for the smaller types of guns greatly facilitated the introduction of many engineering firms into the war production of guns but the large quantities required and the demand for more difficult types meant that the extension of R.O.F. capacity had to be continued in war. Not merely was the R.O.F. capacity extended until it provided more than half the total output of guns and included a much higher proportion of the heavier types; but two R.O.Fs were also provided to meet a large part of the demand for gun barrels and other highly specialised components for many of the engineering firms as well as for the R.O.F. gun factories. Only one of the new gun factories had a range of capacity comparable with the Woolwich gun and carriage factories. All the other gun R.O.Fs had to be supplied with gun forgings and to some extent with other components and intermediate products. On the other hand, the new factories were able to concentrate their effort on a more limited range of guns. This was true even for the largest of the new factories, though the range of that factory included the production of gun forgings, carriages and mountings as well as complete guns. Only one other new R.O.F. undertook the manufacture of carriages as well as guns and this was a subsequent development to meet the urgent demand for anti-tank gun carriages in 1942. For the most part the new gun R.O.Fs were confined to a limited range of guns; two factories concentrated on light A.A. guns; three factories were initially concerned with the production of medium artillery guns; later these three factories were transferred to several types of tank guns. Even so the phasing of demand and production made it possible to concentrate effort on one or two types of gun at a time.

The eventual expansion of gun carriage production was in many ways the reverse of the expansion for gun production. In the 1914–18 war a very large proportion of the output of gun carriages and other gun transports had come from Woolwich. Between the wars there had been very great technical changes in the design and requirements for gun carriages; there was no longer any demand for the horse drawn limber of the larger gun. Gun carriages were now required in articulation with motor transport and their design approximated more to automotive and general engineering than to the work of the wheelwright and cartwright. Unlike gun manufacture, which necessitated specialised munitions equipment, gun carriage manufacture was highly suitable for the utilisation of standard equipment and general engineering methods. Many of the mountings and carriages were of extreme complexity but they were mostly of a kind coming within the scope of the high skill of British engineering firms. In consequence, barely 20 per cent. of the total output of gun carriages came from the R.O.Fs and a slightly smaller proportion from the armament firms employed on this production. As with gun production, the number of carriages produced was much greater than in the First World War—a total of over 80,000 carriages and A.A. mountings compared with a good deal less than 20,000 in 1914–18. However, mere numerical comparison here very much under-states the position of the R.O.F. production. For the most part it was in the larger types that the R.O.Fs produced at least a third and often more than half the output. Nor does output give any indication of the work of the R.O.F. organisation in initiating production in commercial factories.

Despite the addition of so many new factories, the gun and carriage factories at Woolwich remained in operation throughout the war although the labour force was only about two-thirds the peak level of 1918. No less than ten different new types of guns were produced there and even in the middle of the war Woolwich had a significant part in the production of new types of guns and carriages. In addition, Woolwich continued its long established part in the production of naval guns and mountings although the work on naval guns was extended to two of the new R.O.Fs.

In contrast to gun production, no new R.O.Fs for small arms were needed until after the outbreak of war. Yet the R.O.F. contribution to the total output was very similar; of the total output of army small arms the Royal Ordnance Factories supplied more than 50 per cent. As with guns the demand was a good deal larger than ever before. The war-time demand for rifles was no less and in addition there was a much larger demand for machine guns, not merely for the Army but also for the Royal Air Force. All armoured cars and most tanks were equipped with automatic weapons but the largest addition was the demand for aircraft weapons. Not merely was there from 1935 a large demand for machine guns for aircraft but from 1939 there was a rapidly increasing requirement for 20 mm. weapons. In addition there was a very large demand for carbines and for 20 mm. weapons for the Navy and the Army. The rearmament requirement for small arms was exceptional in that there was no demand for new rifles; the supply of rifles from store was adequate up to the end of 1939. The bulk of the pre-war requirement consisted of new types of automatic weapons and a new type of anti-tank weapon. It was symptomatic of the decline of small arms production in the inter-war years in the United Kingdom that most of the new types—the Bren, the Browning and the Besa machine guns, the Hispano and the Oerliken 20 mm. guns, were of foreign design. It was not without significance that the only other new pre-war weapon of small arms calibre—the anti-tank rifle was designed by the Enfield staff; the same was true of the war-time additions—the Sten and Polsten. The absence of any demand for rifles in the rearmament period made it possible to divide the orders for other types of small arms between R.S.A.F. Enfield and the armament firms and to avoid any major addition to factory accommodation. Even in the first half of 1939, when capacity had to be found for two types of 20 mm. weapons, the main orders were placed with armament firms and the R.O.F. production of 20 mm. weapons was limited to Enfield.

The use of rifle factory capacity for the new weapons greatly increased the difficulties of meeting the war-time demand for rifles. For the first time for more than a century the United Kingdom was without a substantial reserve of capacity for rifle production.[1] It was at this stage that the expansion of R.O.F. capacity for small arms

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[1] For an account of the feelings of those directly concerned see—Select Committee on Estimates: R.O.Fs—1947.

production became essential; by December 1939 two new R.O.Fs for rifle production had been approved. Thus after more than a century, the skill and tradition of Enfield production was transplanted in new R.O.Fs. There were important differences between the two new factories: one, relied to a large extent on outside supplies for minor components; the other R.S.A.F. was planned to undertake from its own resources the complete manufacture of rifles including all components. This factory was to become a complete self-contained rifle factory with production resources comparable to Enfield. At about the same time a third new factory was constructed on a comparatively small scale to increase the R.O.F. contribution to the production of 20 mm. guns for aircraft requirements. These three new factories and Enfield were the final total of R.O.Fs for small arms but during the course of the war they were able to extend even further their contribution to small arms production. Thus, although the R.S.A.Fs had no part in the Admiralty programme for the Oerliken 20 mm. gun, they did have a major share in the production of the Army 20 mm. gun—the Polsten. They had an even larger share in the production of the Sten carbine. Both these weapons had been designed at Enfield to facilitate production by engineering firms and initial planning proceeded on this basis but as with so many other weapons the size and urgency of the requirement made it essential to bring in the Royal Small Arms Factories to provide up to or even more than half the total output.

In quantity, the total war requirement for small arms ammunition was not appreciably larger than in 1918, yet here again it proved necessary to construct several new Royal Ordnance Factories.[1] The production of S.A.A. had for long been shared between Woolwich and the specialist firms. In 1918 the armament firms accounted for 70 per cent. of the total output but in 1939 the available capacity was about equally divided between the trade firms and Woolwich. This was the position in the summer of 1939 when to meet the large excess of demand over capacity an almost equal expansion under R.O.F. and trade management was planned. This more or less equal division of expansion was continued in 1940, but in 1941 the R.O.F. expansion went ahead with the addition of a large factory for the manufacture of carbine ammunition. In the R.O.F. organisation the final outcome of planning S.A.A. production was four new factories. These factories by December 1943 employed a total of 30,000 mainly on ammunition of calibres up to 15 mm. There was a very similar expansion of capacity

[1] There was however a much wider range of types and a large proportion of more difficult types. In addition there was a growing demand for 20 mm. ammunition: part of which had to be dealt with in the S.A.A. factories.

with the specialist firms but by 1943 the four new R.S.A.F. together with continued production from Woolwich provided 60 per cent. of the peak output of S.A.A. In addition a new R.O.F. was provided to undertake the manufacture of components for 20 mm. ammunition but as will be shown later a very large part of this production was undertaken by engineering firms.[1] Factories for the manufacture of S.A.A. were the most highly specialised of all engineering munitions factories. At many of these factories, their organisation and equipment were based on the complete cycle of manufacture from raw material and semi raw material to the complete round of live ammunition. Even more than the factories for small arms weapons, these factories could achieve to a very high degree the economies of large scale production based on highly specialised manufacturing machinery; the quantities required would have made the manufacture of S.A.A. in general engineering factories extremely uneconomical. It was only with the introduction of 20 mm. ammunition that general engineering firms and factories could be used with advantage.

At Woolwich and at several of the new factories, the raw materials, brass and other metals, went into the factory and eventually emerged as the complete round of ammunition. Not merely were the metal components manufactured from the raw metal but these components were 'filled' and 'loaded' with explosives and assembled into the final round. This was the customary method at Woolwich and in most trade factories; although some factories might obtain some supplies of components from outside, most factories had always filled, loaded, and assembled the complete round. It was thus somewhat of a break with tradition when in August 1939 it was decided that a large R.O.F. should be constructed for the manufacture of components only and that the loading, filling and final assembly should be undertaken at one of the new Royal Filling Factories. It cannot be said that this division of production caused insuperable difficulties and it may be claimed that in the early stages of the war factory programme it facilitated the construction of the factories. Even so, there were disadvantages and uneconomical factors which as the war progressed were no longer balanced by a saving in construction. When towards the end of 1940, it was necessary to remove potential capacity from Woolwich, the opportunity was taken to add loading and filling capacity to the first and largest of the war-time R.O.F. for S.A.A. which up to then had manufactured components only. At the beginning of 1941, when a further factory had to be planned this was planned and constructed as a combined factory undertaking the production of the complete rounds. There were other ways in which the manufacturing processes undertaken in the new R.O.Fs for S.A.A. were reduced. Manufacturing processes could be eliminated at the other end, especially the

[1] See pp. 179 below.

initial process—the rolling of metal strip and cutting of blanks; this was achieved by concentrating strip mill capacity at two of the new factories.

Specialisation by concentration of each factory on a limited number of types was a more difficult problem. Despite much official concern and investigation, the three Services continued to demand an ever increasing range of types and calibres. When the initial range of war requirements was formulated in 1939 there was an immediate increase in the number of types. Even before this, the adoption of the 15 mm. and 7.92 mm. weapons for armoured fighting vehicles had started the increase in calibres which was to continue and to range from the .22 in. to .303in., .5in., .55in., 7.92mm., 9mm., 15mm. and up to 20mm. An additional problem was the variety of types required for some of the calibres; incendiaries and tracers were particularly difficult to produce and with the outbreak of war were in greatly increased demand. To meet the immediate demands of 1939 and 1940, it was essential for the existing factories and the first of the new factories to undertake a wide range of calibres and types. For later factories it was possible to adopt a significant degree of specialisation. Thus, none of the later R.O.Fs for S.A.A. undertook the production of more than two calibres and not many types within these calibres. An opportunity for further specialisation came in 1941 with the introduction of new weapons and the decision to provide capacity in the United Kingdom for ammunition previously only available from North America. As a result, the last of the factories had the advantage of concentration on one size only and in this achieved the largest output of any factory for any calibre.

The limitation of several of the factories to component manufacture greatly reduced the size of these factories and the total labour force, required at the factory. Had all these factories undertaken the assembly and filling of ammunition, their dimensions and the number employed would have been more than doubled. Even so the largest factory had a peak employment of over 14,000 and the second largest over 8,000. This factory with an employment of over 8,000 could make an unchallenged claim to be the largest munitions factory employed exclusively on one product throughout its period of operation.

Although as we have seen, the Royal Filling Factories were responsible for the bulk of the filling and assembly of gun ammunition there was never any proposal that the engineering R.O.Fs should attempt to meet anything like half the total war requirement of the components—cartridge cases, shell cases, fuzes and the many other parts. Yet several new R.O.Fs were established for this work. For some components, notably cartridge cases and a few types of shell and fuze, the R.O.Fs had a significant place in this production. The outcome reflected very well the technical importance of the R.O.Fs even for production in which they had a comparatively small share in the output. It indicates also the reliance that was placed on the R.O.Fs for difficult and large scale manufacture. There was also the agreed policy of replacing the gun ammunition capacity at Woolwich. In fact, Woolwich continued to manufacture gun ammunition components throughout the war, though on a somewhat reduced scale. Even so five new R.O.Fs for this work were in production, though only one of the new factories had a labour force larger than at Woolwich.

Two of the new R.O.Fs were constructed and brought into operation before the outbreak of war. One of these was provided to meet the large requirement for cartridge cases both for the Army and for the Navy, the other factory was the main source of supply of special fuzes needed for A.A. defence. The work undertaken by these factories could not have been easily placed with engineering firms in peace-time and even under war conditions it was only for cartridge case manufacture that the burden could be extensively divided among engineering firms. Both these new factories were the largest factories employed on this work and provided very real advantages of large scale production. This was also true of two R.O.Fs for shell production approved immediately after the outbreak of war. As will be described later, the manufacture of shell forgings—the main shell case—had by 1939 been planned on the basis of very large scale plants. Most of these large scale plants were operated by engineering firms and many were confined to forging work but it was indicative of the leading position of the R.O.F. organisation that two new R.O.Fs were approved in September 1939 to operate two large scale forging plants and to undertake the machining of their total output of forgings. Unlike Woolwich, these two shell factories were confined to a very limited range of shell; in fact one factory was for a long time employed on only one type of shell and then transferred exclusively to another type. It is not surprising that this factory achieved the largest output for these two types and the other R.O.F. could claim second place in output.

With the output from these four new factories, the contribution of the R.O.Fs to the supply of shell, cartridge cases and special types of fuze was on a very large scale. In addition, the Woolwich gun ammunition factories continued to operate. But with the exception of cartridge case production the Woolwich output was mainly for comparatively small quantities of a wide range of sizes and types. It was mainly the need to limit the extent of the work undertaken at Woolwich which led in 1941 to the equipment of another ammunition R.O.F., this time in requisitioned premises in the home counties. This factory mainly undertook work on small components, especially for naval ammunition, which would otherwise have been undertaken at Woolwich. The importance of naval work at Woolwich continued; in most of the war years Woolwich produced more shells for the Navy than for the Army, but production of naval shell at the new factories was small although the Admiralty had an important share in the cartridge case production. Employment at Woolwich on gun ammunition was only about half the 1918 total, but with the addition of the five new factories the war output of gun ammunition components from the R.O.Fs was much larger than in 1918. Moreover most of the new factories demonstrated the value of R.O.Fs for large scale production in a manner which had rarely been possible at Woolwich.

Progress in the construction of the engineering factories was usually rapid. The supply of machine tools and plant was a more difficult problem and delays did occur on this account, but three of the pre-war factories had started deliveries well before the outbreak of war. The contribution of these first three was indeed vital. Birtley—the cartridge case factory—was in production by the summer of 1937 and at the Blackburn fuze factory, not approved until 1937, production was starting up in the summer of 1938 although deliveries did not start until early 1939. At Nottingham, the new gun factory, production and deliveries of guns started in 1937 and by September 1939 it had provided over 200 complete A.A. equipments for the A.D.G.B. and about an equal number of 2 pdr. guns. Similarly, Birtley and Blackburn provided supplies of cartridge cases and fuzes essential to air defence. In the early months of the war, supplies of the 40 mm. Bofor gun came in quantity from Nottingham; and a little later the sorely needed 25 pdr. gun for the equipment of the field forces came from the new R.O.Fs at Leeds and Dalmuir, which had been approved in the last twelve months of peace. Thus, in the days of inadequate supplies and urgent need, these R.O.Fs contributed a large part of the all too meagre supplies.

The schemes for the additional gun and shell factories which were approved in rapid succession on the outbreak of war followed a similar course. Separately, they made a relatively limited demand on building resources and encountered no special difficulties in construction. Their requirements for deliveries of manufacturing equipment might delay some section of production, but with one exception, all these factories were making deliveries of much needed supplies within twelve months of the building contractors moving to the site. Progress on the construction and equipment of the small arms and small arms ammunition factories was generally about the same as for gun factories, although the machines required for both these types of factories were highly specialised and the problems of finding suitable sites for small arms ammunition factories often delayed the start of construction. Furthermore, most of these factories were larger factories, their separate demand on both building resources and specialised equipment was greater. The record of construction and speed of starting up production in the engineering factories was thus far and away the best. There were only three factories which did not make deliveries within twelve months of the start of construction. Apart from these factories, most factories were making deliveries in eight to nine months of the start of construction. In addition, there was usually a period of six months required after financial approval of the scheme and before construction was started. There was no means of eliminating the period of planning and prospecting, unless as occasionally happened, there was previous warning of the scheme.

The twenty-three new engineering R.O.Fs were in number by far the largest group of R.O.Fs although with a total employment of about 90,000 they fell a good deal short of the more than 150,000 employed at the new filling factories. Even so, with Woolwich and Enfield added the total employed in the engineering group exceeded 100,000. As we have seen, the provision of the new factories did allow the war demands on Woolwich to be reduced. In August 1918 the total employed in the engineering factories at Woolwich was over 32,000. In December 1942 the engineering factories at Woolwich employed over 14,000. Between then and March 1943 the twenty-three new engineering R.O.Fs had a total employment of over 85,000. By no means all the new factories had a total employment higher than the respective factory group at Woolwich. The same was true of the new small arms factories in relation to Enfield, for the employment at Enfield of over 6,000 in 1942 was only exceeded by one of the new small arms factories. Enfield like Woolwich retained a very important place in war production. The scale of operation as indicated by peak employment varied considerably within the same group of factories but none of the factories employed less than 1,000 at the peak of production.

Factories for	*Range of peak employment at the new factories*		
Guns	1,076	—	6,532
Small arms	1,775	—	9,663
Gun ammunition	2,349	—	7,192
S.A.A.	2,908	—	14,225

For most factories it was important that there should be a fairly large engineering population likely to yield sufficient men with engineering experience. Several of the sites chosen were old factory sites which had been used for National factories in the First World War. Strategic and economic policy favoured the western fringe and in consequence the greater number of the engineering factories were located in Wales, Lancashire, Cheshire, but the complete list of locations shows a very wide distribution.

Region	*No. of Factories*
North West	8
North East	5
South Wales	3
Midlands	2
Home Counties	2
South West	1

Planning required careful attention to the accommodation of specialised plant and some anticipation of probable changes in weapons to be produced e.g. increase in length of guns, but for the most part, except where filling capacity was included in S.A.A. factories the factory designs mainly followed normal engineering factory principles. The cost of construction was closely related to those for commercial engineering factories and although the engineering R.O.Fs were half the total number of R.O.Fs constructed between 1936 and 1945, they accounted for only a fraction of the total cost for the construction of R.O.Fs. The major difficulties and cost related not to construction but to the equipment of these factories. Here the expenditure was on a very different scale. Thus the building expenditure for nine new gun factories was £3.5 million but expenditure on plant was about £12 million. In the total expenditure for the twenty-three engineering factories, over £20 million was for plant and over £11 million for building. It was only for S.A.A. factories that building costs approached equality with the cost of plant and equipment and this was due to the inclusion of filling capacity at two of the factories. Much more typical of the costs for specialised engineering factories were the small arms and gun and carriage factories. For both these groups the total expenditure on building was only a quarter of the total cost.

The engineering R.O.Fs by no means escaped the difficulties of war-time factory operation; but compared with the giant filling factories the problems of bringing the factories up to maximum production and labour strength were much less onerous. Many of the factories had a peak labour force of under 5,000 and most of the factories were in, or close to, fairly well populated industrial areas. Special subdivision of skilled processes was a much larger problem and it was the training of labour and the adaptation of processes to unskilled labour that needed the greatest attention in order to secure satisfactory operation of the factories. In this work many of the engineering R.O.Fs secured very real achievements. The general application of engineering R.O.Fs to this problem is shown to some extent by the high proportion of women employed.

Percentage of women employed at new R.O.Fs

	Range for group
Gun and carriage . .	21% to 53%
Small arms . . .	42% to 68%
Shell ammunition . .	47% to 63%
Small arms ammunition .	51% to 62%

Of the older factories, Enfield had only 21 per cent., at the Woolwich engineering factories the range was from 22 per cent. in the gun factory to 43 per cent. in the S.A.A. factory. It was in the factories established in war-time that the full achievement was attained. The extent to which the training of women succeeded is shown by the factory with the highest proportion of women—the rifle factory at Fazakerley with no less than 68 per cent. There could hardly have been a more complete demonstration of the large scale employment of women in very highly specialised weapon production. The other factories which attained a proportion over 60 per cent. were the fuze factory at Blackburn and the S.A.A. factory at Blackpole.

The management and key workers for these factories were drawn, to far larger extent than at any other of the new R.O.Fs, from the parent factories, Woolwich and Enfield. Additions there had to be from general industry both for the management at the factories and to some extent for the organisation at headquarters, but this was never sufficient to remove the predominance of Woolwich and Enfield trained officers and managers. Several of the superintendents of factories came from general industry but this was the exception and did not result in any real loss of R.O.F. traditions and control. Indeed, this was true even of S.A.A. factories, where there was a fairly significant incursion of management from industry. In this field the collaboration with I.C.I. was very important for some types of production but the effect on the factory management was by no means as extensive as was the position in the filling factories and the explosives factories.

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R.O.F. Organisation and Control

The administrative task which confronted the R.O.F. organisation in 1940 was far and away larger than that which confronted any commercial undertaking. The R.O.Fs with a total of over 300,000 employed at 44 factories, far exceeded the undertaking of any industrial firm in the United Kingdom. Moreover the growth from 3 factories in 1935 to 44 factories in 1942 and from a few thousand employed to more than 300,000 was an expansion which no industrial undertaking approached. The R.O.Fs did not undertake aircraft construction or shipbuilding but within the sphere of munitions production their range of production was wider than that of any other undertaking. The R.O.F. organisation was thus confronted with problems of size, and a diversity of technical problems and administration which had no real counterpart in any other industrial organisation.

It was not merely size and variety nor even the speed of expansion which created problems, but the need for rapid change of emphasis from the planning, construction and equipment of the factories, to production. Indeed, it was a lesson that there was barely time to learn, that the problems of the direction of production were very different from the problems of construction and equipment. The essential story of the war years is of an initially small organisation, which having learnt to meet the problems of planning and construction, had to find methods and an organisation that would ensure efficient and full scale production. As will be seen the measures that had to be taken to ensure full scale production were thought by some to threaten the very unity of the R.O.F. organisation. Yet drastic as they were and diverse as they appeared, they did not efface the essential characteristics of the R.O.F. factories and organisation. Even at the peak of war production what appeared to some as a disjointed and even a disordered organisation was essentially the same R.O.F. organisation, responding without restriction of logical theory to the necessities of war production, but within the limits of the Ministry of Supply.

In 1939, before the outbreak of war, the organisation under D.O.F. was in the main essentials very similar to what it had been in 1930. The main changes that had taken place related to the planning and construction of factories and not to their management and control. The planning of factories was largely undertaken by technical officers attached to the three parent factories, Woolwich, Enfield, and Waltham.[1] This task required some addition to the staff but up to 1939 it had not generally altered their position in the R.O.F. organisation nor had it resulted in any large expansion of the headquarters staff. The staff of D.O.F., which transferred to the Ministry of Supply in August 1939, was only a small group but it was in control of a rapidly expanding industrial and technical staff operating at the factories and on the new factory sites. Immediate steps had to be taken to strengthen the Directorate staff. By the end of 1939, three Deputy Directors had been appointed from outside the government service and one deputy post had been filled by an Assistant Director of long service in the R.O.F. organisation. This deputy was particularly concerned with the engineering R.O.Fs. Two of the other three Deputies were appointed specifically to deal with what were then the three major

[1] The administration of factory construction is dealt with in *Works and Buildings* by C. M. Kohan, in this series (H.M.S.O. 1952).

problems, the direction and control of factory construction and the equipment of the factories. In the same period the number of assistant directors had been increased to seven. Several of these officers, including the Assistant Director (Accounts) were from the staff transferred from the War Office. Two were responsible for planning production at filling factories, two at engineering factories and two at explosives factories.

In the first few months of war with the rapid approval of additional R.O.Fs, bringing the total to over 40 factories, it was clear that the position of the Directorate must be strengthened. In February 1940 the Directorate was upgraded to a Division under a Director General who was made a member of the Supply Council of the Ministry of Supply. The position of D.G.O.F. to which D.O.F. was immediately appointed in March 1940 gave the R.O.F. organisation the status and independence within the Ministry of Supply more in accord with the growing importance and resources of the rapidly expanding R.O.F. organisation. Even so this improved status could not in itself solve the major problems of headquarters organisation and whilst it greatly increased D.G.O.F's powers in relation to other sections of the Ministry of Supply, it did not provide the full independence which would be accorded generally to a large industrial organisation.

From the summer of 1940 onwards with many more factories coming into operation, the problems of production superseded the problems of construction. With a wide range of factories in production, the problems of management and of the policy relating to the manifold aspects of management greatly increased. Here one tendency was for D.G.O.F. responsibility to be limited not by division of responsibility within the R.O.F. organisation but by the vesting of responsibility for many functions in the specialist branches of the Ministry of Supply. In this D.G.O.F. was in the same position as other Director Generals in the Ministry of Supply. In the immediate reorganisation in the summer of 1940 under D.G.O.F., the central organisation remained broadly divided as before. There were now Directors for each of the main fields of production—explosives, filling and engineering: a Deputy Director was concerned with the construction of the factories and another with the equipment of the factories. The most significant change was the appointment of a D.D.G.O.F. responsible for filling and explosive factories. This appointment pointed to the eventual reduction of D.G.O.F. responsibility for production. For, in July 1941 the D.D.G.O.F. was appointed D.G.O.F.F. and a separate division formed under him responsible for production at the filling factories.

The headquarters organisation for the engineering R.O.Fs although greatly expanded did not meet serious difficulties. Broadly, it was possible to elaborate and expand the early organisation on a fairly consistent functional and factory basis. At the outbreak of war, only three new engineering R.O.Fs were in production and in consequence the emphasis was on construction. Responsibility for this was largely centred at Woolwich, where the Chief-Mechanical Engineer was in charge of the construction of all the new engineering factories. By the spring of 1940 the production at the three factories was increasing rapidly and preparations were advanced for the start of production at several more factories. In the summer of 1940, the headquarter's control of the engineering factories was divided between three groups of factories—the ammunition factories, the small arms factories and the gun and carriage factories. Each group was directed by an assistant director and they were under the direct control of D.O.F. (E) who had been in charge of engineering factory work for several years. This division placed a very heavy burden on the A.D.O.F. responsible for the ten gun and carriage factories and in October it became necessary to divide this group into two groups of five factories.

By the end of 1940 almost all the new engineering factories approved at the outbreak of war were approaching the production stage and it became necessary in 1941 to subdivide some of the groups again. This was particularly necessary for the S.A.A. factories and the same was true of the new rifle factories which were ready for production work early in 1941. To meet the rapid expansion of the factory production and employment, the further subdivision of factory grouping was undertaken and two Directors appointed under the D.D.G.O.F. (E) to which rank D.O.F. (E) had been promoted. This process of expansion and subdivision was to continue until the summer of 1942 when the organisation attained its maximum extension. There were by then six main sections, one for each of the main groups of products —guns, carriages, small arms ammunition, small arms, shell and cartridge cases and 20 mm. gun production. In addition there were five sections responsible for ancillary functions —(1) subcontract work, (2) supplies of spares, tools and gauges for R.O.F. gun production and for some trade production, (3) production programme co-ordination, (4) maintenance services for all factories, (5) rationalisation of gun production. The total number of senior technical staff including all headquarters staff who were on salary scales with a maximum of £800 and over, numbered little more than 50 in 1942. This proved to be the maximum expansion. This staff was responsible for the operation of 22 engineering factories in addition to Woolwich and Enfield and employing over 100,000.

In September 1942, D.G.O.F. responsibility for production was reduced by the transfer of the control of production at the S.A.A. factories to the production division. The continued increase in the demand of S.A.A. and the heavy responsibility for overall planning had already led to the appointment of a Director General to deal with the trade and agency production of S.A.A., and in September 1942 the decision was taken to place the production of S.A.A. at the R.O.Fs under his direction and control. The factories remained for general administration and maintenance under the care of D.G.O.F. and this arrangement of direct control by D.G.S.A.A. in no way affected the status of the factories as R.O.Fs nor the position of those employed there. Indeed, at the factories only a few would be aware of any change of control. The personal control remained unchanged, for the A.D.O.F. and his staff were transferred to the D.G.S.A.A. who was also given the rank of a D.D.G.O.F. The transfer reduced the D.G.O.F. responsibility but at the same time removed the appropriate staff. It was not until the summer of 1943 that the stability of other production made it possible for D.G.O.F. to reduce the headquarters organisation. The reduction was by no means far reaching and was mainly incidental to the reduction from three to two Directors and the consequent arrangement of the control of production into two main groups in place of three. One director was now made responsible for production of carriages, rifles and fuzes with nine factories for this production under his care. The other director was responsible for guns, machine guns and cannon, shells and cartridge cases with ten factories including Enfield under his control. This re-organisation was not marked by any overall reduction in factory production. The employment at these factories totalled at least 60,000 which was very little less than it had been twelve months earlier. Employment did not fall to less than 50,000 until March 1945.

Towards the end of 1943, the final major addition to the engineering factories work came with the introduction of tank production. The decline in other production which made it comparatively easy to fit in the work of tank conversion and later tank construction, also facilitated the organisation of headquarter's direction. Thus although some additional junior technical staff was necessary, the senior staff and director for the new production were those who were also concerned with carriage and forging production. The Treasury questioned the necessity of bringing the complete direction of this work under the D.O.F. and suggested that it might be undertaken to some extent by the Fighting Vehicle Production Branch of the Ministry of Supply. Indeed the position of the S.A.A. factories might seem to present a precedent but this would have ignored the fact that these factories were planned and continued to be managed by the D.O.F. staff operating under the general direction of a production division. It was indeed a misconception of the position of R.O.Fs in the Ministry of Supply to assume that whilst they remained R.O.Fs they could be taken in any fundamental sense out of the ultimate scope of the Royal Ordnance Factory organisation. It would indeed have been ironical for the

R.O.Fs, so long excluded from tank production, to have been restricted in the direction of the work eventually accorded to them. As it was the equipment and operation of the first R.O.F. for tank production was to be the major task of the R.O.F. engineering factory organisation in the last eighteen months of war. This more than any other task was to mark the way of the R.O.Fs into the post-war world.

For explosives and propellant factories, the main spring of control was to a very large degree at the factory level. This was true to a much greater extent than for any other type of factory. Large, complicated and to a high degree automatic and continuously operating plants, or as with some propellant production, highly specialised and dangerous processes, required effective control to be mainly exercised at the factory. In consequence, the headquarters staff for these factories was never very large and in the period of factory construction, most of the senior technical staff were located at the factories. Even later, the Assistant Directors were more often at the factories than in London. Moreover, the headquarters control of explosives and propellant factories had to be closely related to the largely parallel and complementary group of agency factories producing the same or similar products.

In May 1941, a Controller of Ordnance Factories (Explosives) was appointed to function under D.D.G.O.F. This somewhat anomalous arrangement was comparatively short lived for in September 1941 the responsibility for production at the explosives and propellant factories was transferred from the Royal Ordnance Factory organisation to the explosives production division of the Ministry; it was transferred from D.G.O.F. to D.G.X. It was only the responsibility for production which was transferred, it did not involve a loss of status or identity as Royal Ordnance Factories. The factories and all concerned with the management and administration whether at the factories or at headquarters remained part of the R.O.F. organisation. What had been given up by D.G.O.F. was the power and responsibility of planning and authorising production. Previously the allocation of production between the R.O.Fs and other factories had been arranged by consultation between D.G.X. and D.G.O.F. Now D.G.X. was the final authority for allocation of production and for the output from the factories. The change so far as D.G.O.F. was concerned was very slight. D.G.O.F. remained responsible for the construction and maintenance of the factories and for the employment of all staff at the factories and at headquarters; and indeed for the appointment of all senior officers. Throughout the war all accounting and administration for the explosives factories was to remain under the ultimate control of D.G.O.F.

Factories planned, constructed and brought into production by one organisation were placed under another organisation for use as production units. The outcome of this industrial transmutation might appear to some as an unfortunate infringement of the R.O.F. organisation but this would be to ignore the continued identity of the D.D.O.F.(X) organisation within the production division and the essential links retained with D.G.O.F. With about half the explosives and propellant capacity outside the R.O.F. organisation, a production division had developed on a considerable scale. The advantages of partnership, as it were, in one and the same production division were substantial. From the inception of the rearmament programme there had been ready and fruitful co-operation between the D.O.F. and the I.C.I. technical directorate; this had continued and was now greatly augumented by this partnership under the same production authority.

The Royal Filling Factories had by far the largest total employment of any group of factories planned and controlled by the R.O.F. organisation. Indeed, they were the largest homogeneous group in munition production. The planning and progressing of the construction of the filling factories was in itself a large and unprecedented task. So large indeed that it may be said that until at least the summer of 1940 it tended at headquarters to overshadow the organisation of production. Indeed, it was not until the spring of 1941 that the headquarters organisation was fully re-organised with production as the primary function. At the outbreak of war, Chorley and Hereford each employed just over 1,000 production workers. Woolwich with over 8,000 on filling, still dominated the output. Woolwich was to remain important until the end of 1940 when the effects of enemy bombing and the increasing capacity at the new factories led to a substantial decline in operation. At the other factories the position was radically changed in the summer of 1940. Chorley which in the first four months of war had taken on over 5,000, was in June 1940 approaching 15,000, Hereford was near 5,000 and Bridgend and Glascoed were both employing over 1,500. Even so, there was still a good deal of construction work to be done and five more large factories still in various stages of construction. This early expansion in labour force was not immediately reflected in production and it was not until the third quarter of 1940 that output reached double that of the last quarter of 1939. By the end of 1940 there were seven new filling factories in operation; the change of emphasis from construction to production could be delayed no longer.

The scale of the production problem in the filling factories tended at times to exceed the administrative resources; for almost twelve months after the outbreak of war, the headquarters control had not the authority, status or resources to deal adequately with the problem. It was not until August 1940 that a D.D.G.O.F. was appointed responsible for the re-organisation and direction of the filling factory organisation. Even then, he was also responsible for the explosives factories. By February 1941 a complete re-organisation of headquarters staff for the filling factories and the explosives factories was submitted to D.G.O.F. and the Treasury, for approval.

Although much had been done in the course of 1940 to improve the planning and efficiency of production at the filling factories in operation, there was now an urgent need for an organisation that would be adequate for the control and direction of all the new filling factories. At this stage the final number of factories was expected to be over thirty. The main lines of the organisation of February 1941 were to continue in force for the rest of the war. By far the most unusual feature was the inclusion of Assistant Directors to act on behalf of headquarters in each of the three regions within which the nine filling factories were grouped, Lancashire, Northern England and Wales. The problem of directing the activities of nine major factories far removed from London had to be solved. It was not merely that they were distant but there was an urgent necessity of working out the most efficient methods of production and securing the highest level of recruitment possible. Throughout construction and in the starting up of production the filling factories had needed representatives from headquarters at the factory. Many of these were now needed on the headquarters staff in London but the problem of direct control at the factories remained. If as with the engineering R.O.Fs the factories had been formed into groups under the control of an Assistant Director and technical staff in London it was very likely that the many urgent and largely unprecedented problems raised at the factories would require most of the headquarter's staff to spend much of their time at the factories. Moreover, the obvious grouping of filling factories was by geographical proximity; there were important interlinking of functions and flow of products within these groups. To cope with this situation, a measure of decentralisation was adopted; the factories were formed into three groups, and the Assistant Directors with technical staff were located at one of the factories in the group and operated as regional directors.

In July 1941, the D.D.G.O.F. (F) was appointed D.G.O.F. (F) and his section became a separate division, fully responsible for the operation and production at the filling factories including the six agency filling factories which were under construction. Since the summer of 1940, the control of filling factory production by D.G.O.F. had been entirely nominal. This separation of the production responsibility was thus inevitable and the promotion of D.D.G.O.F. (F) to a Director General with a seat on the Supply Council of the Ministry of Supply indicated both the scale and importance of the production programme for which he had been largely responsible for almost a year. It was for a while thought that he might also continue to be responsible for production at the explosives factories but this duality of function was ended in September 1941 with the transfer of this responsibility to D.G.X.

In the main the organisation which D.G.O.F. (F) had planned and established in 1941 continued without any far reaching changes for the rest of the war. Inevitably, additional technical staff were required as the measure of detailed production planning was investigated. The frequently changing range of stores, the increasing requirement of types of S.A.A. and bombs and the need for the regional administrators to have technical officers, all added to the nominal roll of headquarter's staff. Yet the total for so large a factory undertaking was remarkably small. In July 1941 when most additional needs had been assessed, the total number of technical officers under D.G.O.F.(F) was 101 and of these only 37 were on salary scales of £750 and over. At that time the factories were employing 90,000 and were to increase to an employment of 150,000. The salaries for headquarter's staff were estimated at £64,000 and the annual pay roll at the factories was then about £20 million and was to reach at least twice that amount.

The peak of the ammunition programme and of the operation of the filling factories came less than twelve months after the separation from D.G.O.F. It was at this moment of achievement and the approach to stability that the filling factory organisation was to come under severe criticism both in the Report from the Select Committee on National Expenditure and following this report,[1] in the House of Commons.[2] Paradoxically, the criticism of the organisation was mainly directed against the two innovations which had facilitated the major improvements of the previous year—the regional administrators and the appointment of a separate Director General responsible for filling factory production. It was significant that the main reason given for criticism was the effect of these appointments on other officers and on other aspects of organisation rather than on the production and efficiency of the factories. Following the debate in the House of Commons the Minister of Supply reviewed the position both of D.G.O.F.(F) and of the regional administrators. He was fully satisfied as to their importance in the existing organisation and emphasised his support by strengthening the position of both D.G.O.F.(F) and the regional administrators. It was shortly afterwards that the title of D.G.O.F.(F) was changed to D.G.F.F. and the separation from D.G.O.F. was made complete.

The recruitment of superintendents for over 40 major factories, some of them the largest factories in operation, was a matter of some

[1] See p. 104 above.

[2] H. of C. Deb., Vol. 382, Cols 1071-1154.

difficulty. The resources of the three historic R.O.Fs were fairly quickly exhausted and with the expansion of the headquarter's staff many of the key men were needed in London. In addition, finding suitable candidates for other managerial posts and even comparatively junior administrative posts was by no means easy. Further, the organisation of an efficient managerial unit from the staff appointed, was often a prolonged process. These difficulties were found at all factories but inevitably they were most acute at the filling factories where the special problems of dealing with a very large labour force greatly intensified the difficulties. In the filling factories, at least, it was not the problems of production management which proved the most difficult but sheer problems of administration for so large a labour force. Thus at many factories production problems were solved before any stability had been reached in labour administration. It was these difficulties which led to the decision to operate the last six filling factories on an agency basis. None of the firms appointed had any connection with explosives or ammunition work; their important asset was that they could provide an existing team of management including junior staff who were skilled in dealing with the administration of factory employment. Fortunately, the agency factories were on a much smaller scale than the Royal Filling Factories; but it would have been difficult to provide management for these factories in any other way without very serious delay.

Every R.O.F. whatever the type of production was directed by a superintendent. The position of the superintendent in the historic R.O.Fs was of long standing and well understood; he was a man of undoubted authority whose status both in the War Office and with the men at the factory was well established. In some of the new R.O.Fs his position was not so fully secured. At times those employed at the factory failed to understand the position of the superintendent and were inclined to regard any limitation of his powers as a pretext for evasion; the superintendents themselves found the limitations irksome and at times there appeared to be a serious limitation of the authority within the factory. Much of the difficulty arose simply because the factory was a new factory with workers unaccustomed to the R.O.F. methods of procedure and in which a good deal had to be learnt before reasonable relations and procedure could be established. In this situation, limitations of the superintendent's powers did not facilitate a speedy settlement of differences but in the end promoted a satisfactory and uniform settlement. Even more trying to some superintendents was the control over welfare, canteens, housing and some aspects of labour at the factories exercised by officers operating not under their instructions but under the specialist branches in the Ministry of Supply. In fact, the superintendents suffered in many ways from limitations similar to those of the R.O.F. organisation at headquarters. These difficulties were to some extent a reflection and a result of the divided control at headquarters.

The position of the superintendent was in many ways unique and difficult to define. If it could be said that the Director General was the managing director and chairman of a group of some 40 factories, the superintendents were in the position of general managers of the factories. This was the position, for under their charge were works managers, assistant works managers, principal clerks and medical officers. Yet there were many signs that their authority was not so extensive as that of a general manager. In reply to criticism in the House of Commons, the Minister of Supply acknowledged that the superintendent should be 'captain of his own ship'.[1] The analogy was apt, for although it could not entirely remove the fact of direct instructions from headquarters to some of his officers, it served to emphasise the heavy responsibilities which fell on the superintendent far removed from headquarters. In many factories, and particularly the large factories which assumed the proportions of a small town, the superintendents felt the need of well-trained officers to undertake specialist services in relation to labour conditions, wages, canteens and general welfare. Even so most superintendents would have preferred to have these officers under their effective control without the possible intervention of instructions from outside the D.G.O.F. organisation.

The size of the task of the superintendent varied greatly from factory to factory. Some factories employed little more than 1,000 but a few employed over 25,000. All the new factories were far removed from London and the 'managing director's' office. Many were at very isolated places. More than in most private factories, the superintendent as the general manager, had to be able to maintain the work of the factory without direct contact with headquarters. The superintendent had to be fully capable of directing and controlling the production in the factory; but he was also, in a way that might not often happen in private factories, the representative of the 'managing director' and to a large degree of what might be considered as the board of management of the R.O.F. organisation—the Ministry of Supply. The superintendents had thus an exceptional place in a unique industrial organisation. In some factories there was the added responsibility in face of the great hazards which attended the handling of highly dangerous products. When disasters came—they occurred several times at some factories— the immediate responsibility for all possible action fell upon the superintendent.

At the peak of war production fourteen out of the total of 44 R.O.Fs were operating under the control of production divisions. The factories

[1] H. of C. Deb., Vol. 382, Col. 1082, 5th August 1942.

that remained under D.G.O.F. or D.G.F.F. had, with a total of over 210,000, more than two-thirds of the total employment. Thus what remained completely within the R.O.F. organisation was very much larger than the aggregate of the factories transferred. The transfer of the responsibility for production at the fourteen factories emphasised what in many ways was the most valuable function of the R.O.F. organisation in the rearmament period and in the early stages of the war—the planning and provision of new factories in readiness for production. This was a continuous task from 1935 to 1942 which could not have been so readily fulfilled by any other available organisation.

The headquarters organisation under D.G.O.F. although it continued to grow, failed to develop in function and responsibilities to the extent that might be considered essential for so large an industrial organisation. A possible ideal was as set forward in 1942 by the Select Committee on National Expenditure :

> The Royal Ordnance Factories should be contained in a single organisation which comprises all the functions, and only those functions, necessary to their operation. They must be regarded as a self-contained industrial unit which happens to be under the control of the Ministry of Supply but has no more essential connection with the other departments of the Ministry than the management of a private concern engaged on its contracts.[1]

No doubt 'self-contained industrial organisation' would have been a more accurate description. It is clear that the scope of the organisation was quite large enough to justify a headquarter's organisation which included all the essential specialist branches devoting their attention entirely to R.O.F. responsibilities. Indeed there might well have been three Director Generals, one each for the filling, explosives and engineering group of factories with the complete organisation under a Controller of Royal Ordnance Factories.

Such a complete and largely self-sufficient organisation was never considered. The tendency, in the main, was to overcome the difficulties of the size and scope of the R.O.F. organisation by the convenient process of division. D.G.F.F. was separated from D.G.O.F.; the small arms ammunition and explosives production was taken over by the production divisions. These were practical and immediately beneficial arrangements. Similarly, despite the size of the undertaking which in 1942 was in total employment comparable to that of the Post Office—a separate department of state—the R.O.F. organisation continued to operate as a division or rather as two divisions of the Ministry of Supply. In consequence, like other divisions it was dependent on the

[1] Eleventh Report from the Select Committee on National Expenditure, Session 1941–42, para. 59, July 1942.

specialist branches of the secretariat of the Ministry for specialist service—matters relating to labour, wages, conditions of employment, welfare, housing and canteens. So great was the scope of R.O.F. undertaking that a very large part, and for some the major part of the work of these branches was devoted to the needs of the R.O.F. organisation. Nevertheless, these branches were responsible not to D.G.O.F. but to the Second Secretary (Supply) and through him to the Permanent Secretary and to the Minister. The only real alternative to this arrangement was the development of the R.O.F. organisation as a semi-autonomous industrial organisation directly responsible to the Minister of Supply or indeed outside the Ministry. The impracticability of such an arrangement under the stress of war and the loss of stability and of common departmental services, which would have accompanied such an arrangement, were too obvious to make the notion a practical proposition. The staffing of such an organisation would have presented very serious difficulties. It might indeed be claimed that the success of the R.O.F. organisation under the stress of war was due in no small measure to the support and service which D.G.O.F. and D.G.F.F. received from the department within which it achieved the war-time expansion—the Ministry of Supply.

CHAPTER V

THE ARMAMENT INDUSTRY: AGENCY FACTORIES AND FIRMS

(i)

The Armament Industry

THE decline in the armament industry after 1918 has already been described.[1] To those concerned in 1934 with exploring the capacity available for gun and ammunition production the effects of the decline were all too obvious. In both the heavy and light sections of the armament industry only two or three firms had survived. In the heavy section, Vickers-Armstrongs and Beardmores were the only two firms with capacity for gun production. In addition, there was some specialised capacity in iron and steel firms for the production of armour plate and gun and shell forgings, but this was at fewer firms and less in extent than in 1914. In the light engineering section, B.S.A. and Vickers-Armstrongs had capacity for small arms production and I.C.I. and Greenwood and Batley for small arms ammunition. For explosives almost all the capacity for military explosives was with I.C.I. and this was but a fraction of what had been available in 1914.

The position in the light armament section for small arms and small arms ammunition, was a good deal better than in other sections. In part, this was because small arms plant at the Enfield R.S.A.F. and the small arms ammunition plant at Woolwich had been increased during the First World War and was now available to replace some of the losses due to a reduction in the armament firms. Moreover, it was a tradition in this section of the armament industry, accustomed as it was to wide fluctuations of demand, to maintain specialised plant ready for almost immediate use. Even after 1918 it is very probable that this tradition would have been followed quite apart from government encouragement on a very limited scale. The affect of the decline in the heavy armament section was much more serious. Here, the maintenance of plant was more difficult and the only schemes for maintenance with government support was for Admiralty requirements for armour plate and heavy gun mountings. A large part of the heavy armament capacity was closely integrated with iron and steel manufacture; once abandoned, this specialised capacity could not be quickly re-instated. The capacity immediately available in 1936 at the iron and

[1] Chapter I, page 14 ff.

steel firms, for shell and gun forging work was very small. Even at the two remaining firms for gun manufacture, Vickers-Armstrongs and Beardmores, it was not easy in 1934 to estimate the output which could be obtained from the rehabilitation of the existing plant.

The revival of Admiralty requirements from 1927 onwards brought a slight increase of activity in some of the heavy armament firms but this had little bearing on the capacity for War Office requirements, nor did it go far to solve the main problems of armament production for a major naval programme. When in 1936 the War Office programme was added, it was clear that even when combined with the resources of the Royal Ordnance Factories, the total resources available in the armament industry would be much less than would be required for war requirements. Thus a wide deficiency confronted the committee of industrialists who in 1934 were asked to make recommendations as to the best methods of meeting the many deficiencies in armament capacity.[1] Despite the importance which the industrialists gave to the recruitment and training of firms from outside the armament industry, the committee were, as we have seen, no less insistent that there must be the fullest possible expansion of the specialist resources both in the R.O.F. organisation and in the armament industry. They recommended the maximum expansion of capacity at the existing factories of the armament industry, in addition to the construction of additional factories under the management of the armament firms. It was assumed that the new factories would, if necessary, be provided at public expense, and so the main immediate limiting factors would be the share of expenditure allocated for armament industry schemes and the willingness and ability of the firms to extend their activity and management. The demand placed on the armament firms, though large and increasing, proved to be within their powers of revival. In 1934, there was some doubt as to the ability of the remaining armament firms to carry through a large scale expansion programme, but the inherent strength of the firms was to prove much greater than was at first expected.

When in 1936 the War Office had to consider the capacity available and the expansion possible within the armament industry there was a very short list of firms to approach. The immediate concern was the production of guns and carriages, cartridge cases, fuzes, shell and explosives. Vickers-Armstrongs were concerned with all these items except explosives, Beardmores with guns, shell, and armour plate, I.C.I. with explosives and cartridge cases. For shell, apart from Vickers-Armstrongs and Beardmores there was the Projectile and Engineering Co. and a number of iron and steel firms who had some suitable plant for small quantity production. It did not take long to approach these few firms, though it was by no means easy for all the

[1] See Chapter I, p. 28.

firms to give precise replies. What was soon clear was that for most items in immediate demand, expansion of plant would be necessary to secure the output required even under the limited rearmament programme of 1936. The main exceptions to the general need for immediate expansion were small arms ammunition and small arms. For small arms ammunition, the capacity available in the two remaining firms, I.C.I. and Greenwood and Batley, and at the Royal Arsenal, Woolwich, was sufficient not merely for the rearmament programme but, up to the spring of 1939, for the war potential requirements. For small arms, some additional plant was necessary but no large scale factory expansion was needed until 1939.

In the expansion of capacity under the armament firms, the first process was to expand capacity at the existing factories, if necessary with government assistance for the provision of plant. The second process, was to provide new factories under the management of the armament firms. With both Vickers-Armstrongs and with Beardmores the first process continued until after the outbreak of war. With I.C.I. the scope for expansion of the existing factories for cartridge cases and for explosives was quickly exhausted; and by 1937 the necessity arose for the construction of new factories under agency agreements with I.C.I. for cartridge cases, explosives, propellants and for chemical defence stores. In the second half of 1939, when capacity for small arms ammunition had to be expanded I.C.I. undertook the construction of three agency factories for S.A.A. production, in addition to some expansion of their existing capacity at Witton. In consequence, between 1937 and the end of 1939 I.C.I. undertook the construction and management of no less than eighteen agency factories. This total in the course of the war increased to at least twenty-five factories. Expansion of the capacity under I.C.I. was preponderantly, indeed almost entirely, by agency factories.[1]

In 1939, B.S.A. also reached the stage at which any further major expansion justified the adoption of the agency system. In 1936, with no demand for rifle production, they had undertaken the production of Browning machine guns for the Air Ministry at the Small Heath factory. In 1938, when they undertook the production of the new Besa machine guns for the War Office, they had extended their factory capacity by making use of a factory building available in an adjacent town. But when in 1939 there were demands from the Air Ministry and the Admiralty for 20 mm. guns and from the War Office for rifles, new major factories under agency agreements were eventually arranged with B.S.A. by all three departments. It was not until November 1939 that the increased demands on Beardmores for gun and shell production made the provision of a separate factory necessary and thus

[1] An account of the agency factories under the War Office and the Ministry of Supply is given below at p. 154 ff.

justified the adoption of the agency system. In 1940, when Beardmores were asked to undertake an even larger expansion, a new major gun factory was constructed and managed by Beardmores under agency agreement.

In contrast, Vickers-Armstrongs, who had inherited the largest armament factory organisation in the United Kingdom, found it possible to undertake almost continuous expansion of capacity within their existing factory accommodation. For the most part there was little scope for the application of the agency system to this widespread and interlocked organisation of factories. In the very large expansion which was undertaken at Vickers up to 1939 and throughout the war, with considerable assistance from public funds, there was no extension under agency agreement. The factory territory which Vickers-Armstrongs inherited under the amalgamation of 1927 was very large, but there was one major armament factory which was not included. This was the Armstrong-Whitworth factory at Scotswood, where a large range of armament had previously been manufactured. In 1936 this was purchased by the War Office and the Admiralty and leased to Vickers-Armstrongs for a wide range of armament production. With the lease of this factory, Vickers-Armstrongs had available the very wide range of armament factories previously operated by Armstrong-Whitworth and Vickers. This included the armament factories on the Thames and the Tyne, at Barrow and at Openshaw. At all these factories, Vickers-Armstrongs began the process of re-equipment which was to enable them to undertake the same wide range of armament production which had been undertaken up to 1918 by Armstrong-Whitworth and Vickers. By 1939, the range of products, though not the quantity of output, had been substantially regained. The products, which now included tanks, ranged from fuzes, cartridge cases and shell, to the medium artillery and A.A. equipment for the Army and to the largest guns and mountings for the Navy.

Despite the long period of inactivity, the specialist armament firms responded readily to the demands made upon them by the production departments, in rearmament and in war. Indeed, all the firms were to show, that, whatever may have been the external estimate of their technical capacity in 1935, they were capable of undertaking the planning and establishment of a volume of production at least equal to that which they had undertaken at the height of war production in 1917. Several of the firms, in 1936, were amalgamations of several separate firms of 1917; the results achieved showed an output in the Second World War which was rarely less and often more than the total 1917 output of the firms they had absorbed. Indeed, in only two major sections of production was the combined peak output of the remaining firms substantially less than the output of the armament industry in 1917. The peak output of explosives and propellants from the industry was somewhat less than the output from the industry in 1917; and the peak output of S.A.A. from the two remaining specialist firms was only 60 per cent. of the output from the industry in 1917. In the production of guns the two remaining firms, Vickers-Armstrongs and Beardmores, achieved a peak output as great in quantity as that provided by all the armament firms in 1917, though not quite equal to the peak output of 1918. In the production of small arms, the supply from the two remaining firms—B.S.A. and Vickers-Armstrongs—was at the peak very much greater than the total peak output from all the armament firms between 1914 and 1918.

In most sections of production, I.C.I. and Vickers-Armstrongs not merely achieved a level of output not far short of that of the firms they had absorbed but, in addition, they undertook much greater production in newer fields of war production. The war-time activities of I.C.I. were manifold and in total were certainly no less than those of the predecessors of 1914–18. In some production the output of Vickers-Armstrongs exceeded that of 1918; for example, neither Vickers nor Armstrong-Whitworth were in effective production of tanks in 1918. Beardmores, no longer engaged on shipbuilding, were able to concentrate their efforts on armour plate and gun and carriage production; with a very large addition to their capacity under the agency system their output of guns was certainly no less than it was in 1918.

The B.S.A. Company was able to achieve an output far exceeding their armament production in 1918. This was the one leading armament firm which had retained its former identity in all the changes of the 1920's. Despite this, the technical resources of the firm for armament production were somewhat underestimated by the departments at several stages of rearmament; but by 1939, their services were in heavy demand by all three production departments, and by the middle of the war, B.S.A. had an output of rifles and machine guns and sub-machine guns far in excess of any previous output. In addition, they had the largest output of 20 mm. guns and were also undertaking the production of 2 pdr. carriages and the manufacture of barrels for several types of light guns and the production of 40 mm. ammunition. During the war there was a very large increase in the demand by all the Services for light weapons—machine guns, 20 mm. guns, 40 mm. and 2 pdr. guns, and B.S.A. played a major part in meeting many of these new requirements. At the peak of war production B.S.A. had more than sixty factories under their management, and an employment roll more than double that of 1918.

The formation of new companies to undertake the manufacture of armaments did not seem likely in the political and industrial climate after 1930. It was not a method of expansion that received any general encouragement, yet between 1936 and 1939, three important companies were formed to take a major part in armament production.

With one exception these companies were formed to manufacture a specific product and not to provide a general addition to the armament industry. Moreover, two of the companies remained subsidiaries of large industrial organisations. The first company—Nuffield Mechanisation Ltd. was formed in January 1937, to undertake rearmament work. It was a private company and a subsidiary of Morris Motors Ltd., who were already closely connected with War Office vehicle mechanisation through the activities of another subsidiary, Morris Commercial Cars Ltd. The immediate concern of the new company in 1937 was with tank development, but, in the same year, Nuffield Mechanisation agreed to undertake the manufacture of the new A.A. Gun—the Bofor. For both tanks and guns, Nuffield Mechanisation organised and managed highly specialised factories mainly in existing factory buildings. The only other major firm formed for the manufacture of finished armaments was the British Manufacturing and Research Co.—a company formed in 1938 to manufacture the Hispano 20 mm. gun and ammunition in the United Kingdom. New Crown Forgings—a subsidiary of Stewart and Lloyds was formed in 1938 for the manufacture of shell forgings, and was a major addition to the basic industry for armament manufacture[1].

The integration of iron and steel firms and the armament industry before 1914 has already been described. After 1918, the close integration was severed at several points and a new integration of iron and steel resources established, as in the English Steel Corporation and in the merger of the steel works of John Brown and of Thomas Firth. Whatever the new alignment, the metallurgical basis of armament production remained. Here, the decline was due not so much to the loss of firms or factories, but to the discarding of plant because of lack of orders for armament forgings and armour plate work. The Admiralty had made arrangements with several firms to retain plant for armour plate up to an agreed capacity but no similar arrangements were made for gun and shell forging plant. The plant available in 1936 was not even sufficient for rearmament requirements.

The manufacture of guns including the 20 mm. was dependent on the supply of gun forgings. It was not merely forging capacity that was required at the steel works but suitable plant for the subsequent process of heat treatment, and for most guns, for rough machining and boring. A fully equipped gun factory had forging facilities to provide the forgings required. This had been true of the gun factories of Vickers, Whitworth, Armstrong, and Beardmores, and of the Royal Arsenal gun factory. In 1936, however, Beardmores was the only firm of gun manufacturers who also manufactured gun forgings. In the R.O.F. organisation the great gun forge at Woolwich had been

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[1] See p. 154 below.

retained and in 1937 forging capacity was provided at the new R.O.F. at Nottingham, but capacity at these R.O.Fs was not sufficient to meet their own needs under the pressure of war requirements. The main part of gun forging capacity had therefore to be sought with the forgemasters, most of whom had undertaken this work before and had some suitable capacity available. Within the Vickers group, what had previously been the steel works of Vickers, and Cammell Laird at Sheffield and of Whitworth at Openshaw were now combined under the English Steel Corporation and were available to undertake the production of gun and mounting forgings, armour plate and a host of intermediate products required in armament manufacture. In periods of rapidly increasing demand, it had been usual for the specialist gun factories, including Woolwich, to rely on additional supplies of gun forgings from the leading forgemasters in the iron and steel industry. In war, it was to be expected that a large part of the requirement of gun forgings would have to be met by the work of the forgemasters.

Some expansion of capacity with assistance from public funds was necessary even in 1936. From 1939 onwards until 1942, there was a continuous succession of expansion schemes to meet the increasing demands for gun forgings, culminating in the large requirements for 2 pdr. and 6 pdr. forgings in 1942 and 1943. These schemes were with five leading forging firms most of whom had a long connection with armament requirements. The government expenditure on plant and buildings amounted to over £3 million and of this less than £½ million was for building work. In addition, a very large scheme for gun forging production was undertaken as an agency scheme under Beardmores in 1940. Including Beardmores and the English Steel Corporation, there were eight iron and steel manufacturers employed on gun forging work for guns of 40 mm. and over. In addition, a firm of oil mining engineers undertook the production of 25 pdr. gun barrel forgings. The only other gun forging capacity was at the R.O.F. gun factories at Woolwich and Nottingham. Both these factories had a larger output of gun forgings than some of the firms employed but by far the largest output came from four of the forging firms. Indeed, to a very large extent the supply of gun forgings came from many of the same factories and from the same firms, or their successors, from which they had come since 1900 and before.

In the First World War the supply of shell forgings had been dealt with in a very similar manner to gun forgings. The armament firms and the specialised national shell factories were usually equipped to produce shell forgings but a large part of the supply came from steel forging firms many of whom were unexperienced in shell manufacture. In 1939, as a result of developments between 1936 and 1939, the supply of shell forgings for War Office requirements was dealt with in a very different manner. In a later section[1] it will be shown that by 1937 plant for the large scale production of shell forgings had been developed; this enabled the supply of all types of shell in large demand to be provided from over forty large scale forgings plants erected in the United Kingdom between 1937 and 1941. Twenty-three of the plants were operated at factories under the control of New Crown Forgings or of the parent company, Stewart and Lloyds; five plants were operated at R.O.Fs and fourteen at factories managed by other firms. Most of the other firms operating the forging plants were iron and steel manufacturers or firms undertaking forging work. This new plant made possible the standardisation of shell forging production, specialised plants for shell forging production were established on a scale never achieved before. Industrially, it was a major redeployment of the iron and steel firms in relation to the armament industry. Smaller types of forging plant of much lower capacity were used throughout the war. In the rearmament period these were the main source of supply and later were used to supply types of shell forgings not required in very large quantities; but all except a small percentage of the war-time production of army shell came from the large scale plants. Most of these plants were installed adjacent to existing factories but some new factories were constructed. Thus it was possible and eminently economical to deal with the bulk of the shell forging supply in some 42 large scale plants installed at less than 40 factories.

(ii)

Agency Factories for Munitions Production

A very large part of the expansion of output from the armament industry was obtained without an increase in the factories and industrial plant owned by the armament firms and indeed without the use of working capital from the industry. This was possible because a large number of the new factories operated by the armament firms, and indeed by other firms, were agency factories. They were state factories, the property of the state and provided and operated at public expense but under the management of commercial firms. By the peak of war production the Ministry of Supply had over 170 agency factories, but of these sixty-six factories were for raw material production. Of the factories for the production of finished military requirements most of the larger factories and more than half of the total number were under the management of armament firms or other specialist firms. Thus for armament production, the agency system was used more to extend the use of the armament firms than to introduce outside firms to war production.

[1] Chapter XI, page 305.

In 1914, there was no clear policy regarding the ownership of major additions to munitions capacity. In the main, the armament firms were encouraged to undertake extensive expansion of their capacity and retain the ownership of the assets, even though considerable capital assistance was given from public funds. But eventually, the additional factory capacity required for most production far exceeded the range of expansion which the armament firms wished to retain, or indeed, for which they could provide management. The result was the development of a large number of National Factories, owned and directly financed by the government; some of these factories were managed by the armament firms, others were managed by firms outside the industry. This method of expansion was soon recognised as inevitable for the scale of production required for a major war. Moreover, the disposal of these factories after 1918 gave rise to few, if any, financial or legal difficulties of ownership.

In 1936, there was an immediate need for expansion by the construction of new factories, some of which would be under the control of firms, either in or outside the armament industry. In these circumstances the Treasury Inter-Services Committee agreed that on balance it was a definite advantage for the government to pay at the outset for the new factories and thus acquire immediate ownership and control.[1] The agency system, as it was generally called, could however be readily adopted only where the capacity provided was operated as a separate manufacturing unit. In the rearmament period, all the armament firms were able to accommodate some expansion without the necessity of new factory units; but with the exception of Vickers-Armstrongs, all the main firms reached the position where separate manufacturing units became a necessity. A similar process operated with some outside firms. Some of these firms could not accommodate the armament work within the existing factory and an agency scheme was arranged. But as one of the main reasons for employing outside firms was to use existing factory accommodation, the agency system was in the main only used with outside firms when specialised production needed large accommodation for specialised plant, for example gun cartridge case manufacture. By far the largest expenditure and the largest factories under agency schemes for munitions production were with the armament firms.

Under the War Office programme almost up to the outbreak of war the agency factories for chemical and explosives production were the only important groups of agency factories. Apart from the gauge making factory which had been approved in 1937 to supplement the supply of gauges for munitions production, there were only two engineering agency factories approved in the rearmament period up to January 1939. The first of these two factories approved in September 1937 was

[1] See W. Ashworth, *Contracts and Finance*, in this series (H.M.S.O. 1953), p. 217.

for the manufacture of gun cartridge cases under the management of I.C.I. and the second, approved a few months later, was for the manufacture of the new Bofors A.A. gun and mounting, under the management of Nuffield Mechanisations Ltd. It was not until August 1939 that an agency factory for small arms production was approved and this was under the Air Ministry not the War Office. It was also August 1939 before the construction of an agency factory for S.A.A. production was approved. By the end of the war the total number of engineering munitions agency factories under the Ministry of Supply was over fifty. This was a fairly large number but only in a few sectors were the agency factories fundamental and on a large scale.

The main stores, for which large scale specialised plant was necessary or highly advantageous were explosives, small arms ammunition, chemical stores, small arms, cartridge cases and ammunition filling. For all these stores agency factories were extensively used. For all explosives and chemical agency factories, construction and management were undertaken by firms from the specialist industry; a very large proportion were with I.C.I. For small arms ammunition, with one exception, all the firms were specialists in small arms ammunition manufacture. For small arms, all the major agency factories in all three production departments were under armament firms but the Admiralty had two agency factories for the production of 20 mm. guns with outside firms. For gun cartridge cases, the first agency factory was with I.C.I. but later factories were with firms outside the armament industry. The filling of ammunition remained for long a prerogative of the Royal Ordance Factories but the need for rapid provision of factory management led in 1940 to the adoption of the agency method for a number of filling factories, all under the management of non-specialist firms. In gun and carriage production, the existing factories of outside firms were widely used and there were few agency factories. In addition, the agency system was applied to a wide range of products ranging from diesel engines to hand tools, from the processing of seaweed to the manufacture of penicillin.

Agency factories were not merely owned by the state but they were usually financed entirely from public funds. Thus in addition to meeting the cost of construction and equipment, the Ministry provided an imprest account to meet the cost of operation and of wages and salaries. Orders were issued to the factory direct from the Ministry and the cost of providing the stores was the sum total of the operating costs. Financially, the position of the agency factories was very similar to that of R.O.Fs, but in other ways they were quite distinct. In particular all employed at the agency factories were employed by the agent; the conditions of employment, rates of pay and all other similar matters were in accordance with the usual commercial practice of the agent or otherwise decided by the agent. This was the most important difference and although most of the agency factories under the Ministry of Supply became known by the general title of Ministry of Supply agency factory, the conditions of employment remained under the control of the management. This was a very important difference but it only caused difficulty when an R.O.F. was made an agency factory. Then, the transfer from state to commercial employment was a matter of some concern for many of the employees. For the most part, however, commercial management and commercial conditions of employment were satisfactorily combined with state ownership and finance. Inevitably, the absence of any incentive to efficiency raised doubts. The Ministry it is true was able to exercise some control over capital expenditure, but the efficiency of operation of the factory depended very much on the commercial standards and efficiency of the management. In this, however, agency factories were very little different from other factories. For, effective competition had been largely eliminated from almost all munitions production.

In 1936, the main reason for laying down the agency system as a primary method of expansion was to ensure public ownership of major additions to capacity. Complete public ownership, it was seen, would avoid many difficulties about the eventual disposal of the assets and the contentious problems of redundancy and future use. The system had other advantages. Not merely was public ownership considered desirable but the principle of management on behalf of the government met the prevalent objections to increasing the factory territory of the private firms at public expense. It also facilitated the use of a wide range of firms, as it removed the difficulties of providing working capital. The progressive combination of state ownership with private management was in accord both with the spirit of the times and with the disposition of many commercial undertakings so far as the manufacture of arms was concerned. The agency system brought many advantages, not merely in the sphere of production but also in construction and planning. The planning and responsibility for the construction and equipment of agency factories were as a rule undertaken by the firm that was to manage the factory as a production unit. The only general exceptions to this rule were the agency factories for filling; responsibility for their construction rested with the Ministry of Supply and the Ministry of Works under very similar arrangements to those made for the Royal Filling factories. The sharing of the burden of planning and responsibility for construction and equipment with private firms proved a very great advantage.

In the pre-war period, most of the War Office agency factories, including chemical, explosive and propellent factories and a cartridge case factory, were under the Imperial Chemical Industries Ltd. The total cost of the factories under construction between 1936 and 1939 for which I.C.I. was responsible as managing agent, was not far short of the total for R.O.F. construction. As a result the building and planning sections of the I.C.I. were, like those of the R.O.F. organisation, fully extended throughout these years. Up to 1940, many of the agency factories were similar in size to the new R.O.Fs provided for the same type of production. In 1939, and later, the number of smaller agency factories tended to increase; in this period the agency system was frequently used merely to facilitate the employment of additional firms or to provide smaller additions to the total capacity available. The large agency factories were often easier to build than R.O.Fs of a similar size. Many of the agency factories were constructed on partly developed sites adjacent to or near the agent's own factory. Moreover, almost all agency factories were planned on strictly utilitarian lines with little regard to the possibility of being retained as a permanent peace-time factory. Thus some, though by no means all, agency factories were built more quickly than R.O.Fs of a similar type.

In the Ministry of Supply the main contact with agency factories was through the finance and production branches. Some of the production branches, depended on agency factories for a very large part of the total capacity. In the manufacture of explosives and small arms ammunition, for example the capacity was almost completely divided between the main agency firm—I.C.I.—and the R.O.Fs. For the greater part of the war the production branches for these sections of production were headed by a director drawn from the executive staff of I.C.I. and as we have seen the responsibility for this production at R.O.Fs was eventually transferred to this production branch. This meant that there was a very close integration between the control of the agency factories and the R.O.Fs and that the agent firm was in a unique position. This close integration was not however achieved in other production branches, where the agency factories, important though they might be, did not form so large a part of their capacity. Even so, the agency factories were fitted into the production programme without difficulty and often with exceptional advantage. What difficulties there were arose mainly from the exceptional legal and financial status of the factories as state owned factories under the management of a commercial firm. There were many liabilities and commitments, not specifically provided for in the agreement, which had to be referred to the owner of the factory—the Ministry of Supply. Some of the problems were financial questions but some raised wider issues which required reference to a general policy such as would be formulated by a common board of management but which under the existing arrangements could only be decided by a fairly wide consultation within the Ministry, ranging well beyond the confines of the production and finance branches.

In 1942, with over 170 agency factories in operation, some concern was expressed by senior officers in the Ministry of Supply about the effectiveness of the existing arrangements for the general control of so large an aggregate of publicly owned industrial capacity. For example, were special control arrangements necessary to ensure the economic and efficient management of these factories? The financial officers of the Ministry felt that more information should be available about the comparative costs of production and that a supervisory board should be established to deal with the general questions that arose. Such a board would consist primarily of representatives of interested production branches, the finance branches and of certain sections of the secretariat.

This concern although in principle correct, proved largely unnecessary. In the production for which agency factories were especially important—explosives and S.A.A.—the control of both agency and R.O.Fs was soon to come under the direct control of the Director General for this production. With such close integration it became possible to develop and maintain a very close check on comparative costs not merely of manufacture but also of management. For other production the same integration of capacity was not possible but as the process of costing developed in the second half of the war, the information available on the comparative costs at agency and other factories was sufficient to disclose any tendency to excessive costs. As was to be expected of specialised factory units, the agency factories were to be found mainly among lower cost factories. It was indeed a further merit of the agency system that with careful selection of the managing firm, the operation of a specialised manufacturing unit brought a high level of productive efficiency.

Ministry of Supply Agency Factories for Munitions Production

		Capital Cost		
	Number	*Buildings*	*Plant*	*Total*
		£m	£m	£m
Explosives and propellants	8	5,619	4,825	10,444
Explosives materials	11	2,731	4,959	7,691
Small arms ammunition	5	3,877	5,229	9,106
Small arms	3	341	1,054	1,395
Cartridge cases	10	1,500	3,850	5,350
Shell and fuzes	7	507	1,681	2,188
Signals and transport	5	511	488	999
Penicillin	3	606	1,340	1,946
Equipment and stores	2	14	62	76
Filling	6	13,754	2,113	15,867
Chemical defence	12	10,900	8,300	19,200

The first general application of the agency system by the War Office was for explosives and propellants. Indeed in the War Office programme almost up to the outbreak of war by far the greater number of agency factories were for chemical and explosives production. For explosives the policy was to share production more or less equally between agency factories under the main trade specialist firm I.C.I. and new R.O.F. factories. Capacity with I.C.I. for production of specifically military explosives had been concentrated at their Ardeer factory in Scotland. In the spring of 1936 the War Office decided to expand the capacity at Ardeer for cordite. The new factory proved to be the first War Office agency factory; it was adjacent to the existing factory and was operated under an agency agreement with I.C.I. The other pre-war agency factories for explosives were planned to duplicate I.C.I's ammonium nitrate factory at Billingham, which was particularly vulnerable to air attack. The original recommendation was for three factories to replace Billingham capacity for ammonia and two factories for ammonium nitrate. Between 1936 and the outbreak of war however only two agency factories for the production of ammonia were approved; for ammonium nitrate one agency factory was approved in addition to new plant for this chemical at the R.O.F. Pembrey. In the first few months of war two large agency factories were approved under I.C.I. for the manufacture of rifle and cannon cordite and a third factory on a small scale for the production of gunpowder. During 1940, several additions were made to existing factories but the agency factory programme for explosives, like the R.O.F. programme, was affected by the general policy of seeking capacity for explosives and propellants overseas. In consequence, no further agency factories for this production were planned in the United Kingdom until 1941. It was then the additional requirements for high explosives which made two further agency factories necessary—one for T.N.T. and one for ammonium nitrate. In September 1941 a small agency factory was approved for the manufacture of picric acid, an explosive which was in much more limited use than in the First World War. This was the last agency factory for explosives production and the only one not under I.C.I. management. The final cost of the eight factories exceeded £10 million and the total planned output was about 14,000 short tons a month; this was not much below the total of 17,000 short tons for the new R.O.Fs.

The production of essential raw materials was an integral part of specialised capacity for explosive and propellant production. A few of these materials were available as by-products but many of the raw materials had to be provided from specialised chemical factories. The immediate supply of many raw materials for military explosives was limited by the demand for essential industrial and agricultural requirements. In the expansion of capacity for many of the materials a good deal was achieved by the extension of existing plants and by the provision of more by-product plants. Thus the supply of Toluene, essential for the production of T.N.T. was obtained to a large extent by the provision of special distillation equipment at about twenty by-product plants. In 1941, additional requirements for ammonia were dealt with in this way and a substantial addition to supplies was obtained from by-product plants. These were partly held in reserve against damage to the large synthetic plants. For many raw materials large scale plants had to be provided and most of these were provided as agency factories under the management of a chemical firm.

The bulk of the demand for ammonia could only be met by expansion of capacity operating the synthetic process. The vulnerable position of Billingham led to the erection of two agency factories before the outbreak of war. In war, the demand for ammonia for agricultural fertilisers absorbed a large part of the production from the pre-war plants. Including two factories for the production of cotton waste, there were at least fourteen agency factories for the manufacture of intermediate products at a total capital cost of more than £8 million. Of the fourteen factories only five were under I.C.I. management; the others were constructed and managed by the chief and often the only manufacturer of the materials required. The agency system facilitated the expansion of supplies of explosive materials, particularly when the requirements for other purposes were especially onerous, but it was usually only resorted to when a direct addition to existing plant was not sufficient to meet the requirements.

In the not unrelated field of chemical warfare requirements, agency factories were used to provide the total capacity and several of these were also under I.C.I. management. The twelve factories constructed for the production, were approved between 1937 and 1942. Fortunately, their noxious products were never required, but the construction of these factories amounting to £10 million for building work alone was a major portion of the factory building programme. The total cost of nearly £20 million exceeded the total cost of the agency factories for explosives and propellants.

In the expansion of capacity for small arm ammunition production there was an almost equal division between agency factories and the Royal Ordnance Factories. Here again specialised factories were essential, the largest trade supplier was the I.C.I. and almost all the new agency factories were under I.C.I. management. For the other trade firm, Greenwood and Batley, it was found more convenient to deal with expansion without the use of the agency system. With I.C.I., in addition to some expansion of capacity at their Witton works, three agency factories under their management were approved in the last six months of 1939. The three agency factories under the I.C.I. were planned to provide a total capacity about equal to the total capacity of the two new R.S.A.A.Fs approved in 1939. In the meantime, the necessity of using available plant and factory accommodation to accelerate production had led in 1940 to the introduction of an outside firm—Crompton Parkinson—to manage a further agency scheme operated in requisitioned premises. This proved to be the last of the agency schemes and by the time all factories had been brought into operation the agency factories accounted for about a third of the peak output from new factories and rather more than a quarter of the output from all sources.

Quarterly Output of S.A.A. (complete rounds)[1]

Factories	*Number of factories*	*Total output (millions)*			
		1940	*1941*	*1942*	*1943*
Pre-war factories	3	95	135	150	122
New R.O.Fs	5	36	81	280	423
Agency factories[2]	4	31	65	280	252

The application of the agency system to S.A.A. production exemplifies the main characteristics. It could be used either to extend the production of an armament firm beyond the range of peace-time requirements or it could be used to introduce an outside firm to manage a large scale specialist factory.

The final development of agency factories for small arms weapons production did not result in so general a division of expansion between the Royal Ordnance Factories and agency factories. Yet in 1936 the position was very similar. There were two armament firms with a continuing interest in small arms manufacture—B.S.A. and Vickers-Armstrongs. These firms had retained some plant for possible future requirements and large demands were made on these firms in the rearmament period. An extensive rehabilitation and expansion of capacity had taken place before 1939, but it was not until then that agency factories for small arms manufacture became necessary. All extensions at Vickers-Armstrongs were made at existing factory premises and the agency system was not applied either by the Air Ministry, the Admiralty or the War Office, all of whom had requirements for Vickers' small arms. Up to 1939, B.S.A. had also been able to find factory accommodation for two new weapons, the Browning machine gun for the Air Ministry and the Besa tank machine guns for the War Office. In 1939 in response to urgent demands from all three Services for other weapons, B.S.A. undertook the operation of three

[1] The output includes all types and calibres from .30 in. to 15 mm. and is for the last quarter of each year.

[2] Including one new trade factory not under agency management.

agency factories, one for each production department. Two of the factories were for the 20 mm. gun production: a Hispano gun factory for the Air Ministry and an Oerlikon gun factory for the Admiralty.

It was indeed the requirement for the 20 mm. guns which made the wide application of the agency factory system to small arms necessary. A new firm, formed in 1938 specifically for the purpose of manufacturing the Hispano Suisa 20 mm. gun for the Air Ministry, was at the start largely financed by the foreign companies already interested in the manufacture of the gun in continental countries. When after the outbreak of war further expansion of capacity was necessary in addition to that provided under B.S.A. and in the R.O.Fs, the British Manufacturing and Research Co., now reformed and under British control, were asked to construct and operate a second factory on an agency basis. The second agency factory under B.S.A., for the Admiralty 20 mm. weapon, the Oerlikon, was by far the largest agency factory provided for the Admiralty. Some twelve months later, when the Admiralty decided that much larger use must be made of subcontracting and of general engineering firms for Oerlikon gun production, two more agency factories on a much smaller scale were approved. These were two of the very few agency factories for small arms not managed by armament firms. All these Admiralty agency factories were established in existing factory buildings with a minimum of new building work. The third agency factory scheme undertaken by the B.S.A. Company in 1939 was for the production of rifles under the Ministry of Supply. Parallel production by B.S.A. and R.S.A.F. Enfield in emergency was of long standing; in October 1939 with both B.S.A. and Enfield almost fully committed to other weapons, a scheme of more or less parallel expansion was approved, although the output planned for the two R.O.Fs was twice that of the B.S.A. agency factory.

The only other sector of armament production for which the most of the capacity was either in R.O.Fs or in agency factories, was ammunition filling. But, as we have seen, it was only when the R.O.F. organisation for filling work had become very extended that recourse was made to the agency system. The primary reason for this decision was not the difficulty of providing technical management but the difficulties of finding staff and management for general factory administration. The large Royal Filling factories had presented these problems on a very wide scale; with employment between 20,000 and 30,000, there were very few firms in the United Kingdom with experience of management of such large factory units. Fortunately, it was decided that the agency factories should be smaller units with between 1,500 and 10,000 labour force. Even so, the administrative organisation was considerable and there were immediate advantages in obtaining commercial management by firms able to supply all ranks of managerial and executive staff. That commercial and industrial administration and not technical experience was the primary factor is clear from type of firms employed as agents; these included companies well known for products far removed from munitions production—J. Lyons & Co. Ltd., Imperial Tobacco Co. Ltd., Courtaulds Ltd., The Co-operative Wholesale Society, Metal Closures Ltd. and Lever Bros. They were all firms who could be expected to spare managerial and executive staff from less vital work. The agency filling factories had many advantages over the Royal Filling factories: the factories were all on a very much smaller scale—the actual range of employment was from 1,000 to 5,000. They were employed on a very limited range of work—some on only one type of store—for which technical methods had been established in the Royal Filling factories. The agents were not responsible for the construction and equipment of the factory and were free to apply themselves to a study of production problems before the construction was complete. With these immediate advantages, to which were added the asset of a management team already used to working together, it was hardly surprising that it was possible at these agency factories to reach a high level of efficiency within a very short period.

In the expansion of gun production capacity although there was a very extensive provision of new R.O.Fs there were very few agency factories. As will be seen, the main reason for this was the extensive employment of outside firms. There were two firms with gun factories available in 1936—Vickers-Armstrongs and Beardmores—and there was much scope for re-equipment and extension of their factory accommodation. In the large scale expansion of guns and carriage capacity under Vickers-Armstrongs no use was made of the agency system but in 1939 an agency factory scheme was adopted for Beardmores and a second scheme with them in 1940. In this way the agency factory system was used to extend the action of a specialised firm with very limited factory accommodation. Indeed, both the agency schemes with Beardmores were of immense importance not merely for the final manufacture of guns but also for the manufacture of gun barrels both as forgings and as finished gun barrels. The second scheme on a very large scale at a total cost of over £4 million was for a complete gun factory capable of undertaking all processes from steel melting and forging to final machining and assembly of complete guns of medium and heavy types. In August 1941, Beardmores received an unexpected addition to their agency factories when the Minister of Supply decided to transfer the R.O.F. at Dalmuir to agency management under Beardmores. It was long before that the first agency gun factory had been approved; this was in 1937 and with Nuffield Mechanisation for the large scale production of a new A.A. equipment—the Bofor gun and mounting. In this scheme the technical resources of a large undertaking were brought at a very early stage of rearmament into the manufacture of a very highly specialised equipment. So specialised and novel was this work that the final manufacture of this gun, both in the rearmament period and in war production, was confined to highly specialised factories—the Nottingham R.O.F. and the Nuffield Mechanisation agency factories.

These three factories with the addition of a dispersal factory for Nuffield Mechanisation were the only agency factories for gun production. All these agency schemes were of very great importance and established highly specialised gun producton on a very large scale. Even so, their output of complete guns was numerically only about 10 per cent. of the total output of guns and their capacity was very much less than was provided in the new R.O.Fs for gun production. The share of agency factories in the numerical output of gun mountings and carriages was even less. The Nuffield Mechanisation agency factory for Bofor guns, undertook the production of mountings for the guns and a much smaller number of mobile platforms. The only other agency factory was approved in June 1939; this was under the management of G. and J. Weir and was for the final assembly of 25 pdr. gun carriages manufactured by a group of firms. From this factory was to come a third of the output of the 25 pdr. gun carriages. But the total output of these two agency factories was only a small part of the total output of gun carriages from all firms and R.O.Fs.

Although there were several agency schemes for shell and fuze production, most of them were on a relatively small scale and the total output of shell from agency factories was a very small fraction of the total output of shell. The same was true of the two agency factories for the production of fuzes. For the most part these schemes were adopted when the firm selected had no suitable factory accommodation available. In contrast, several major agency schemes were arranged for cartridge case production. One of the first of the War Office agency schemes in 1937 was for a large cartridge case factory under I.C.I. After the outbreak of war ten agency factories for cartridge cases were approved. Of these factories seven were for the manufacture of cases, the other three were to roll the metal and prepare the blanks from which the cases are formed. The Admiralty shared in one of these agency schemes but the largest Admiralty scheme for cartridge case production including a rolling mill for the metal strip was on a rental basis. The cartridge case factories were among the costliest of the engineering munitions factories both in building and plant. The range in cost for the factories manufacturing cartridge cases was, for building, from £42,000 to £340,000 and for plant from £350,000 to £780,000. The cost of each of the three large schemes was about £1 million and for the remainder the total cost ranged from £350,000 to £590,000.

Despite the large provision of agency factories for cartridge cases their peak output was exceeded by the R.O.F. output and also by the several outside firms operating government plant in their own factories.

The application of the agency system in the main sectors of Ministry of Supply production for military requirements has now been described. In the remaining sectors of final manufacture there were only about a dozen agency factories. These schemes ranged from the production of searchlight carbons, to internal combustion engines for landing craft, and to penicillin.[1] These schemes were vital to military requirements but for the most part the agency factories did not amount to a major development in the supply of a military requirement. The penicillin factories were an exception. Agency factories were often used to facilitate the introduction of a new weapon of exacting manufacture and in 1943, the last major use of agency factories in the Ministry of Supply was to make possible the general supply of this new product for the medical services. With only a small output of penicillin available from laboratory production, from pilot plants and small factories equipped by firms of manufacturing chemists, the approval of three major factories in 1943 and 1944 on an agency basis made possible the rapid development of large scale capacity for penicillin production.

(iii)

The Role of Outside Firms

The third method of expansion proposed by the Weir Committee in 1936 was the introduction into armament production of a number of engineering firms.[2] The introduction of outside firms which started in 1936 continued right up to the last few months of the war. The introduction of a wide range of firms in the second half of the war was mainly for new stores and equipment somewhat outside the main line of weapon production; by then the general use of thousands of outside firms on war production had become automatic. The introduction of firms for more specialised armament production in the early days needed a much more careful process of selection and proceeded much more slowly. As early as 1937, a number of firms were introduced for the conversion of field guns but the general invasion of gun production by outside firms did not come until after the outbreak of war. With

[1] There were no agency factories for tank production but in the agency schemes for iron and steel production, there were several for castings and other products primarily to meet the needs of tank production. These were agency factories for raw materials production and are outside the scope of this volume. The major use of the agency system in aircraft production is dealt with in Chapters VI, VII and VIII.

[2] See Chapter I, p. 23

tanks, progress in the employment of outside firms had proceeded much further by the outbreak of war. Some firms were introduced for light tanks in 1937 and other firms in 1939 for heavier tanks. There followed a rapid introduction of new firms as each new type of tank was ready for production. In shell machining, where the employment of outside firms was the essential basis of expansion, about 40 firms were introduced before the outbreak of war but the number was to be increased to more than 300 in the course of the war.

For most stores, the size of the rearmament requirements up to the spring of 1939 limited the number of firms that could be employed even though the total requirement was divided into as many separate orders as was practicable. For ammunition production the number of firms would have been fewer had not additional requirements been approved to provide educational orders for the firms. More could have been done in several sections of production had more orders been available. But the scope for general employment of outside firms was also limited by the need to maintain normal industrial output and exports. Many of the firms that were introduced before 1939 were firms who were not sharing in the general improvement in industrial activity—notably engineering firms largely dependent on the textile industry. Despite all these limitations, the work that was done before the outbreak of war to initiate outside firms into the production of armaments, was of first importance in laying the foundations of the much larger shadow industry that was to be developed in war.

By the outbreak of war much valuable experience had been acquired in the selection and equipment of outside firms for most of the main sections of production. The capacity of several thousands of firms had been investigated and, as a result, many firms had been selected for suitable stores. In addition, an inventory had been prepared of the additional plant required at many firms. This pre-war allocation of firms to suitable production prevented a good deal of possible controversy. For some stores, notably shell and other ammunition components, a fairly standardised machine unit had been developed by 1939 and arrangements had been made for the direct purchase of machines for these units. As a result, a large number of firms could be rapidly introduced and equipped within a few months of the outbreak of war. In addition, for most stores process manuals had been compiled to guide the uninitiated. Thus by September 1939, the investigations and preparations undertaken in the rearmament period made it possible for a large number of firms to be introduced to a wide range of armament production.

Calculations of deficiencies both for rearmament and even more for war, warranted the introduction of outside firms. As war approached other considerations were even more important. No arbitrary restriction was imposed on the provision of specialised factories either under state or under commercial management but there were many insuperable limitations. In particular, the resources for the construction and equipment of new factories were limited, but outside firms had factories and often some suitable plant available. The economy was not merely a saving of resources but in the balance of advantage; employment of outside firms made it possible to use a large part of the firm's existing resources even though a provision of some new plant might be necessary. No less important were the managerial, administrative, technical and works services which were available and already integrated in the firms' factories. Very often the advantages available in this way offset the effects of a more limited degree of productive efficiency. Even so, much could be done, by the subdivision of processes, to offset the possible lower manufacturing efficiency. Indeed differences in production costs between outside and specialist firms were often reduced to those arising from differing size of production units. Except in shell production where specialised production units of optimum size were installed in the factories of the outside firms, some form of group administration was adopted for all the major products manufactured by outside firms. Within the group organisations it was possible, by division and subdivision of processes, to secure many of the advantages of large scale production and also a higher general level of technical knowledge on specialised processes than was readily available in many of the members of the group.

The careful selection of firms made it possible to secure valuable technical knowledge and equipment. For all manufacture, good and efficient management was important; but for particularly difficult manufacturing processes, special efforts were made to seek out firms that could contribute valuable knowledge and plant for particular kinds of armament work. For example, the manufacture of oil drilling plant had valuable affinities with medium gun barrel manufacture and stone drilling plant with lighter gun production. This matching of processes was only possible; to a limited extent, but it was generally possible, particularly in gun manufacture, to select firms whose normal production required a high degree of accuracy in mechanical parts and assemblies. With the reduction in civilian production, a large number of highly skilled firms normally employed on the manufacture of specialised manufacturing machinery and equipment of many kinds were largely freed from the commercial demand for these products. The same was true to a somewhat less extent of a large part of the light engineering industry whose normal products were mainly consumers' goods, for example, cycles and sewing machines. The technical knowledge, skill and plant of these firms were particularly valuable in the manufacture of many light ammunition components.

As a result of the matching of processes, the subdivision of manufacture, and for some production, the provision of specialised manufacturing units of optimum size, a very high level of efficiency was achieved despite the employment of a very wide range of firms. Inevitably, there were differences in the efficiency achieved by firms with varying resources of plant and experience. The production departments however chose their main contractors very carefully and it was mainly in the sphere of subcontracting that very wide variations in efficiency, were found. Here, close matching of process was not often possible nor were supplies of specialised plant usually available. A very wide variation of costs for the same kind of work had therefore often to be accepted; this was particularly true of much of the machining work for tank production. These difficulties mark the margin which was inevitably reached in the extensive employment of engineering firms for armament production.

With the employment of such a wide range of firms, it was not to be expected that production could be as economical as in fully specialised armament factories. It would however be hazardous to suggest that this assumption was not disproved by some firms and for some products. Even so, despite the high general level of efficiency achieved among main contractors by group administration and by standardisation of production units, production costs of outside firms over the whole field of ammunition production were undoubtedly higher than could have been achieved in large scale specialised factories. But munitions at somewhat higher cost and lower efficiency were better than no munitions. Moreover, the use of these firms led to very large and important savings in capital costs and in the demand for capital equipment. The saving in new capital resources was most definite in factory building. The amount of new building or indeed extension or adaptations required for outside firms for most stores was comparatively negligible. It was indeed unusual for a new factory building to be necessary. For the most part, the existing factory buildings were used and with the factory, the works services and much general equipment. The availability of suitable plant varied for different products and between different firms. For no major armament was it possible to avoid the provision of some plant. For many types of shell and cartridge case production, the economy and efficiency of production in standardized specialised units generally justified the provision of complete plant units but these were almost invariably erected in existing factories. Apart from ammunition components it was not usually necessary to provide a complete unit of plant. But in the main, although wherever possible firms' existing machine tools were used, use of different processes led to a very large total provision of new plant for the outside firms.

Labour employed provides the best general indication of the extent of the work of outside firms in armament production. This can be given approximately for Ministry of Supply production. In December 1942 the total labour force in Ministry of Supply production classified as operatives was about 1½ million.[1] Of this total about half a million were employed on the production of commercial products or near commercial products, e.g. motor transport, engines and signal equipment, machine tools, ball bearings and general equipment. The total employed on specialised armament production was about 1 million. Of this total, about 240,000 operatives were employed in R.O.Fs and less than 200,000 in armament firms: more than 530,000 were employed in outside firms. Thus the employment of outside firms in specialised armament production under the Ministry of Supply programme alone substantially exceeded the combined total employment at R.O.Fs and armament firms. If labour employed at the outside firms on similar armament production for the Admiralty and M.A.P. were included, the total would reach at least three times the R.O.F. employment and about four times the employment under the armament firms. If the comparison is limited to the engineering factories—engineering R.O.Fs, armament firms and outside firms—the predominance of the outside firms is far greater: on this basis the employment in the outside firms was more than three times the combined total employment at the R.O.Fs and the armament firms.

GUNS AND AMMUNITION

In many ways the extensive employment of outside firms on gun production was the most significant development. Gun manufacture was one of the most exacting and specialised in munitions production; a few carefully selected firms had been employed on the work in the First World War, mostly under the direct tutelage of the armament firms, but even in 1917, the bulk of the supply of guns came from the specialised factories of the armament firms and Woolwich. In the Second World War, the position was very different; the output of guns coming from outside firms amounted to at least a quarter of the very much larger total output of guns. In fact, in quantity, the output of outside firms substantially exceeded the total output of guns from all sources in the First World War. It is true, that only in the production of one type of gun was the production of outside firms greater than the output of the R.O.Fs; but except for two types of guns the supplies from outside firms were greater than the supplies from the armament firms and their total output was substantially greater than the output from the armament firms, including Nuffield Mechanisation. In 1943 seventeen firms were employed on the final assembly of guns and a much larger number of firms were undertaking the intermediate processes of gun manufacture. The entry of outside firms into the gun programme began in 1937 when several firms were invited to take part in the conversion of the 18 pdr. guns to the 25 pdr. specification. In 1937, to

[1] This excludes employment on intermediate products.

supplement the resources of Woolwich and Vickers-Armstrongs (Elswick) for this work, two groups were formed, a Lancashire group under Metropolitan Vickers and a Scottish group including Beardmores. Later, the groups were enlarged and formed into three groups. These groups formed the basis of the three groups which in 1941 undertook production of new 25 pdr. guns and in 1942 were brought into the production of the 17 pdr. gun.

Other outside firms were initially concerned with final manufacture of either the 2 pdr. or 6 pdr. and subsequently the 3in. Tank Howitzer and 95 mm. guns. In all, on the 2 pdr. seven outside firms undertook responsibility for the final assembly and partial manufacture of the guns under various arrangements for free issue of components. The first of the firms was introduced in April 1939 but the orders were not placed until September and not until the end of 1940 had all the seven firms received orders for the gun. In 1940, capacity had also to be found for the 3in. Tank Howitzer. The planning of this capacity was remarkable in that all the final manufacturers were 'outside' firms. Woolwich was the only R.O.F. involved and only for pilot production. These firms had to be found at the same time as capacity was being found for the 2 pdr. and different firms had to be employed. Production began in 1941 but the demand began to decline in 1942 and the firms were available for other gun work. Capacity for the 6 pdr. gun was then under development and three of the firms went into 6 pdr. production and one into 2 pdr. production. By this time, 6 pdr. capacity had been substantially developed making use of five R.O.Fs, two armament firms, and three outside firms. One of these firms was already on the final manufacture of 2 pdr. but the other two were engaged on carriage production. This was the last extensive organisation of outside firms for gun production. The only other gun for which they undertook final assembly was the 95 mm. gun Howitzer and for this there were only two firms on the final assembly work but they were responsible for over 45 per cent. of the output. These two firms were drawn from the 6 pdr. group and had previously been on the 3in. Howitzer.

The mere counting of the firms who were responsible for completion and final assembly of the guns, gives no indication of the number of firms engaged in the manufacture of the major sections of the guns. Subdivision of manufacture was an essential basis for the manufacture of guns by non-specialist firms. Some firms were responsible for the barrel, others for the breech mechanism and others for the breech ring; quite often other firms undertook the final assembly. Thus, for every firm completing the guns, there were at least two or three who had shared in the major process of manufacture. Some firms performed one function on one type of gun and another on another type. The total number of outside firms engaged in gun production was thus several times the number of firms making the final delivery of the complete gun. For example, for the 25 pdr. with only three firms making final delivery, there were in addition nine firms on main assemblies and at least six further firms when the muzzle brake was added to the design. For the 3.7 gun, although all deliveries came from R.O.Fs and armament firms, there were several outside firms employed on spare barrel production. For the 17 pdr., with R.O.Fs supplying some barrels to outside firms, there were three firms making final delivery with three main supporting firms and in addition several other outside firms on spare barrels. For all types of guns made by outside firms, the R.O.Fs and the armament firms supplied some of the barrels required but also for every type some came from outside firms. For the 2 pdr. and 6 pdr., at least nine outside firms were undertaking the manufacture of barrels.

Many of the seventeen firms undertaking final assembly of the guns also undertook major assemblies for the same or other types of guns; but many supporting firms did not undertake final assembly on any type. The total number of outside firms on major assembly work including the seventeen making final delivery of guns was about forty. Of these, no less than 24 firms were machinery manufacturers. Prominent among them were manufacturers of textile machinery, sugar refinery machinery, oil mining, printing machinery, colliery machinery and ships machinery. In the full list of forty firms, there were also three motor vehicle manufacturers, two railway workshops, a heavy electrical engineering firm and a paper manufacturer. With very few exceptions none of the firms were very large; most of them in 1936 were employing less than 500. Almost all of them had a definite degree of specialisation requiring accuracy in manufacture of mechanical equipment but only a few had experience in the long boring so essential to the manufacture of the larger gun barrels. A list of the normal production of the firms with a total delivery of over a thousand guns indicates the wide range of firms but also in some measure the high degree of specialisation in their normal production.

Engineers and millwrights
Sugar machinery
Wrapping machinery
Mechanical engineers
Ships machinery
Hydraulic and fire fighting equipment
Printing machinery
Oil mining machinery
Electrical turbine plant
Colliery engineers
Colliery owners and engineers
Sugar and laundry machinery

In the production of mortars—a much simpler production problem which was within the capacity of most general engineering firms—it was possible to make use of a rather wider range of firms. By careful subdivision, all the manufacturing processes could be undertaken on existing engineering equipment and no additional manufacturing plant was provided. Apart from prototypes produced at R.S.A.F. Enfield, the total war-time production of over 44,000 of the 2in. mortars came from twelve outside firms. Neither the R.O.Fs nor the armament firms came into the production and only two or three of the firms were employed on other gun production. Manufacturers of textile and other machinery and of cables were prominent. For the 3 in. and 4.2 in. mortars, armament firms and R.O.Fs undertook some production but by far the greater number came from over twenty outside firms. Several of these were also employed in other gun work but the range of firms employed was somewhat wider.

The full scope of the contribution of the outside firms to gun production is not easily determined. In total number of guns delivered their output excluding mortars was rather more than the total number of guns produced by the armament firms including Nuffield Mechanisation. Even taking into account the supply of some barrels from R.O.Fs, and armament firms and the absence of heavy guns and 4.5 and 3.7 guns from the work of the outside firms, the actual volume of output may have been in favour of the outside firms. In order to provide capacity to give an output equal to that of the outside firms, it would have been necessary to provide five factories with capacity equivalent to that of an R.O.F. built and equipped at a cost of over £3 million of which over £800,000 was for the building work and factory services, and in addition, the same multiple of any manufacturing done for this R.O.F. by outside firms. The manufacture of guns in the outside firms was not secured without considerable government expenditure on manufacturing plant and equipment, and some building work. The heaviest expenditure was incurred for barrel production for which specialised plant was essential but most of the firms required some additional plant for other components and sub-assemblies. In total, on army gun production, excluding mortars the total government expenditure on plant and buildings was about £7 million, the greater part of which was for plant.

The capacity developed for gun carriage and mounting production presents an even more striking picture of the employment of outside firms. Output of carriages and mountings from these firms greatly exceeded the total supply from the armament firms and the R.O.Fs. In pre-war planning up to 1939, gun and carriage production was matched for some guns in the same factory. This was true for some production at Nottingham R.O.F., at Nuffield Mechanisation and at Vickers but not at Beardmores. In total, however, there was a deficiency of mountings and carriages and it was arranged as early as 1937 that a considerable supply should be obtained from outside firms. In the spring of 1939 the expansion of the medium gun programme led to the introduction of several more outside firms. Henceforth, the greater part of the increase in gun capacity was matched with capacity for mounting and carriage production at outside firms. For all types of mounting and carriage their production was substantial and for at least five types the deliveries from outside firms exceeded, and for most of these greatly exceeded, the combined output of R.O.Fs and armament firms.

For one type, sixteen firms were employed on final assembly; for most types, the number of firms on final assembly was between four and eight. In all, there were forty-one outside firms undertaking the final assembly of gun carriages and of these only four were also employed on the final assembly of guns. At least ten more of the firms were employed on major assemblies for gun work. In the normal industrial work of the firms, manufacturing machinery was again prominent and accounted for fourteen firms, with textile and printing machinery leading. Vehicle manufacturers were much more prominent than for the final assembly of guns; most of these firms were however brought into carriage production in the middle of the war and for the production of the lighter gun carriages. Nineteen outside firms manufactured more than a thousand carriages each; their normal production covered a wide range of mechanical and electrical engineering.

Manufacturing machinery
Ships machinery and pumps
Paper manufacturers
Structural engineer and hydraulic machinery
Flour mill engineers
Boilermakers and power plants
Gas and internal combustion engines
Precision and automobile engineers
Biscuit machinery and mechanical stokers
Heavy electrical engineers
Electrical manufacturers
Structural engineering and vehicle components
Railway rolling stock equipment
Railway and colliery engineers
Colliery and structural engineers
Printing press manufacturers
Weighing and balance equipment
Electrical manufacturers
Textile machinery

The products of the other firms indicate an even wider range.

Pumps and iron castings
Textile machinery
Motor cars (3 firms)
Electrical vehicles
Springs and hinges
Agricultural machinery
Boilers and power plants
Printing machinery (2 firms)
Electrical switch gear
Railway workshops (2)

The greater subdivision of the manufacture led to the introduction of a large number of supporting firms and many of the forty-one main firms undertook component manufacture for other types. In all, over one hundred firms were employed on major components and assemblies and over three hundred firms on the manufacture of smaller components and spare parts of all kinds. Many of the supporting firms were mechanical engineering firms and many of them were also employed on gun manufacture. The three hundred firms employed on spares production included a large number of small general engineering firms.

In the production of gun carriages and mountings, the output of outside firms was almost three times that of armament firms including Nuffield Mechanisations and B.S.A., and considerably in excess of the combined output of R.O.Fs and armament firms. In addition the outside firms supplied components to the armament firms and to a lesser extent to the R.O.Fs. Even for the heaviest carriages and mountings the output of the outside firms was far in excess of the output from other factories. Moreover, the number of manhours required for the manufacture of gun carriages was usually about 2½ to 3 times the number required for the manufacture of the corresponding gun. In consequence, measured by labour required, the capacity developed in outside firms for carriage production was about four times the capacity at outside firms for gun manufacture. Again, measured in average manhours required for output, the capacity developed in outside firms for carriage and mounting production alone exceeded the capacity, measured in the same way, in the armament firms for both gun and carriage production. The total employment in the outside firms including the supporting firms exceeded the total employed at the R.O.Fs for the manufacture of carriages, mountings and complete guns. This was undoubtedly one of the largest developments of munitions manufacturing capacity in outside firms.

Even so the provision of plant and buildings for this capacity at outside firms was a good deal less than for guns. The total expenditure for plant and buildings was a little over £4½ millions, of which less than £400,000 was for building work. The main reason for the lower expenditure was the large amount of the work that could be done efficiently on general purpose plant already available at the firms' factories. With the larger machine capacity and the larger labour force required the advantages of securing productive units together with management was in total even greater for carriages than for guns. Moreover, it was possible to employ a much larger number of medium sized firms without serious loss of productive economy. Indeed, it was possible to subdivide the production much more extensively and thereby achieve the advantages of employing each firm on a very limited number of components. In plant requirements and in possible subdivision of manufacture, carriages and mountings proved highly suitable for manufacture by the extensive employment of outside firms.

Even for small arms manufacture, which continued to be largely undertaken in specialised armament factories, there was scope for the introduction of outside firms. Indeed, engineering firms had always been important as suppliers of components to some of the small arms factories. In 1940, a number of firms up to then employed on Bren gun components as subcontractors for R.S.A.F. Enfield, were formed into a production group to manufacture the Bren machine gun complete. This group of firms included typesetting machinery manufacturers, pneumatic drill, motor car, cycle, textile machinery, pump and office machinery manufacturers. In 1943 the group supplied over a third of the peak output of Bren guns and was the only source of supply apart from R.S.A.F. Enfield. In order to introduce a much wider range of firms into small arms production and also to greatly reduce labour cost, it was necessary to design new weapons. This was done at Enfield in the designs for the Sten carbine and in the 20 mm. Polsten. As a result, the production of the Polsten started in 1942 with two main firms—pneumatic drill and pump specialists—supported by twenty other firms. In all, at least thirty outside firms were employed on the Polsten and not until 1943 were R.O.Fs brought into this production. The demand for the Sten was so urgent and so large that R.O.Fs were brought into the production from the start. Even so two main firms—a toy and cycle manufacturer and a sewing machine firm—supported by a very large number of other firms had a total output very little less than the output from the R.O.Fs. In general, the economy of large scale manufacture for small arms production limited the scope of outside firms, except when they were provided with specialised plant or when they could assist in the supply of components. The construction of one new rifle R.O.F. was based on the supply of components from outside firms and all specialised factories obtained some components in this way. In volume, the supply of components may well have been greater than the work of outside firms on the final manufacture and assembly of small arms. But it was the final manufacture by outside firms that relieved the production programme of the burden of the construction of additional specialised factories; it also proved that some types of small arms could be economically manufactured outside the specialised factories.

By far the largest number of outside firms was employed in ammunition component production—empty shell, cartridge cases, fuzes and other components. From the start of rearmament, and even before, it had been decided that the war requirements for shell components would have to be met almost entirely by the employment of firms outside the armament industry. The construction of new factory buildings to accommodate shell machining plant would have entailed a very heavy demand on building resources. It was decided as early as 1936, not merely to develop special purpose machines for the machining of the most important types of shell but also to work out a suitable battery of plant for installation in the factories of firms with general engineering experience. For early rearmament planning existing plant had to be balanced by specialised plant but at the same time, technical work was pressed on to secure the advantage of completely specialised units.

Before the outbreak of war completely specialised units were in operation in the factories of some outside firms. By the spring of 1939 development of plant for a full range of shell was substantially complete; much plant had been ordered and delivered and several firms

Output of Machined Shell Empties

	War Output (thousands)	*Peak Quarterly Output (thousands)*	*No. of firms 1943*	*No. of firms 1939*	*R.O.F. % of Total Output*
25 pdr. H.E.	54,000	4,800	88	14	19
3·7 A.A.	12,000	1,200	18	11	12
6 pdr.	5,589	1,044	25	1	1
5·5 in. Howitzer	6,800	700	24	—	×
4·5 in. A.A.	4,121	418	29	10	—
95 mm.	3,184	700	17	—	19
6 in. Howitzer	2,405	369	23	4	×
3 in. Howitzer	2,220	624	19	1	—
17 pdr.	1,950	380	11	—	23
18 pdr.	1,950	445	22	—	3
4·5 in. Howitzer	1,200	344	19	—	1·5

× — less than 1%

were operating the plant in their own factories. The same method could be extended to a very large number of firms and this was the basis of war-time expansion of capacity. Some machining units were installed adjacent to a few of the large forging plants while others were installed in the R.O.Fs undertaking shell production, but by far the greatest part of the total output of shell was machined by over 200 engineering firms operating shell machining units in their own factories.

Many of the firms employed on 25 pdr. and 3.7 A.A. shell, achieved peak outputs as large as the outputs of the R.O.Fs and the forging factories. Firms with the larger outputs were drawn from a fairly wide range of manufacture with textile machinery manufacture the most prominent.

Textile machinery
Colliery engineers
Iron and steel
Glass manufacture
Metal windows
Cables
Railway rolling stock
Fuel appliances

For smaller calibres of shell, mainly 2 pdr. and 40 mm., it was possible to use very different production methods; standard machine tools, automatic lathes and also capstan lathes were specially equipped giving high rate of production. Much of this plant was available in light engineering firms such as cycle and electrical component manufacturers. This brought into ammunition production many firms not used for the heavier shell; but the largest sphere in ammunition production for light engineering firms was for fuze and 20 mm. ammunition components.

In the First World War it had proved exceedingly difficult to introduce outside firms for any types of fuze. In the rearmament period however methods of manufacture had been carefully developed and the basic unit of machine tools determined. For production in quantity, the main machines required were light automatic screw machines and capstan lathes; between the wars there had been a very considerable increase in the installation of these machines in light engineering factories, especially for cycle, motor car engine, and light electrical manufacture. The position was thus greatly improved and there were now many firms with the experience and machines suitable for this type of work. In total, a very large number of machine tools had to be provided at public expense but much use was made of existing installations. The total number of firms employed was over 100 but many firms were employed on the production of several types of fuzes and for many types over 20 firms were employed. The main firms were all light engineering firms who made use of automatic and capstan lathes in the manufacture of their normal products. These covered a wide range from fountain pens to electrical equipment and motor vehicles.

Cycles
Motors
Telephones
Vacuum cleaners
Scales and balances
Motorcar engines
Cycle chains
Electric lights
Electrical equipment
Toys
Gaslighter equipment
Fountain pens
Gramophones
Cameras
Electric razors
Wringing machines
Clocks
Duplicating machinery

The introduction of 20 mm. shell for all services, presented a new production task which affected the planning of S.A.A. and gun ammunition production.[1] Fortunately, although early planning had relied on the use of specialised factories, a large part of this new requirement was met by the use of outside firms. From 1940 onwards, an increasing proportion of the requirement was met in this way although it was only for shell that the output from outside firms was larger and very definitely larger than the output from specialist factories.

Planned Monthly Output (millions)

20 mm. cartridge cases	*1941*	*1942*	*1943*	*1944*
R.O.F.	2·5	4·4	8·0	9·2
S.A.A. trade firms	2·6	2·6	5·2	6·2
Outside firms	1·3	5·0	8·0	10·2
20 mm. shell				
R.O.F.	1·1	2·4	2·1	12·1
Outside firms	1·0	7·1	9·2	12·1

Although several additional firms had to be introduced, a large number of the firms employed on 20 mm. cartridge case and shell manufacture were already employed on other ammunition components. As the essential basis was the use of automatic and capstan

[1] See above p. 128.

lathes, most of the firms were in the light engineering sector of industry and many of them were already employed on larger fuze production. The range and type of firms employed on 20 mm. ammunition components was indeed very similar to the firms employed on fuze production.

The manufacture of cartridge cases for gun ammunition of 40 mm. and all larger calibres, was completely separate from the manufacture of shell and indeed from any other ammunition production. Manufacture on special purpose machines and presses was essential but the process of manufacture and the plant was similar in principle to other metal press work. In all, eleven outside firms were brought into cartridge case manufacture and of these, seven operated agency schemes. All the eleven firms were specialists in large press work in sheet metal—a specialism that had increased with the demands of motorcar production. At the R.O.Fs and at Vickers-Armstrongs and at I.C.I. the cartridge case factory included a casting and rolling mill for supply of brass blanks from which the cases were formed but the same facilities were only provided at one of the outside firms. To meet the demands of the other firms there was some expansion of capacity at the specialist factories but in addition four mills were installed at non-ferrous manufacturers.

In the provision of cartridge cases, a valuable economy could be achieved by the reforming of used cases, which could then be re-issued with new ammunition. With the large scale use of ammunition in air defence the possible supply of used cases for reforming warranted the provision of separate capacity for this. Some capacity for this was available at Woolwich, but in addition plant was installed with six outside firms. The amount of plant required was less and the work less exacting than for complete manufacture. Two of the firms employed were gas stove manufacturers; two other factories were railway engineering shops which were also employed on new case manufacture. As the manufacture of new cases was from special purpose plant which had to be provided at public expense and as a substantial amount of plant was also required for the reforming work there was a very large capital expenditure for cartridge case production.

The forging and machining of shell, fuze production and 20 mm. component manufacture at outside firms, all came under the Director of Ammunition Production in the Ministry of Supply. Many of the firms were employed in more than one sector of ammunition production and work for D.A.P. was often by far the greater part of their war-time production. Thus although the erection of a new factory building for gun ammunition work was extremely rare, there were large commercial factories almost entirely devoted to the work of ammunition component production.

The manufacture of all aircraft weapon ammunition came under the Ministry of Supply and the only armament production under M.A.P. was for bomb cases and aircraft weapons. The supplies of 20 mm. guns and machine guns for aircraft were obtained entirely from specialised factories, the armament firms or from R.O.Fs. It was only in the manufacture of bomb cases that there was extensive employment of other firms.[1] A large number of these firms although outside the armament manufacturing industry were part of the essential basic industry of specialised iron and steel production or of the light alloy industry. The manufacture of bomb cases made use of the common industrial processes of casting, forging and, for some bombs, of welding. Cast cases were made in many foundries of all kinds, forged cases were made by several forging firms and by the R.O.Fs, welded cases were made by plate working firms such as container tank and boiler makers. As the demand increased, a wider range of smaller foundries and forging firms had to be employed. To a large extent the machining of the cases was undertaken by the casting and forging firms but general engineering firms were also introduced to undertake machining only. The manufacture of incendiary bombs presented special difficulties as these were made of light alloy—mainly magnesium. For this, light alloy foundry and forging plants were necessary and many special units had to be set up at government expense. These were mainly under light alloy manufacturers and one or two firms who undertook alloy forgings and casting work for their normal requirements e.g. motor vehicle engine manufacturers. These firms also undertook the machining of most of the castings. The filling of the incendiary bombs was also extremely difficult and hazardous and for this special M.A.P. agency factories were provided under the management of I.C.I. The only other agency factory for bombs was with Hadfields for the manufacture of steel cased bombs.

The greater part of the supply of new plant for bomb cases went to casting and forging firms; for light alloy cases, a very extensive provision had to be made, but plant was also provided for some of the general engineering firms. Including what may be called the specialist metallurgical firms, plant was provided up to June 1943 to over one hundred and twenty firms at a cost of over £2 million and building work at less than £½ million. The total of over £2½ million was somewhat less than the £3 million for agency factories but the larger part of this was for the incendiary bomb filling factories.

The Admiralty's range of munitions production was very similar to that of the Ministry of Supply but on a smaller scale. For the most part the Admiralty retained responsibility and organised their own capacity;

[1] The wide use of outside firms in aircraft production as distinct from armament production is dealt with in Chapters VI, VII and VIII.

the only major product transferred to the Ministry of Supply was 20 mm. ammunition. The place of outside firms in the whole range of Admiralty munitions production proved to be very similar to their place in the Ministry of Supply. The smaller quantities required a smaller number of firms but, as the production of fire control gear showed, the Admiralty could, when necessary, employ outside firms very extensively on exceptionally difficult manufacturing work.

The Admiralty used outside firms for many products before the outbreak of war; and in war-time the number of outside firms was greatly increased and for most production provided a significant output. In 1942, over 20 per cent. of the total output of Admiralty guns came from outside firms—a proportion very similar to that in the Ministry of Supply; although only three outside firms were needed by the Admiralty for their much smaller production. The output of gun mountings for the Admiralty from outside firms amounted even in 1939 to 80 per cent. of the total. Early in the naval rearmament programme the Admiralty had decided to introduce outside firms into mounting manufacture. In the main they were successful in finding firms who could devote a very large part of their attention to this work. In 1939, there were four firms already in production; by 1942 nine outside firms were producing naval mountings for 2 pdr. guns and larger calibres. These firms produced between them over 1,000 mountings that is 70 per cent. of the total in this range. In addition over 20 firms produced over 2,000 mountings for machine guns, 20 mm. guns and rocket projectiles—over 90 per cent. of the output for this range. Thus the proportion of naval gun mountings produced by outside firms was even larger than for army gun carriages and mountings. A very similar position was reached in the production of naval shell. By far the greater part of the output came from over 30 firms covering a very wide range of commercial products. In the production of fuzes although Vickers-Armstrongs had the largest output for any one firm, over 70 per cent. of the total supply came from over 20 outside firms. The same was true of other small components for gun ammunition. The production of cartridge cases was exceptional in that only one outside firm was employed but in 1942 this firm was the largest single supplier and produced over a third of the total supply of naval cartridge cases.

In the manufacture of 20 mm. guns the Admiralty were the first to employ outside firms on the final manufacture of this difficult type of weapon. In 1942, three outside firms were introduced and by the end of 1943 when the peak output was approached these three firms provided about 40 per cent. of the monthly output. Two other highly specialised products for which the Admiralty were able to introduce outside firms with great success, were torpedoes and fire control gear. By 1944, over 30 firms were employed on the supply of major components for torpedoes. In addition, several outside firms were employed on the final assembly of complete torpedoes, where only one specialist firm had been employed in 1939. In many ways the manufacture of fire control gear presented the most difficult problem. This product was of ever increasing complexity and extremely difficult to manufacture; it required in the same firm the skill of precision instrument makers and the capacity for the manufacture and assembly of heavy mechanical components. The main part of the complete apparatus could not generally be subdivided and, in the main, division of the work had to be achieved by employing each new firm on one type of apparatus only. In 1936, it was a highly specialised field with only four firms including Vickers-Armstrongs engaged on this work. By 1939, however, a total of 35 firms had been selected and in the course of the war the total number of firms was increased to 80.

Many of the outside firms employed by the Admiralty were also employed on munitions production by the Ministry of Supply. Concentration of any production in a very few firms was strategically undesirable and for this reason alone, most firms were employed by more than one department. Even so, the Admiralty were able to retain some firms almost entirely on their own work, for example on heavy gun mountings. When firms worked for several departments it was often on a similar type of store. Thus many firms produced fuzes, guns and shell for the Admiralty and for the Ministry of Supply. The types of firm employed by both departments proved in the end to be very similar and the blend of normal specialities proved to be very much the same. In the rearmament period the Admiralty like the War Office sought the services of many under-employed machinery manufacturers especially printing and textile machinery manufacturers. With the special need for heavy mountings they were able to make very valuable use of two boiler and power plant manufacturers and a firm of locomotive builders. But soon the range had to be widened into the field of light engineering and, as for many army munitions, firms were selected with experience of light precision engineering production such as typewriters, electrical and domestic appliances, instruments and light machines of all kinds.

TANKS AND VEHICLES

The tank is a major example of a new instrument of warfare for which the initial development and production were undertaken outside the armament industry and the Royal Ordnance Factories. Development and production from 1916 up to almost the end of the First World War were the work of automotive engineering firms—manufacturers of agricultural tractors, railway carriage builders and locomotive builders. It was not until 1918 that the Royal Arsenal, Woolwich and Armstrong-Whitworth were undertaking the development of prototypes. But after the war it was at Woolwich and at

Vickers-Armstrongs that tank development was continued; and up to 1936 the limited requirements of tanks were met from these two specialist sources. After 1935, no further production orders for tanks were placed with Woolwich although development work continued in the design department. In 1936, Vickers-Armstrongs had the only capacity immediately available for tank production. Experience in the First World War, when the entire output of tanks came from heavy engineering firms and particularly from railway carriage and locomotive firms, indicated a possible method of expansion; and this was the policy adopted in 1937 when four firms were given contracts for the production of light tanks. All the firms were in the locomotive industry and thus had experience of handling, fitting and assembly of heavy automotive components.

Engineering firms suitable for tank production needed an educational period in which to adapt methods and plant to tank production, but up to 1938 and even later, there was a lack of orders to place with suitable firms. Until the summer of 1938, orders were only available of divisible size for light tanks and these were only sufficient to divide among the four firms and Vickers-Armstrongs. In the summer of 1938, larger orders were available for cruiser tanks and contracts could be allocated to other engineering firms. In addition to Vickers and Harland and Wolff, contracts were given to two railway carriage and wagon builders—Birmingham Railway Carriage and Metro-Cammell Carriage and Wagon. The latter firm was a direct descendant of the largest erector of tanks in the First World War. An important innovation had however been made in January 1938 when orders for cruiser tanks were placed with Nuffield Mechanisations Ltd. Earlier, Morris Commercial, a member of the Nuffield organisation and a leading War Office contractor for motor transport vehicles had co-operated with the War Office in the investigation of foreign tank and vehicle developments. It was now agreed to apply as far as possible the mass production methods of vehicle manufacture to a new cruiser tank developed by Nuffield Mechanisations in co-operation with the Mechanisation Board. This was the first entry of the motor vehicle industry into tank production and the new factory was the first tank factory to manufacture tank engines and other automotive components

The lack of stabilised designs was another difficulty. Design required a good deal of practical trial and development work; and with several designs on hand, allocation to separate firms was essential. Vickers were responsible for the early designs—the light tanks, the Infantry tank Mk. I and the Cruisers Mk. I and II but from 1936 other firms were given development orders for new types. In 1937, Nuffield Mechanisations, a locomotive firm and the L.M.S. railway shops were all undertaking design and development work on new types of tanks. In the summer of 1938, three of the locomotive firms who were already employed on light tanks were given orders for Infantry tanks Mk. II—the Matilda II—which had been largely designed and developed by one of the firms. At the same time a production contract was given to the L.M.S. railway for the same tank. In April 1939, a further order for cruiser tanks was placed with the L.M.S. railway shops.

No further firms were introduced up to the outbreak of war. When in June 1939 contracts were placed for the new infantry tanks—the Valentines—they were divided almost equally between Vickers-Armstrongs, Birmingham Railway Carriage and Metro-Cammell. Up to August 1939, contracts had been placed with Vickers-Armstrongs, Harland and Wolff and Nuffield Mechanisations, all of whom should be accounted as armament firms, two carriage and wagon firms and in addition with five locomotive factories including the L.M.S. Apart from Nuffield Mechanisations new capacity was thus exclusively within the locomotive and railway carriage industry. In the summer of 1939 plans were being prepared for the introduction of more firms for cruiser tanks. These plans were approved in September when contracts were placed with Leyland Motors, Fodens, Wests Gas and English Electric. This brought into tank production a major manufacturer of electric locomotives—English Electric—and of heavy motor vehicles—Leyland Motors. These firms were to become two of the largest manufacturers of tanks. This marked the end of the almost exclusive employment of locomotive firms. No other firms were brought into tank assembly until after Dunkirk and all deliveries of tanks up to May 1941 were to come from the firms given contracts by the end of September 1939.

Up to the outbreak of war only 146 cruiser and infantry tanks had been delivered and of these over 100 came from Vickers and over 40 from Nuffield Mechanisations. The main contribution of outside firms up to August 1939, was in light tanks; 1,000 of these were delivered before the outbreak of war. Vickers supplied over 600 light tanks and the remainder came from the four locomotive firms that had undertaken this work in 1937. The production of these light tanks ended during 1940, and the production of two new types of light tank was undertaken by Metro-Cammell between 1940–45, but in comparatively small quantities. Almost all the available resources were employed on the production of infantry and cruiser tanks. Even by the end of 1940 not all the firms introduced up to the summer of 1939 were making deliveries and even in May 1941 none of the firms introduced in the first few months of war had started deliveries. Even so by the end of 1940, the deliveries from the outside firms were in excess of supplies from the armament firms. More than half the total deliveries for 1940 were from the locomotive firms and the railway carriage firms who thus showed the dominance which they maintained throughout the war.

The demand for tanks was greatly increased after Dunkirk and it was necessary to increase capacity both by expansion of the existing capacity and by the introduction of new firms. Expansion for the two infantry tanks already in production—the Matilda and Valentine—was achieved by extending the existing capacity and without the introduction of new firms. The increase in requirements for cruiser tanks was much greater and well outside the scope of any practical expansion of the existing capacity. This was particularly true of the Crusader. In consequence, six firms were added to the three already employed on Crusader production. This addition brought in three light motor vehicle firms—all members of the Nuffield Organisation, and an iron and steel firm, a manufacturer of excavating machinery and a manufacturer of metal office equipment. In the same period capacity had to be found for the new infantry tank—the Churchill. This involved not merely finding additional capacity but also finding a firm with technical and managerial resources to organise the development and production of a new type of infantry tank of heavier construction than any other type. Responsibility for development of the tank and for organisation of production was undertaken by Vauxhall Motors. Under the parentage of Vauxhall Motors, ten other firms were employed on the final assembly of the Churchill tank. Of these, four were already employed on the assembly of other tanks. The six new firms were two locomotive firms, a railway carriage builder, a motor vehicle firm and two engineering firms, the one in iron and steel and plant construction, the other a manufacturer of pumps and pneumatic tools. With eleven firms in all, this was the largest group of firms employed on tank production. With the exception of Harland and Wolff, none of the firms was from the armament industry, but three were motor vehicle manufacturers.

The entry of Vauxhall Motors into tank development and production emphasised the growing trend to make more use of motor vehicle firms in this work. In part this reflected the need for the organisation of large scale production and the progressing of large quantities of components; it also showed the increase of automotive problems in tank development and production. It was now seen that tank work required the resources of the automobile industry combined with the resources and equipment of locomotive factories. The employment of locomotive firms depended on motor vehicle specialists for automotive components; the employment of motor vehicle specialists on tank assembly required a fairly extensive supply of heavy manufacturing and handling equipment. A combination of the two types of firm provided the greatest possibility of economy in plant and technical resources.

The peak output of infantry tanks was reached in 1942 and the peak output of cruiser tanks in 1943. By the summer of 1942 all the additional firms introduced in 1940 and 1941 had come into production. The cumulative deliveries up to June 1943 give a reasonably representative picture of the main division of capacity between the several types of firms.

Total delivery of Tanks to June 1943
(excluding light tanks)

	Number of Firms	*Total deliveries to June 1943*
Vickers	1	2,234
Nuffield Mechanisations	1	1,333
Harland and Wolff	1	473
Locomotive factories	8	4,713
Railway carriage firms	3	4,262
Motor vehicle firms	7	3,674
Other engineering firms	7	2,366
Total	28	19,055

Despite the very large contribution from the motor vehicle firms the dominant groups remained the locomotive firms and the railway carriage firms. The eleven firms in these two groups accounted for nearly half the total output. The outside firms with the two largest cumulative deliveries 2,174 and 1,740 were both railway carriage firms and of the next two, one was an electric vehicle manufacturer and the other a heavy motor vehicle firm. The total output from the locomotive, railway carriage, motor vehicle firms and from the Nuffield Mechanisations factory accounted for over 70 per cent. of the cumulative total up to June 1943. This substantially confirmed the policy of finding suitable capacity for tank production in the locomotive and the motor vehicle industries.

A very large part of the expansion of assembly capacity was obtained by the addition of new firms. The peak monthly output of tanks reached 750 but this total came from no less than 28 different firms. More than 20 of these firms had a peak monthly output ranging between 20 and 35 tanks; by far the greater number had a peak monthly

Peak monthly output of Tanks

Peak monthly output (range)	*Firm or Normal Product of the Firm*
90/100	Railway carriages
80/90	Electric locomotives
75/80	Vickers-Armstrongs
60/70	Railway carriages
60/70	Heavy motor vehicles
40/50	Nuffield Mechanisations
20/35	22 other firms

output of less than 30 tanks. Clearly, the production unit was comparatively small. Of the six firms, including Vickers and Nuffield Mechanisations, with a peak monthly output of over 40 tanks, the highest peak output was achieved by a railway carriage firm.

The analysis so far only relates to the assembly of the vehicle as a tank complete with turret and armament. Much of the production of components had to be planned as a separate problem. Indeed as early as 1936 the organisation of capacity was set out on these lines.

(a) The fabrication of hulls and final assembly of the complete vehicle.
(b) The complete manufacture and bench tests of transmission units (excluding the engines—a separate unit).
(c) The production of the many sub-assemblies required.
(d) The manufacture of specialised items such as radiators, oil coolers, fuel tanks, etc.

Without this subdivision the wide distribution of final assembly would have been extremely difficult.

Some firms did not undertake any work in connection with tanks except final assembly; all components and parts for assembly were supplied to them. But this was exceptional. All firms it is true received many components and sub-assemblies from other suppliers; but many undertook work on sub-assemblies. Three assembly firms also supplied engines and other automotive components for the tanks they produced and in addition for the other firms assembling the same type of tank. The Nuffield factory manufactured Liberty engines, a special version of the American aircraft engine. Leylands supplied Leyland engines for Matilda tanks, and Vauxhall Motors produced a special engine for all the Churchill tanks. It is not surprising that these three firms came nearest to developing a fully equipped factory capable of manufacturing complete tanks. In addition, although they did not manufacture engines or automotive components, Vickers-Armstrongs had capacity to manufacture the major sub-assemblies as well as to undertake the final assembly. Engines, gear boxes, steering equipment and automotive parts were usually supplied by specialist firms within the orbit of the automobile industry. Three engine suppliers were also parent tank manufacturers; but whilst all Churchill tanks had Vauxhall engines not all tanks assembled at Leyands or Nuffield Mechanisations had engines of their manufacture. Other engines were also used, Meadows, A.E.C. the Rolls-Royce Meteor and imported United States engines. Other major automotive assemblies were supplied mainly by specialist firms; but most of these firms found the tank requirement somewhat outside the range of their normal production.

Like other heavy munition manufacture, tank production was specifically dependent on specialised capacity in the iron and steel industry.

From 1940 onwards, the demand for armour for tanks and other armoured vehicles greatly exceeded the requirement of armour for naval ships; and by 1942, at least fifteen iron and steel firms were undertaking the manufacture of armour plate for armoured vehicles. Other firms were undertaking the heat treatment and machining of armour plate so far as it could not be undertaken at the armour plate firms. The impact of tank production on the iron and steel firms was thus comparable with that of warship construction much earlier in the century. Other metallurgical requirements, including large castings and forgings, involved a high degree of specialisation of capacity. For example, the manufacture of track link castings and of armour castings required specialist capacity and led to the introduction of new techniques.

By the end of 1943, the total expenditure approved for the provision of additional machine tools and plant for tank manufacture was about £30 million. Almost half of this amount had been allocated for the production of automotive components—for engines, gear boxes, brakes and steering units. The amount provided for armour plate, castings and tracks exceeded £4 million. For the assembly of tanks and for the assembly of major sub-assemblies the total amount had also reached about £4 million. The extensive use of firms had reduced the amount of new building work required, but many firms lacked the factory accommodation and facilities to undertake heavy assembly work and at several firms assembly shops and cranage facilities had to be provided. At other firms, factory buildings had to be erected for engine manufacture. In general, the demand for automotive components had to be placed with specialist firms whose own capacity was already fully employed on automotive requirements for other vehicles. It was therefore inevitable that much additional capacity had to be provided to meet the tank requirements for these components. To a very large extent the machining of components had to be given out to a very wide range of subcontractors using their own plant. The result was a very wide range in cost and efficiency. Thus, despite the extensive allocation both of assembly work and of machining, the expenditure on factory building and additional plant proved substantial; it was very similar to expenditure for gun and carriage production. For the production of engines and to a somewhat lesser degree for the production of armour plate new capacity had to be provided for the greater part of the output required; but over the whole field of tank production the provision of new factories and plant was very much less than the total capacity employed on tank production.

Capacity for tank production was dependent to an exceptional degree on the introduction of outside firms. This was true, although capacity at Vickers was extended, and in some ways the Nuffield Mechanisations should be considered as the formation of a new armament firm. Even more exceptional, there was no production of tanks in R.O.Fs until the last year of the war although they were employed on conversion work in the middle of the war.

The nearest to tank production both in type of product and in method of expansion was the armoured carrier. This completely tracked vehicle was peculiar to British war equipment. It had a moderately armoured open body and was a far simpler production task of much lower cost than the tank. Roughly, it was equivalent to the lightest of light tanks without the gun turret and enclosed superstructure. The design of these vehicles was subject to much variation and development but these changes, whilst they greatly increased the operational value, did not greatly add to the manufacturing problems. Despite the much simpler construction, the carrier was like the tank in that it had no place in normal vehicle manufacture and had many features outside the normal processes of vehicle manufacture.

Capacity was expanded on very similar principles to those applied to tank production but the scale of capacity required and the number of firms introduced were very much smaller. In 1936, as for tanks, the only specialised capacity available was at Vickers and at Woolwich. No production orders were placed with Woolwich, and after the delivery of a small quantity of training vehicles, Vickers concentrated their efforts on tank production. Thus even before the outbreak of war, armoured carrier production was entirely confined to firms outside the armament industry. As a fully tracked vehicle, the armoured carrier was as far removed from the normal automobile as the tank; but as it was much simpler vehicle there was less for the manufacturer to learn. By 1938, orders for armoured carriers had been placed with four firms. Two of these were motor vehicle manufacturers—Wolseley Motors and Thornycroft & Co.; the normal products of the other two firms Sentinel Wagon and Aveling Barford were rather different kinds of vehicles, railway wagons and road rollers. These four firms continued to produce certain types of armoured carriers throughout the war and only one additional firm—the Ford Motor Co.—was introduced for their type of carrier. The motor vehicle manufacturers Thornycroft, Wolseley, and Ford became predominant in this production.

In 1941, when another type of carrier of a slightly different design was introduced, several other firms had to be employed. Only one of the new firms—Dennis Bros.—was a motor vehicle manufacturer. The other three firms were all specialised mechanical engineering manufacturers—textile machinery, hydraulic and electrical machinery, winding and pumping machinery. No further firms were introduced for carrier manufacture but by the end of 1943, three of the pre-war firms and the Ford Motor Company were employed on the second main type of carrier. The complete list of manufacturers now included four motor vehicle firms, a railway wagon manufacturer and four mechanical engineering firms.

As for tank production many of the final assembly firms were supplied with most of the components from the production of other firms. Engines, gear boxes, radiators and rear axles were supplied by the Ford Motor Co. though a large proportion of the engines had to be imported from U.S.A. Bullet proof plate, tracks and brakes were manufactured by other firms. The extent of the work was very much less than for tanks and it was therefore possible to limit manufacture to a much smaller number of firms. The manufacture of engines, gear boxes, rear axles and many other automotive parts was undertaken from existing commercial capacity without additional manufacturing plant. Plant had however to be provided for all the final assembly firms, and for bullet proof plate manufacture and machining. The largest scheme of all was for the fabrication and erection of welded carriers. Even so, expenditure on plant and buildings by the end of 1943 was less than £1 million. With only 8 assembly firms, the total output for carriers for 1943 exceeded 18,000. The peak output indicates a final predominance of motor vehicle firms in armoured carrier production.

Annual peak output[1]

Motor vehicle firms (four)	11,172
Railway carriage firm (one)	2,690
Other engineering firms (five)	4,719

One further group of armoured fighting vehicles remains to be considered—the armoured cars and scout cars; these unlike tanks and carriers were not tracked but wheeled vehicles. The production of armoured cars and scout cars had very direct connections with motor vehicle manufacture and as would be expected, all orders for these vehicles were placed with motor vehicle manufacturers. Even so despite the close similarity to motor vehicle construction, the manufacture of armoured cars presented many difficult problems. Many of the difficulties were directly concerned with the level of design and development to obtain the performance specified; but even when the design was complete, manufacture was a task far more exacting than for the normal vehicle chassis and automative components.

The design of scout cars and armoured cars was in the main the work of three motor vehicle manufacturers. Two of these firms—Daimler and Humber—were responsible for the design of at least one main type

[1] The firm's peak output either in 1942 or 1943. With the smaller production task it was possible to achieve much higher monthly rates of output and scale of manufacture. The five firms with the largest output achieved monthly outputs ranging from 170 to 370 carriers a month.

of scout car and more than one type of armoured car. These two firms were also responsible for the bulk of the total output of the vehicles. Much of the work on the armoured bodies was undertaken by other firms; hulls, turrets and mountings were constructed by these firms, but engines, chassis and automotive component manufacture as well as final assembly, was undertaken by the motor vehicle manufacturers. Although output of these cars was less than tank output, manufacture was much more concentrated; the greater part of the output came from two firms and the scale of manufacture was a good deal larger than for tanks or armoured carriers.

Motor vehicle firms had a large part in every section of armoured vehicle manufacture—tanks, armoured carriers and armoured cars. In addition, several leading motor car manufacturers had a very important part in aircraft production. In consequence, the resources of the motor vehicle industry available for military motor transport production were quite substantially reduced. It is true that there was very extensive new capacity provided under the motor vehicle firms for aircraft production and also on a much smaller scale for armoured vehicle production. Even so a good deal of the industry's existing resources were absorbed in aircraft and armoured vehicle production and indeed in other munitions production.

Before 1939, all calculations of the war-time requirements of military transport vehicles seemed to come well within the scope of the existing industrial resources. Here, it was possible to argue, was an expanding industry, producing close commercial counterparts of military requirements, in which there would be considerable resources to spare for other war production. In consequence, no objection was raised to the extensive allocation of several motor vehicle firms to other war production. The suitability of some of their capacity for military vehicles was in fact limited. The military demand for motor vehicles was very largely for the equivalent of medium and heavy commercial vehicles but a very large part of the motor industry was equipped for motor car and light transport vehicle manufacture. In 1937, the output of all types of motor vehicles exceeded 400,000 but of these more than three quarters were private cars. Pre-war estimates of war requirements came well within the scale of the pre-war output of medium and heavy commercial vehicles but the actual war-time requirements for all years were far in excess of this. The average requirement for the three years 1942 to 1944, exceeded 400,000 vehicles and included only a small number of light vehicles. Only by converting most of the motor car capacity to medium or heavy commercial vehicle capacity would it have been possible to approach the output for war requirements; even then this calculation would have ignored the exacting designs and equipment of military vehicles which absorbed even more industrial resources, especially in component and engine manufacture. In war, the problem of supply had to be solved by importing an increasing number of vehicles from Canada and the United States and by accepting, to an undesirable extent, a limit on the proportion of vehicles manufactured to the full military specification.

*Supply of motor vehicles for United Kingdom requirements**

United Kingdom production†	Pre-war Average 1937–38	1940	1941	1942	1943	1944
Cars and light vans . .	385,000	21,338	20,692	23,183	21,605	19,704
Load vehicles . . .	85,000	112,531	124,738	137,339	127,703	113,251
Overseas Supplies						
Canada		16,919	57,464	113,374	162,844	137,232
U.S.A.		7,710	24,168	74,349	89,627	60,508

* United Kingdom requirements includes some requirements for all armed forces under the Imperial Command.

† Of United Kingdom production of load vehicles in the war years 1942–44 at least 20 per cent. was for civilian requirements.

The very large expansion in war-time requirements was partly due to the much larger use of motor vehicles in all military formations and operations. But the total United Kingdom requirement included a large part of the requirements for Imperial Forces and so to some extent the war-time dependence on North American supplies reflects the pre-war commercial exports from North America to many parts of the Empire. But even the requirement for the United Kingdom forces alone was always greater than the output available from United Kingdom production. The serious deficiency of the United Kingdom industry for war requirements could have been substantially reduced only by a very large scale expansion or re-equipment programme. This was granted for aircraft and armoured fighting vehicles but not for transport vehicles. Apart from a number of expansion schemes for components, mainly to increase the proportion of vehicles built to full military specification, the war output of motor vehicles in the United Kingdom had to be obtained from the existing factories and plant of the motor vehicle industry, so far as they were available.

The growth of the motor vehicle industry between the wars was viewed as an important addition to industrial resources for war production. This it most certainly proved to be; it was an essential industry for the mechanisation of the land forces. But as was seen even before 1936, especially in the early plans for war-time expansion of aircraft production, this rapidly advancing industry was of very great value quite apart from the manufacture of motor vehicles. The demands made on the motor industry both in rearmament and in war proved very great and very wide in their range. In consequence, the total employment under the motor industry firms in war greatly increased but the bulk of that increase and a large part of the initial labour force available at the outbreak of war was eventually employed on aircraft, fighting vehicles and other munitions production; the output of motor vehicles in war came from resources a good deal less than the total pre-war resources of the industry. If armoured fighting vehicles as well as aircraft are counted as outside the normal range of the motor vehicle industry, the motor vehicle firms' role as outside firms in specialised munition production was much larger than their role in motor vehicle production.

CHAPTER VI

EXPANSION OF AIRCRAFT CAPACITY

(i)

Policy and Planning

In 1935, the position of aircraft production was, in some ways, comparable to that of shipbuilding; for both there was a professional industry which was under-employed. But, unlike the shipbuilding industry, the aircraft industry had never been a large industry in peace-time. Thus, whilst in 1914 the shipbuilding industry was at about the peak of expansion, the aircraft industry was merely an industrial embryo. The task that faced the aircraft industry in the First World War was much smaller than that which confronted it in 1935; not only were larger quantities of aeroplanes needed but the design and construction of aircraft had become a much larger industrial undertaking. Again, in comparison with the shipbuilding industry it should be remembered that in 1930 the aircraft industry employed little more than 30,000 whereas shipbuilding and marine engineering despite the decline in trade, had an employment exceeding 100,000 and an almost equal number of unemployed. In the 1920's it was mainly the demands of design and development stimulated by the Air Ministry, that kept the aircraft industry alive. Orders for production, both for civil and military aircraft, were exceedingly small and not such as to result in any important developments in industrial structure or capacity.

In the period between 1925 and 1935, the general outlook in the Air Ministry was based on the assumption that the aircraft industry, as it was then constituted, was not large enough nor strong enough to meet the demands of war production. In consequence, at least as early as 1927, it was considered that large scale expansion of output required for war production would need a considerable addition to capacity from outside the industry. Thus, at an early stage the plan was for a definite change in structure from what might be described as a single industrial capacity to a dual capacity with a professional industry and a shadow industry. In 1936, it was decided that this plan for war production was needed to meet the demands of rearmament. Up to 1938, this principle of adding to the structure of the industry, in the form of what was called from 1936 onwards the shadow industry, was in many ways, the predominant factor in the Air Ministry expansion policy. In this period, the attitude of the Air Ministry to the expansion of the professional industry was mainly to see what the industry could do on the basis of its own plans and resources, though from 1936, with a financial guarantee for approved schemes. It was not until 1938 that the Air Ministry adopted a general policy for expansion of the professional industry with the direct use of government finance.

In 1938, there was a major re-orientation of policy. Many further additions to the structure of the industry were planned in that year, and later, by the expansion of the shadow industry. But by the end of the year it was clear that expansion of the professional industry was now a direct alternative to the shadow industry method and that in many circumstances this would probably prove to be the easier and more advantageous method of expansion. As this expansion was now to proceed largely by the provision of government owned factories or government owned extensions to existing aircraft factories, it soon led to considerable changes in the internal structure of the professional industry. Although the Air Ministry maintained their long standing policy of denying themselves a state aircraft factory owned and managed by the government, as were the Royal Ordnance Factories, they were now to provide, at public expense, a very large number of aircraft factories owned by the state but managed by the professional firms. A very large proportion of the factories from which the aircraft industry made the war-time record delivery of aircraft, were state owned factories. This resulted in what may be described as a hybrid structure within the aircraft industry which was a unique development even in the variegated pattern of industrial capacity for war production. Thus, from 1938, whilst the shadow industry continued to add externally, as it were, to the industrial structure for aircraft production, the integration of state owned factories with the capacity already operated by the aircraft firms brought about many internal changes in the structure of the professional industry.

A further policy was adopted in 1938 which was to affect the structure of all capacity for aircraft production and to greatly facilitate the expansion of capacity under the professional and the shadow industry. This was the decision that all firms should subcontract airframe parts and other components to a very high proportion of the total capacity required. This again was a policy aiming at large-scale expansion of capacity by a definite structural change; for the subcontracting that was required, eventually to the extent of 50 per cent. of capacity, was a kind of subcontracting that had virtually no place in the existing industrial structure. Assessed by the labour employed, this proved to be quite as large a structural innovation as the introduction of the shadow industry. One further policy, affecting industrial organisation, was introduced before the outbreak of war. Under this, several firms were required to undertake the production of the same type of aircraft and for this purpose to establish some form of group organisation. This method had already been employed in the earlier shadow industry schemes but in 1939 it was necessary to secure the co-operation of more than one professional aircraft firm in some of the groups. This introduced into the more or less competitive structure of the aircraft industry a degree of co-operation that proved to be capable of almost unlimited extension. This policy, primarily concerned with organisation, resulted, at the peak of war production, in an industrial structure which showed a very high degree of industrial co-ordination.

In addition to changes in structure and organisation arising from expansion policies, there were many changes that arose from technical developments in design and construction. Many of these increased the dependence of the industry on suppliers of specialised products. By far the most fundamental was the change from the use of wood to a very extensive use of metal. As a result the aircraft industry became dependent upon a basic metal industry which in the form and scale required was barely in existence in 1935. Although the change from wood to metal had been proceeding for some time before 1936 and the trend of new types approved after 1936 was definitely towards a larger use of metal structures and coverings, the full industrial impact of this was inadequately appreciated even in the spring of 1939. In consequence, a large part of the expansion of the basic industry for light alloys had to be undertaken during the war.

By 1939, the expansion of the professional industry had emerged as a method which was already proving as effective as the provision of capacity under the shadow industry schemes. In addition, the readiness of all firms to co-operate in the group organisations shewed that the industry was ready to enter into a variety of industrial arrangements which would greatly extend the importance of their existing technical and industrial resources. Throughout the rapidly expanding and changing industrial structure, the policy of subcontracing was, at almost every point, introducing ancillary sources of capacity which were soon to become an essential part of the new structure. Thus, although effective capacity was limited at the outbreak of war, most of the factors that were to determine the war-time structure were already in operation. There was one further policy of long standing that was intended to come into operation specifically for war production. In war-time the aircraft factories were to proceed, as soon as possible, by the operation of a second shift to double their output and thereby the value of their capacity. This provision had been included in all pre-war planning but, maybe because it was so generally understood, it received very little direct emphasis, either in the pre-war period or in the early stages of war production. As will be shown, this policy involved quite fundamental changes in the outlook of industry and in the organisation of production and proved to be by far the most difficult to apply. It was, in fact, the least successful of all the policies of expansion.

There was one major problem of physical capacity which had perforce been largely neglected in pre-war preparations and which in 1940 was dealt with more drastically for aircraft production than for any other field of munitions production. The vulnerable location of a large part of the aircraft industry was well known in the pre-war period but the need to avoid any interference with production prevented any special measures which would affect output. A few, but by no means all the new factories, were more safely located but in general a large proportion of the factories directly contradicted the Air Ministry policy for the avoidance of vulnerable areas. The success of the enemy attacks in the summer of 1940 led to an immediate policy for the dispersal of capacity from all aircraft factories whatever their location; in twelve months the vigorous application of the policy of dispersal completely changed the physical structure of aircraft capacity.

At the outbreak of war, the requirements on which aircraft production planning was proceeding were very near in quantity to the final war requirement. They were much nearer than in any other munitions programme. It is therefore not surprising to find the main principles of expansion already accepted and widely applied. Many changes were to occur in types and the quantity of different types required but these changes did not greatly affect the physical planning of capacity. Even the bomber programme of 1941 was in many ways no more than an insistence that the output should include the full output of heavy bombers required under the programme laid down in the early months of war. Much work of planning and expansion remained to be done after the outbreak of war but the size of the problem and the principles of expansion were already familiar to those directly concerned.

War brought many diverse secondary problems of capacity but there was only one additional major requirement: this was the increasing need for capacity for aircraft and component repair, this had been foreseen but only limited preparation had been possible. Pre-war calculations could not be precise; much depended on the location of air warfare and the state of aircraft that could be salvaged. Moreover, the deficiency in industrial capacity, quite apart from other considerations, had led the Air Ministry to view repair as an R.A.F. responsibility.[1] In war it was to be proved that despite the heavy burden imposed on the aircraft industry and other industries for new production, the burden of repair could be borne largely by the same industries and to some extent by the same firms; with a comparatively small addition to industrial resources it was possible to greatly augment the supply of aircraft.[2]

[1] For the Admiralty policy on aircraft repair, cf. p. 68.

[2] *British War Production*, *op. cit.*, pp. 316-320.

Emphasis has been given to the changes in the structure of the industrial capacity rather than the sheer expansion of capacity. It was change in structure which, in part, at any rate, enabled the expansion to be secured and sustained to an extent which could hardly be envisaged in 1935. Expansion in itself brought many changes in organisation and, eventually, in structure. Some account will be given of this expansion which from an industrial capacity in 1936 employing less than 60,000 in the main firms and in the ancillary industries, increased to a war-time capacity in 1944 employing more than one and a half million. By then aircraft production had become by far the largest sector of war production.

(ii)
Expansion 1936–40

In the production of aircraft, more than in any other sector of war industry, the programme of factory construction closely reflected the plans for the expansion of production. This was true not merely in 1936 but at several later stages of expansion. There were two main reasons for this. The capacity available even in 1936 was a good deal less than was required to meet the demand and this deficiency was generally measured in terms of the factories required for the assembly of the additional number of aircraft. In consequence, a large, and up to 1940, a comparatively homogeneous factory programme, was the essential basis for the expansion of aircraft production. There were some dangers in this tendency to express production programmes in terms of aircraft factories. For, during rearmament and even more so later, the aircraft factories became, to a much larger extent assembly factories and manufactured far less of the complete aircraft than before. During the course of the war, aircraft production made increasing use of thousands of firms of all types and sizes. For most of these firms the existing factory buildings sufficed, for others, additional factory accommodation often on a relatively small scale was provided. To measure the production effort in terms of aircraft factories alone, was to underestimate the great importance of subcontractors and specialised component factories of many kinds.

The second reason is rather complicated. Throughout the rearmament period and indeed throughout the war it was possible and indeed necessary to make plans in terms of the quantity of aircraft required and of the list of aircraft factories from which, in different quantities and types, these aircraft were to be delivered. It did of course become increasingly necessary to plan with great care the large, complex, and widespread capacity supplying these aircraft factories with all manner of products both for new aircraft and for repairs—fabricated metal, components, engines and even major airframe assemblies. As early as 1936, new factories had to be built for the manufacture of engines and by 1938 new factories were under construction for propellers, light alloy materials and components. By the peak of war production, government expenditure on new factories for engines was no less than for aircraft assembly; expenditure on factories for light alloy material and intermediate products was not much less. In addition, new factories had been provided for almost every major aircraft component and equipment, including propellers, radio and radar, instruments, undercarriages, guns and turrets. The production programme became complex in other ways; the percentage of spares of all kinds that had to be provided was greatly increased, the demands for the repair of aircraft increased rapidly after 1940. Despite these changes and although from the end of 1938 the factory programme had to be accepted as highly complex, the central aim remained the production of an increasing quantity of new aircraft. In consequence, the possibility of achieving further expansion in the output of new aircraft still tended to be equated with changes in the programme of factory provision and even more directly with the total departmental commitment for capital expenditure for plant and buildings.

The rapid increase in Air Ministry requirements before 1939 and the impact of this demand on Air Ministry programmes and policy has been recorded elsewhere.[1] Here it is the impact on the factory programme which must be followed. The expansion of Air Ministry requirements began in 1934, but up to the end of 1935 the aircraft industry were left to meet the additional demands from their own factory capacity. The first Air Force re-equipment scheme of 2,400 aircraft in two years was well within the scope of the existing factory accommodation. The second Air Force programme in May 1935, which required an output of at least 2,000 aircraft a year, led several firms to make some extensions to the factory capacity but there was no immediate suggestion that the industry would not be able to meet the additional demand. By February 1936, when a third and larger programme was introduced, it seemed unlikely that the industry would be able to meet this programme, let alone a new programme of 8,000 aircraft by March 1939. The risk of failure was very great. It was at this stage, in May 1936, that the Secretary of State for Air decided that the time for the formation of a shadow industry for aircraft and aircraft engines had arrived. This meant that the first government factory construction programme for aircraft production was to be planned entirely with firms from outside the industry. Thus although most of the aircraft firms were making additions to their factory accommodation, by far the largest single additions to factory space were the new factories under outside firms approved in 1936.

[1] cf. *British War Production*, *op. cit.*

The spring of 1938 saw the initiation of a new and more ambitious aircraft programme which envisaged the production of 12,000 aircraft in the two years up to March 1940. This required a very large increase in output—from 2,000 in 1937 to 7,000 aircraft in 1939. Moreover, it was also necessary to bring into production several new types of aircraft. These plans for expansion of output had largely been decided by the estimates given by the firms of their potential capacity. The Air Ministry had now to determine how far and under what conditions the firms were likely to be able to fulfil these estimates. In order to keep better control over production and the expansion of capacity a special Air Council Committee of Supply was therefore set up and from henceforth firms had to produce evidence of their capacity to complete the programme. This committee was to continue in operation throughout the war and was to be the effective control and authority for the expansion of capacity and for the approval of new factories and extensions. Thus in the Air Ministry and later in M.A.P. a very direct link between the control of the factory programme and expansion of requirements was established. It was by no means easy for the firms or for the Air Ministry to assess the potentiality of the rapidly developing production units. An investigation made in 1938 on behalf of the Air Ministry by the newly appointed Director General of Production revealed a very diverse scale of potential expansion. The report emphasised the need for fuller use of existing facilities and for a more rapid increase in the labour force but it also recommended several schemes for expansion of factory space and manufacturing capacity both for airframes and engines. All these schemes were with the professional industry and in the form of extension of existing factories or new factories to be operated in conjunction with the firms' existing factories. For these schemes and for all subsequent schemes the building and plant were to be provided at government expense.

In the summer of 1938 it was decided that capacity should be planned and constructed so that an output of 24,000 aircraft a year could be achieved in the twelve months from March 1940. Even allowing for a doubling of output from general second-shift working in war, additional factory capacity was required for about 12,000 aircraft a year. As a result, the schemes approved in the second half of 1938 and early in 1939 were the largest yet planned. Not merely were three of the largest shadow schemes introduced—Castle Bromwich, English Electric and Metro-Vickers but an almost equal expansion of the aircraft industry, largely in the form of new factories, was approved. Approval of schemes for new engine factories was on a similar scale with large new factories under shadow firms as well as under the two main engine manufacturers Rolls-Royce and Bristol.

It was early in 1939 that the full complexity of the aircraft programme was appreciated more precisely; it was no longer possible to think even mainly in terms of aircraft factories. It is true that some other factories had been approved between 1936 and 1938; in addition to engine factories there were single factories for propellers, guns, carburettors and bombs but these were mainly to complete rather than to provide for an entire programme. Now the range of products was increased and every expansion of aircraft output required an equivalent increase in all component and material supplies. Almost inevitably, the first factories approved were those last in the sequence of manufacture—the aircraft assembly factories. By the spring of 1939 the danger of an unbalanced programme was all too clear. Since April 1938, the Supply Committee had authorised new building sufficient to double the floor space at the disposal of the airframe factories. The problem which faced them in the second year of their existence was to match the war potential capacity for 24,000 airframes with the additional capacity for engines, carburettors, magnetos, airscrews, guns armaments, instruments and raw materials. It was estimated that the capacity for 24,000 airframes would be ready in the spring of 1940 and that to provide the additional capacity for the ancillary production would require a capital expenditure of £30 million. The process of matching the airframe war potential in every other field of supply was still proceeding at the outbreak of war and a good deal remained to be done.

Each stage of expansion from 1936 required an increasing commitment of public funds for the construction and equipment of factories. Up to 1936 the extensions undertaken by the aircraft industry for airframe and engine production had been at their own expense and risk but from 1936 onwards approved schemes were guaranteed by the Air Ministry under the Capital Clause arrangement.[1] Most of the expenditure by the firms under this arrangement was undertaken in 1936 and 1937. By the outbreak of war the total guaranteed by the Air Ministry for buildings and plant was £7.4 million. The first government expenditure was for the construction and equipment of shadow factories approved in 1936. The total commitment for these factories by 1938 was £6½ million. Factories for components approved in 1937 added about £1 million to the government commitment. Taking into account expansion by the industry not covered by guarantee, the capital expenditure in this first stage of expansion was broadly shared by the aircraft industry and the government.

The extension of capacity needed for the new programme of March 1938 meant that by the summer of 1938, the government commitment had increased to nearly £10 million but this was small compared with the additional commitments made when it was decided to provide capacity of 2,000 aircraft a month for the war potential. Between the summer of 1938 and July 1939 capital schemes to the total of over £30

[1] cf. *Contracts and Finance, op. cit.*

million were approved.[1] Airframes and engines still accounted for the larger part of the commitment but light alloy production and a wide range of components were now included. The planning for the 2,000 aircraft a month was not entirely complete at the outbreak of war though most of the major schemes had been approved. Within a few weeks the requirement was raised to 2,300 aircraft a month and a further large capital commitment was necessary including the construction of several new aircraft factories. The large additional capacity that was needed to meet the addition of 300 aircraft a month, reflected in some measure the complete saturation of the capacity already planned. But it reflected even more the introduction of many new and larger types of aircraft including a larger proportion of heavy bombers. Large types of aircraft needed many times the capacity of the smaller types; larger components, more sub-assemblies, more material, more engines and propellers and much larger factory space were needed.

In the first four months of war the commitment had increased by over £40 million, to more than double the total pre-war commitment. By August 1940 the total commitment exceeded £110 million—an increase of over £70 million in the first twelve months of war. Even though the target of 2,300 aircraft a month remained unchanged, the capital commitment increased again between August 1940 and August 1941 by £65 million but only a small part of this amount was for new production. The needs of repair and storage of aircraft claimed large amounts but by far the largest amount was for dispersal and for housing and hostels. It was not until the bomber programme was planned at the end of 1941 that the main stream of expansion flowed again.

(iii)
Dispersal and Defence 1940–41

Aircraft factories had for long been recognised as the most valuable target for enemy attack. But the urgent demands of production and expansion after 1936 had left little scope for any general improvement in the location of aircraft factories.[2] In the summer of 1940 the extreme vulnerability of some of the aircraft factories was demonstrated in the first of the enemy air attacks. The factories on or near the South Coast and on the Bristol Channel proved to be early targets for enemy bombers and the large number of vital factories for aircraft production around London and in Birmingham and Coventry proved to be very undesirable concentrations of aircraft capacity.

[1] Excluding provision for manufacture of aviation fuel which in this period required over £12 million.

[2] For an account of problems and policies of location see Chapter IX, The Strategic Location of Factories.

After the outbreak of war there had been immediate concern for the factories in and around London where a very large part of vital instrument production was located. Early in October 1939 a policy of encouraging firms to develop or to enlarge capacity outside London was agreed. It was not until the first attacks by enemy aircraft came, that action to disperse existing capacity developed. Following the first daylight raid on Croydon, an engine repair organisation was moved from Croydon to South Wales. After the first daylight raids on Vickers at Weybridge and Supermarine at Southampton, immediate action was taken to establish part of the production in requisitioned buildings mainly in the upper Thames valley and in Hampshire.

The Minister of Aircraft Production—Lord Beaverbrook—reacted to the enemy attacks on aircraft factories with characteristic energy. An organisation was immediately set up in M.A.P. to secure the dispersal of all aircraft factories. It was essential that production should be maintained and that factories should be able to carry on despite bombing of the main factory. Dispersal was to be applied not merely to factories already damaged but to all factories. In this way part of the capacity would be unaffected by bombing and the loss of capacity due to enemy attack at the main factory might be reduced. Existing buildings of all kinds were used as dispersal units and building work was limited to essential adaptation and repair. This organisation was set up and the policy formulated during the Battle of Britain when several aircraft factories received major damage. The requisitioning of premises proceeded rapidly and by the end of October over 300 premises had been acquired. By the end of the year dispersal had been achieved for many factories. Many of the major aircraft factories as far apart as Chester and Southampton had moved out part of their capacity to about twenty or thirty places for each factory. For Hurricane production in comparatively sequestered Gloucestershire, no less than 48 dispersal units had been acquired. The dispersal of some engine factories was also planned which meant moving a considerable part of the machine tools from the main factory.

Dispersal on this scale, in anticipation of attack, damaged production but it improved the prospect of security. The fall in output in the last three months of 1940 reflected in addition to direct damage both the effect of dispersal and of time lost due to air raid warnings. The loss was no doubt greatest at the time of the actual transfer of capacity though disadvantages continued with the division of the main capacity and the acute subdivision of dispersed capacity. Although later many of the abandoned factories were reoccupied and the dispersal points often became little more than overflow accommodation, there remained throughout the war a substantial measure of dispersal of capacity. Major replacement of severely damaged capacity was excluded, though in time much of the damaged plant was repaired and the main factory at least partly re-established. After the first months of urgency, the advantages of some measure of dispersion for all major capacity was not allowed to prevent the planning of large scale production. Even so, the need for avoiding large scale building work, the increasing availability of existing factory buildings no longer required for civilian production, and the practice of subdivision which had been learnt under urgent dispersal, led to the continued maintenance of subdivision of capacity, though in units of more convenient size. When the heavy air attacks stopped in 1941, the dispersal policy languished, and ultimately it was ruled by the Prime Minister that no further voluntary dispersal should take place.

The process of dispersal resulted in a considerable addition to floor space, especially for airframe factories. By the autumn of 1941 the productive floor space in buildings other than the main factories was well over 4 million square feet and a large part of this had been occupied as part of the dispersal policy. There had been some serious loss of floor space due to enemy action; nevertheless the net addition was about 4 million square feet, all secured in less than 12 months. Moreover, dispersal developed the practice of making use of other premises to provide floor space for work which could be readily separated. Floor space was increasingly required not only for production but for the storage of components. Dispersal of stores was a valuable precaution and a ready means of adding to the total floor space and it therefore continued even when the process of voluntary dispersal was ended. As a result both of the dispersal programme and making use of available premises, most of the aircraft and engine factories at the peak of war production had a fairly large number of much smaller satellite premises of various sizes and functions. Many aircraft firms had over 20 quite separate factory premises in use in addition to their main factories even after the less economical of the dispersal units had been abandoned.

Dispersal was applied in all sections of aircraft manufacture, though the number of schemes and the cost were by far the largest for the aircraft factories. Some engine firms had at least 20 dispersal units though many had much less than this. Aircraft equipment with a large number of firms had by far the largest list of firms affected by dispersal and the largest expenditure after aircraft factories. Apart from airframe engine and engine accessory factories most other factories had only one or two dispersal units. Many of the factories were comparatively small and with some a virtual duplication of capacity was possible instead of general dispersal. A notable exception was the dispersal of aircraft gun manufacture under B.S.A. This was to a large degree compulsory dispersal following the heavy raids on the Birmingham factory in 1940 and established the manufacture of the Browning gun in more than twelve separate factory buildings in Warwickshire, Worcestershire and

Staffordshire and part of the production of the Hispano gun in an underground factory. Dispersal was a rapid means of expansion and it was economical in building resources and labour. Even so it was not obtained without some expenditure of capital resources. In the first twelve months the total commitment on building work amounted to £7 million; the final commitment for building was over £11 million and for plant £9 million. Dispersal of aircraft factories at a total cost of over £6 million was by far the largest item. Engines with less than £2 million was in fact exceeded by aircraft equipment with over £2 million. Radio and radar accounted for £¾ million but no other item reached £½ million. Despite the general policy of adaptation of existing premises of all kinds, some building work could not be avoided. Even the building of new factories had to be undertaken but only when the compulsory evacuation of a large part or all of the main factory was necessary. Thus the dispersal of Shorts to South Marston and to Windermere required nearly a £1 million for building work. In contrast, less than £1,000 sufficed for building work at scores of dispersal units.

Closely related to dispersal was the construction of underground factories. This proved to be a much slower and far more expensive expedient. All the schemes for underground factories arose from the problem of securing safe dispersal for heavily bombed factories, although the largest scheme developed far beyond the first proposal and was at a different location. The possibility of underground factories was discussed at the Supply Board in September 1940 but there was much opposition to the proposal; it was difficult to justify a claim for special treatment of some production and some workers and the cost of a more general application would be prohibitive. Approval was therefore only to be given in very special circumstances. The weight of opposition did not deter Lord Beaverbrook, the Minister of Aircraft Production, from proceeding with a number of underground schemes. The first scheme was approved in September 1940 and what proved to be the last in February 1941; shortly afterwards, the Prime Minister's ruling against further voluntary dispersal left little scope for any more underground schemes. In all, there were four major schemes and several smaller schemes some of which were only partially underground.

The outcome of the four major schemes showed that, in the main, the reluctance to proceed on large scale underground work was by no means unjustified. They all took longer to complete and cost considerably more than was at first estimated; and the cost far exceeded the cost of an overhead factory of equal size. For the first scheme proposed in September 1940 there were indeed many initial advantages though in the end expenditure was considerable. As a result of this scheme some 8,000 workers were accommodated in an unfinished Underground railway tunnel which was equipped for the production of aircraft equipment components. For this although the total cost exceeded £½ million, the main structure was already available. The second scheme, in November 1940, made use of an existing cavern in the Midlands, for Browning gun production. The third scheme was the result of the urgent need after the Coventry raids to create reserve capacity for engine manufacture. The original recommendation in February 1941, was that a tunnel of about 250,000 square feet costing about £250,000 without services, should be constructed at a suitable site within reach of Coventry. A site was chosen and a tunnel constructed but not in the area originally proposed; this was made available for the transfer of the most vital work of important factories which had suffered actual damage or were situated in a vulnerable area. The estimated cost was very greatly exceeded and the final commitment, excluding hostels but including works services reached £1 million. This raised the cost per square foot to about double that for a surface factory.

The other major scheme was by far the largest and the most costly in time and resources, and resulted in a factory space of over two million square feet in underground quarries. This was planned to provide accommodation for 50 per cent. of Bristol Aeroplane Co.'s engine production, both of new and repaired engines (including the output of subcontractors); also 50 per cent. of their airframe and exhaust ring capacity and the major part of their development work. The area to be used was 2,200,000 square feet and the cost was estimated at £1,746,000 for the factory and £595,000 for the provision of hostels for 8,000 single workers. This large and unprecedented task was beset with difficulties from the start. A very large constructional labour force of at least 8,000 was required; this proved difficult to recruit and to retain, despite the large hutted village built for their accommodation. The rock formation hampered constructional work; and the division of the work between four contractors increased the problems of planning and control. Construction took so long that the original dispersal scheme was abandoned and a new engine factory unit installed in the underground accommodation. In addition, accommodation was provided for the manufacture of Browning gun barrels, aircraft turrets and undercarriages. Production of gun barrels started at the underground factory in August 1942 but the first Bristol engine was not delivered from the factory until September 1943.

Construction took longer and cost far more than would have been needed for the construction of new factories of similar capacity. The constructional work was finally estimated at some £4½ million. This alone gave a higher cost per square foot than an equivalent surface factory. In addition there were many other costs many of which would not have been incurred for other factory construction. These included large expenditure on railways and services of all kinds but the largest single item was for hostels and housing to the extent of some £2¾ million. In 1944 the total expenditure on this scheme was estimated at nearly £12 million. This was a high cost for a factory which in manifold compartments provided about two million square feet and at which the labour force employed did not reach 8,000. Furthermore the extreme subdivision of floor space hampered production very considerably and the output was very low for the number of workers employed.

The first scheme, which made use of an underground railway tunnel, was by far the most successful of these underground factories and it is clear that it was only where the main structure was already available and required only limited adaptation that the results of these underground schemes justified the expenditure of very limited resources. The cost and outcome of the largest schemes showed that the opposition to the underground factories in 1940 was well founded. In retrospect it was difficult to justify this scheme even against the background of the situation in December 1940.[1] Had the worst forebodings of 1940 been realised it would have been of little consequence that a fraction of capacity was safely accommodated underground.

(iv)
Expansion 1941–44

Dispersal no doubt did much to reduce the affect of enemy bombing on aircraft factories and the frequent dislocation of work at the main factories in the winter of 1940. Despite these measures dislocation of production persisted for some time and the output of aircraft dropped severely between August 1940 and January 1941. In July 1940 a total of 1,665 was reached for the month; in January 1941 the output was only 1,198. Despite a rapid recovery in February 1941 the total output in July 1941 was no larger than it had been in July 1940. Although the monthly output of heavy bombers had increased from 4 to 38, the output of medium bombers was less than in August 1940. Output was rising again but the prospect of the 2,300 aircraft a month with which war-time planning had started was still a long way off. With the programme of dispersal virtually complete, the time had clearly come for a new assessment of the capacity available. When in August 1941 the Prime Minister called for a large increase in the proposed output of heavy and medium bombers some further expansion of the factory programme was inevitable.

[1] The Public Accounts Committee, 1943, Q.5437.

By the summer of 1941 the capital commitments for 2,300 aircraft a month were in total complete. Dispersal and the special efforts of 1940 had in some measure diverted some of the factory capacity from the initial planning and all factories had to operate under war-time conditions which effectively reduced their output. By 1941, however these abnormal conditions had become fairly 'normal' and it was possible to ask direct questions about potential output from the existing factories and to calculate the extent to which additional factories were necessary to obtain the quantity and types of aircraft required under the new bomber programmes.

The bomber programme of 1941 was the true successor of the 2,300 aircraft a month programme with which war-time planning had started.[1] The bomber programme of December 1941 required an increase of over 260 aircraft in 1943 making a monthly output of over 2,500 aircraft, and of the additional 260 aircraft, 150 were to be heavy bombers. Theoretically, the output of 2,300 aircraft should have been within the capacity already developed and the new factories constructed by the end of 1941. By the end of 1941 most of the capacity lost through air attack had been replaced and the dispersal factories were providing some increase in capacity as both the main and dispersal factories were being fully used by many firms. However, estimates in the summer of 1941 indicated that existing capacity would not provide the full 2,300 but would be likely to give something over 2,000 aircraft a month and rising to 2,150 aircraft if extra machine tools and extra factories were provided for some items especially light metals. To meet the full target of over 2,500 aircraft a month very considerable additions would be necessary to floor space both for aircraft, metal fabricating, undercarriage and propellor factories. On the other hand it was estimated that the existing engine factories would be adequate without expansion.

Including all items the capital provision for building alone was estimated at £17.8 million and involved the provision of over 6 million square feet of floor space. Together with the capital provision to ensure the output of 2,150 aircraft a month the total addition for building was likely to exceed £30 million. The additional capacity actually provided under these programmes, though subject to many changes in detail, proved to be much on the scale proposed in 1941. By September 1943 the output of 2,300 aircraft a month had been firmly reached and by March 1944 the further stage of 2,500 aircraft was in sight. The output of bombers however did not match the programme. This failure can be attributed partly to decisions taken after the programme of capital provision was approved in principle. In particular it was decided not to construct the four new factories that had been planned

[1] For an account of the wide range of aircraft programmes in this period see *British War Production*, *op. cit.*, pp. 66-69 and 123-126.

for heavy bombers but to rely instead on extensions and the use of at least one medium bomber factory for heavy bombers. The plan for the new heavy bomber factories was abandoned mainly because definite hopes were placed on second shift working. But apart from this the practical difficulties of constructing and manning the new factories and obtaining the required output within two years were formidable.

The factory scheme for the bomber programme of 1941 was thus a compromise. It probably proved to be the right compromise; given a little more time and without the manpower cuts of 1944, it would have been successful though with some loss of medium bombers. If the large new factories had been built they would have been complete just in time to be declared redundant or impossible to man. Up to the spring of 1945 the building commitment continued without any substantial reduction largely because a number of schemes of small or moderate scale were grafted on to the older expansion schemes. Large new factories were not constructed and the main pressure was exerted now not so much at the assembly factories—though some extension schemes were necessary there—as at the sources of component and sub-assembly supply. By far the greater number of other schemes in the manufacturing sectors were extremely small. Thus the factory programme which had for long proceeded on the basis of many large new factories was in the final stages mainly concerned with hundreds of very small schemes which in the aggregate amounted to a large commitment. It was equally characteristic that a programme which had started with schemes for a comparatively homogeneous, self-contained capacity, now included the work of more firms than were engaged on any other production.

(v)
The Cost of the Factory Programme

The factory programme which started in 1936 with a capital commitment[1] for less than £10 million had reached in 1945 a total commitment of over £425 million. In 1936, the commitment was for airframe and engine factories only, in 1945 it covered the whole range of production required for aircraft manufacture in addition to airframes and engines. Moreover the commitment was no longer confined to new factories, it included hundreds of schemes for extensions to existing factories and it included very large quantities of plant and machine tools supplied to hundreds of factories of all kinds. It also included

[1] Capital commitment was the term used to denote the maximum amount to which the department was committed for capital expansion schemes. Authorised expenditure was an alternative term with the same meaning. The actual expenditure came later and might be less than the commitment.

schemes for additional quantities of plant and machine tools required for changes of programme or expansion of output at many of the new factories.

The cost of the factory programme was thus a persistently increasing commitment which was applied to an ever widening range of factories, firms and products. By the outbreak of war the commitment exceeded £50 million and within three months the total had reached £100 million. In the next two years £100 million was added and with the bomber programme of 1941 a further £100 million was added to the commitment in twelve months. Thus by December 1942 the total exceeded £300 million. After that the rate of increase was much reduced although for several months the addition exceeded £5 million a month.

In the total of £425 million there were a number of items that had no part in the manufacture of complete aircraft. Installations for aviation fuel, capacity for the assembly of North American aircraft, special landing grounds, storage for reserve aircraft, accounted for over £30 million. Even with these items excluded, the total of £394 million

Capital commitment. Buildings and Plant

	Dec. 1939	*Aug. 1940*	*Aug. 1941*	*Dec. 1942*	*Mar. 1944*	*Sept. 1945*
Cumulative Total (£m) *	102	134	198	318	390	425
Increase (£m)		32	64	120	72	35
Monthly Rate (£m)		4	5·3	7·4	4·7	2

* From April 1936.

includes provision for research and development, for dispersal and repair, for housing and hostels, and for underground factories, but the inclusion of these items does not distort the main trend of the direct capital commitments for the manufacture of aircraft. Of the total of £394 million more than £170 million was for building work. Of this a very large part was for building of complete new factories but a very substantial total was for extensions of all kinds and sizes, from canteens to complete factory buildings. In contrast to munitions production the total for plant and machine tools at about £220 million was only about 25 per cent. more than for buildings. This was partly due to the very large amount of building work and the comparatively small amount of manufacturing plant for airframe construction; the trend of building commitments was also maintained by the cumulative effect of the bomber programme, housing and the underground factories.

The persistent increase in capital commitments did not pass without comment. There were it is true many extraneous items which had no connection with the manufacture of new aircraft. There was also the much higher proportion of very large aircraft and the increasing demand for spare components, sub-assemblies and engines. There was also the increase in the prices of capital goods, especially for factory building.[1] Even so, when the extraneous commitments are removed the capital provision to secure a further increase in output did increase steadily.

A precise tally of the total capital commitments with the output of aircraft is impossible. The factory programme was a highly complex accumulation of needs and expedients. Not merely had it to meet the cost of dispersal and of repair but in the manufacture of new aircraft it had to cater for frequent changes in types of aircraft, engines and equipment. The total commitment at any date included not merely what was thought necessary to meet the current programme but also what had been necessary for earlier programmes; much of the earlier capacity could be used again but some had to be re-equipped. Nor was the final total commitment what was needed to supply the peak output of aircraft; the peak was reached eighteen months before the end of the war and before the factory programme came to an end; and some capacity was available before the programme started. In fact, both the programme of requirements and in consequence the factory programme were subject to continuous change and development.

The trend of government expenditure on capital assets and the

Actual Capital Expenditure and Output of Aircraft

	March 1939	March 1940	March 1941	March 1942	March 1943	March 1944
Capital Expenditure Cumulative* £m	12·7	33·7	131	204·2	288	350
Net increase £m	—	21	97·3	73·2	84	62
Monthly output (12 months later)	860	1,730	1,908	2,264	2,715	1,828
Structure weight (millions lbs)	3·3	7·2	9·6	15·4	20·3	15·2
Net increase						
all types	—	870	178	356	451	—
heavy bombers	—	37	67	268	148	—

* From April 1936.

[1] For building and civil engineering the increase in prices from the 1939 level probably increased costs by 35 per cent. by 1941 and by at least 50 per cent. from 1943 onwards. But the increase in prices for building services and for plant and machine tools was less than this.

output of aircraft twelve months later indicate something of the relation between the factory programme and output.

The contrast with pre-war expenditure is extreme. Before the outbreak of war an increase of at least 600 aircraft a month was achieved with a government capital expenditure of less than £12 million or a total capital expenditure of £30 million including the private capital expansion in the aircraft and ancillary industries. In the first twelve months of war, a further increase of 600 aircraft a month was achieved, again with additional capital expenditure of about £30 million. After 1940, increased output of aircraft seems to have entailed much larger capital expenditure. Even when extraneous items are removed, an increase of 350 aircraft a month followed an additional capital expenditure of at least £70 million and between 1941 and 1944, when the additional capital expenditure excluding extraneous items exceeded £150 million, the increase in output was only 750 aircraft a month. After 1940, every increase in output required capital provision not merely for the manufacture of the aircraft but for every item which went into the manufacture, starting from the raw bauxite from which the aluminium was prepared. The increase in weight and size of aircraft alone made it necessary to greatly increase raw material and fabricated material capacity. Size had also a marked effect on the floor space required both at the aircraft factories and at the subcontractors. Similarly, size and increased equipment resulted in a lengthening of the manufacturing cycle for the aircraft. This, combined with increase in size, reduced the number of aircraft that could be dealt with in a given factory space in a given period. This applied both at the aircraft factory and at the sub-assembly subcontractors. Demands for new types of aircraft and engines, all added to the capital provision. There were thus many factors to account for a large increase in the capital commitment. Every scheme was carefully examined and only approved when it could be shown to be necessary. Given the current organisation of aircraft production and the current assumption as to efficiency of operation, the increases in capital commitment and in the factory programme were unavoidable.

The cost of expanding capacity for aircraft production is seen more specifically in the total capital commitment for each of the major sectors of production. The capital commitments for aircraft and engine factories dominate the account. Only the schemes for light alloy production approach anything like the amounts required for aircraft and engine factories. The amounts for light alloys include commitments for certain extractive plants for bauxite and manufacturing plants for aluminium constructed overseas. These amounted to about £17 million but the total commitment emphasises the dependence of aircraft production on the development of a major basic industry for light alloy production.

Capital Commitments 1936 to September 1945

	Buildings £m	Plant £m
(1) Aircraft factories and sub-contracting*	63·5	39·6
(2) Engines, accessories and sub-contracting	36·0	81·1
(3) Propellors	3·8	12·2
(4) Undercarriages†	·8	3·8
(5) Radio and radar	3·6	6·3
(6) Aircraft equipment and instruments	3·8	5·7
(7) Guns and turrets	2·3	8·3
(8) Light alloys	25·4	44·6

* Including some expenditure for undercarriages.

† Excluding expenditure on undercarriages at aircraft firms, which is included in (1) above. All amounts also include expenditure for repair, subcontracting and dispersal.

In 1936, all capital schemes were for agency factories, they were all new factories to be managed on behalf of the state. In 1938, several factories were approved to be operated as extensions to the firms' existing factories. Although the factories were built at government expense they were rented to the firm who operated the factories on a normal commercial basis. In addition, there were many direct extensions of existing factories in order to enlarge the factory accommodation available for aircraft work. Extension schemes, whether by the provision of a complete new factory or as direct extension of an existing factory, were to become an increasing part of the factory programme. Even so many agency, or shadow factory schemes were also approved and they remained a substantial part of the total programme.

*Main factory commitment at September 1945 (£m)**

	Buildings	Plant
Shadow factory schemes	58·5	87·2
Extension schemes	100·2	124·9

* Excluding government establishments and certain other schemes.

It was not until 1941 that extensions exceeded shadow schemes and not until the second half of the war that the ascendancy of extension schemes was firmly established.

In the aircraft factory programme there were no fully fledged state factories, like the R.O.Fs, owned and managed by the state. This was true even though almost all the factories were constructed and equipped entirely at government expense. The factories were either agency factories managed on behalf of the Ministry, or factories and extensions of existing factories rented to the firm. The aircraft factory programme was the largest of this kind, the total expenditure greatly exceeded the War Office and Ministry of Supply expenditure on agency factories and extensions to factories. Responsibility for the construction of the factories rested with the firms who were to occupy and manage the factories. The firm was given the task not merely of preparing plans for the factory but also of placing contracts for construction and equipment of the factory. This arrangement worked very well and relieved the Ministry of a very heavy burden. Even so, as early as 1938 the Air Ministry set up a Directorate of Air Ministry Factories and from 1939 onwards this Directorate was primarily concerned with the technical approval of the plans for new factories and building work undertaken for the aircraft programme. With the rapid expansion of the building programme after the outbreak of war and the greatly increased competition for building resources, the Directorate quickly assumed the many functions inseparable from problems of priority and acceleration. These functions became increasingly onerous with the transfer of the Directorate to M.A.P. and the inception of the dispersal policy and the further expansion schemes for bomber production. In M.A.P. the functions were widened to include responsibility for direct works and although these were mainly concerned with M.A.P. airfields, hangars, research establishments and storage facilities, the Directorate also undertook the supply of pre-fabricated factory buildings. These in fact constituted the only new factory construction for which the firms were not responsible.[1]

(vi)

The Factory Programme and Output

Broadly conceived in terms of output of aircraft per month, the aircraft programme of 2,500 aircraft a month was achieved by March 1944. But the result in some of the main groups was not so satisfactory —both heavy and medium bombers still fell short of the programme and in the previous twelve months naval aircraft had lagged far behind. Moreover it had taken almost two years longer than anticipated in 1939 and had cost very much more in capital expenditure than had been expected. The programme was not merely a problem of total quantity nor even of main groups of aircraft. Within the overall tally of quantity there was an ever changing flow of requirements in terms of specific types of aircraft and in the demand for spares and for

[1] For an account of the work of the Directorate of Aircraft Production Factories see *Works and Buildings*, *op. cit.*, Chapter XIV.

modifications. In these frequent changes were to be found many obstacles to increased and balanced output.

Mere quantity of aircraft does not give an adequate measure of the size and scope of the problem even at the aircraft factory level. An ever increasing part of production was outside the aircraft factories. In the main, materials and component production were under direct Ministry control and were a separate part of the factory programme but the subcontracting of airframe work was mainly organised and controlled by the aircraft firms. Every change in programme, every expansion in output involved a change in the demands on subcontracting; the increased output of aircraft factories depended less on the capacity of the factories than on the success of the subcontracting organisation. Thus the aircraft factories were the nodal point of an ever growing capacity outside the factories and the output and changes in output were the result of forces operating outside as well as within the factory. All aircraft factories, but particularly factories for heavy and medium bombers, were largely dependent on subcontracting of major aircraft assemblies. This meant that the balanced output from subcontractors set the upward limit of output for the aircraft factory. For the most part any permanent increase in output and any change of type had to be implemented first in the subcontracting capacity. Even the demand for more shift working, unless there was a large stock of sub-assemblies and components, had first to be met in the subcontracting firms. The floor space at most aircraft factories could not be fully used on more than one shift even when subcontractors were working three shifts on sub-assemblies. At the peak of the effort in the production of Lancaster bombers the aircraft factories, with only a partial second shift, were able to take all the sub-assemblies that the subcontractors could provide working on two and even three shifts.

Only when the peak of war production had been passed was it possible to assess and evaluate the policies of expansion. Of the very large measure of success there could be no doubt; the problem of assessment applies rather on the margin. How far were the policies applied in the right proportions? The shadow industry policy was by 1938 providing valuable output and the further application in 1938, 1939 and 1940 proved even more valuable in war production. The decision to extend the capacity under the professional industry by the addition of major agency factories also proved substantially successful, even if in some firms, capacity was extended beyond their managerial and administrative strength. These firms might not have outgrown their strength had not the war forced them to disperse their factories very widely from the main factory. All the same a further extension of the shadow industry and a more limited extension of one or two aircraft firms might have been justified.

The policy of subcontracting that began in 1938 and grew in strength throughout the war undoubtedly played a very large part in the success achieved. In total employment the subcontractors accounted for a good deal more than the shadow industry. Judged by the measure of employment on aircraft construction, subcontracting solved at least half the problem of expansion for war production. Subcontracting was of fundamental importance but extensive reliance on it could bring some disadvantages. The function of some of the new aircraft factories was reduced to the assembly of outside supplies of sub-assemblies, and this limited the part the aircraft factories could take in achieving a change of programme. Thus the brunt of further expansion or the introduction of new types tended to fall on the subcontractors rather than on the aircraft factory. This may have resulted in something like an under-employment of some of the new factories and an excessive load on the subcontractors. The decision in 1941 not to proceed with the construction of new heavy bomber factories but to rely in the main on the expansion of final assembly capacity and subcontracting, swung the balance even further on the side of subcontracting. Had there been time, the best policy might well have been to reduce the proportion of subcontracting by the provision of new aircraft factories able to undertake a large measure of sub-assembly and component work. At the peak of war production the balance may well have been too heavily down on the side of subcontracting with the consequent tendency to under-employment of the aircraft factories.

CHAPTER VII

THE AIRCRAFT FACTORIES

(i)

The Shadow Industry and Shadow Firms

THE formation of a shadow industry for aircraft production was announced in the Statement Relating to Defence in 1936.[1] The term shadow industry was probably used first in 1934 in the Weir memorandum on rearmament expansion but it was then applied to the plans proposed for the development of capacity for munitions production. It was not until 1936 when the new aircraft programme was discussed that the term was applied specifically to the expansion of aircraft manufacturing capacity. But although the term had not been used, a shadow industry had been planned for aircraft production as early as 1929 and it was a revision of these plans that was adopted in 1936. The shadow industry was to consist of factories managed by firms from outside the aircraft industry and initially the term shadow factory was only applied to the factories planned as part of the shadow industry. But when in 1938 and subsequently it was decided to provide new factories at government expense to be managed by aircraft firms for an agency fee—the term shadow factory was also applied to these factories. By the end of 1939 there were at least as many shadow factories to be managed by the aircraft industry as by outside firms. Though the term was not generally used it is convenient and appropriate to refer to these outside firms as shadow firms.

The agency factory system, which as we have seen, was used extensively for the expansion of munitions capacity of all kinds, was not an essential part of the shadow industry policy. Indeed, it was not assumed that new factories would always be necessary for the shadow industry. It was envisaged in 1934 that many additions to the shadow industry might be made by using the existing factories of the selected firms. Even when a new factory building had to be erected it sometimes proved expedient to lease the building to the shadow firm and not to place the scheme on an agency basis. In 1938 and later, several shadow schemes were arranged in this way. Thus agency factories, all of which in the Air Ministry and Ministry of Aircraft Production were called shadow factories, were not essential to the shadow industry and by the

[1] Cmd. 5107.

peak of war production more aircraft shadow factories were under aircraft firms than under the shadow firms.

From the first hypothetical planning for aircraft expansion, the motor vehicle industry had been selected as the obvious and most suitable from which to select firms for the shadow industry. Direct commercial links were in fact few and mainly related to engine production but the technological and engineering similarities provided obvious advantages. In addition, the motor vehicle industry, unlike the aircraft industry, was expanding rapidly and several firms were undoubted leaders in large scale production. Moreover, the motor car industry had by 1935 completed the conversion to metal fabricated bodies and structures. As a result not merely were firms for aero-engine production selected from the motor vehicle industry but the first two shadow factories for aircraft construction were planned and managed by two motor car manufacturers. All the seven firms that came into the shadow industry in 1936 were from the motor car industry. All of them shared in the formation of the aero-engine section of the shadow industry but at first only two entered the aircraft section. These two, Austins and Rootes both undertook the planning, construction and management of an agency factory for aircraft production. In 1936, it appeared that for some time to come the shadow industry for aircraft as well as aero-engine production would be drawn entirely from the motor vehicle industry.

In 1938, the aircraft firms, confronted with the increased requirements for the next two years, were involved in further extensions. Many of them indeed would need considerable assistance from outside firms. A large part of this assistance, it was recommended, should be secured by large scale subcontracting. There were difficulties here. Some outside firms were loath to accept major subcontracts and preferred a direct contract and full responsibility for the delivery of a complete aircraft. An alternative, which was adopted in 1938, was for the selected firm to organise wide scale subcontracting and to undertake the final assembly of the aircraft or of the airframe only. Difficulties experienced with the first two aircraft shadow factories pointed to the advantage of a more extensive use of existing manufacturing units and the reduction of new building and new factory organisation. Three schemes were approved with outside firms in 1938 and two of these were to prove to be the largest ventures in manufacture by outside firms. One scheme brought the English Electric Company into aircraft manufacture; this scheme which was provisionally approved in June 1938 was to provide additional capacity for the production of the Handley Page's new Halifax bombers, which were to be ready for manufacture in 1940. There was no immediate need for the construction of new factory buildings; the English Electric Company were able to provide immediately more than 400,000 square feet of factory floor space and had at least 2,000 workers available at their Preston Works. At the same time, negotiations were proceeding to bring another large electrical firm—Metro-Vickers—into aircraft production. Several schemes were considered but eventually it was agreed that Metro-Vickers should provide additional capacity for A. V. Roe's Manchester bomber and subsequently its successor—the Lancaster. An essential element in the Metro-Vickers scheme was the organisation of extensive subcontracting for fabrication and sub-assembly work. It was necessary for Metro-Vickers to build a new airframe factory near, but not adjacent, to their main factory. Both these schemes were major additions to the shadow industry. In both of them factory space was provided at government expense, but neither scheme was on an agency basis.

The third outside firm to be introduced in 1938 for aircraft construction was the Nuffield Organisation. This was rather more than a mere continuation of the earlier policy of making use of the technical resources of the motor car firms. Difficulties had prevented Lord Nuffield from undertaking the manufacture of aero-engines but the Air Ministry accepted the proposal that the Nuffield experience of mass production should be applied to the problems of fighter aircraft production. Like the two earlier schemes—with Austins and Rootes—the scheme involved the construction of a new self-contained agency factory for aircraft construction, to be directed by the management drawn from a motor car firm. The Nuffield factory was intended to greatly increase the output of Spitfires in the second half of 1940 and to meet the large demand that would inevitably arise for fighter aircraft in the event of war. This factory of over one million square feet was by far the largest shadow factory planned. It did not remain long in the shadow industry, for when production was about to begin in May 1940, it was placed under the management of Vickers—the parent firm of the Spitfire. Nevertheless, the factory was planned and constructed under a shadow firm and in 1943 supplied 70 per cent. of the peak output of Spitfires.

Austins, Rootes, Nuffield, English Electric and Metro-Vickers, these were the five firms introduced in the pre-war period as shadow firms for aircraft construction. From the summer of 1938 much more attention was given to expansion of the factory capacity under aircraft firms and no other aircraft shadow firms were introduced before the outbreak of war. In the first year of war a number of smaller firms were introduced for war production but mostly for rather circumstantial reasons. Standard Motors were adopted for the manufacture of Oxford aircraft in the first month of war; this came about primarily because the firm's capacity was fully allocated to the Air Ministry but was not immediately fully employed. At the same time Morris Motors were undertaking extensive subcontracting work on the Tiger Moth for de

Havilland and in the course of 1940 they graduated to final assembly and delivery of complete aircraft and became a fully fledged shadow firm.

The only other major shadow capacity was the London Aircraft Production Group. Early in 1940 when it became necessary to find additional capacity for the Halifax, it was proposed to recruit a major group of subcontractors which would use several London Passenger Transport Board depots; these buildings were highly suitable for the large structures of the heavy bomber. As the scheme developed, at least nine L.P.T.B. depots and several motor body works in North London were brought in. At an early stage it was decided to form this into a shadow group with direct contracts for aircraft construction. An output of 32 Halifax bombers a month was to be assembled from components to be manufactured by the members of the group. This was the last addition to the shadow industry for aircraft assembly, but since the factories were not agency factories, the scheme did not add to the list of shadow factories.

In 1936 it had seemed probable that the introduction of outside firms for aircraft production would usually mean the erection of complete shadow factories. This was the arrangement for the first two firms and for the Nuffield Spitfire factory approved in 1938; but for other schemes a rather closer integration with existing factories proved possible. Thus in 1938, English Electric were able to provide the greater part of the initial accommodation by use of part of the factory at Preston. Facilities for final and flight assembly and trials were provided at a new airfield which the Preston and Blackburn municipalities undertook to construct. The Metro-Vickers scheme was based on a new and relatively small factory building to be constructed on a new site near to the firm's existing factory at Trafford Park. No aerodrome facilities were provided. The essential basis of the scheme was the organisation of large scale subcontracting under the central direction of Metro-Vickers. This shadow scheme differed from the others in that the final assembly of the aircraft was, until 1943, done by the parent firm, A. V. Roe. But from 1943 all Lancasters and Lincolns produced by Metro-Vickers were assembled by them ready for flight at a new aerodrome which they shared with the parent firm A. V. Roe. All these schemes were eventually to involve extensive new factory construction. It was the war-time shadow schemes that made the most direct use of the existing factory accommodation. The London Aircraft Production Group was eventually to show that a large output of heavy bombers could be achieved with very limited new building.

The war-time additions to the shadow firms were by no means negligible. The London Aircraft Production Group of firms with a monthly output of 30 Halifax bombers and employing some 9,000 on this work, the Standard Motor Company with an eventual output of over 60 Mosquitoes a month made valuable contributions to operational requirements. Even so, the largest shadow industry schemes were those founded in the pre-war period and these schemes were greatly extended both before and after the outbreak of war. The Rootes shadow factory at Speke, planned in 1936 to produce 40 Blenheim aircraft a month, was extended in 1938, 1939, 1940 and 1941 when an output of 60 Halifax a month was scheduled. Despite the use of several requisitioned factories and dispersal centres, all these changes required extensions to factory space and equipment. In addition the new aircraft agency factory at Stoke was allocated to Rootes for modification and repair work on Blenheim aircraft so that capacity at Speke could be released for Halifax production. Thus the factory space under this shadow scheme was increased several times before the peak of war production was reached. Similarly, the English Electric shadow scheme which started with less than 300,000 square feet of factory space was increased throughout 1939 and 1940 and finally in 1942, until over two million square feet were used for the monthly production of 70 Halifax heavy bombers.

Although in the total war output of aircraft the shadow industry accounted for only 12 per cent., the contribution to the supply of many operational types was very much larger than this.[1] Thus the shadow industry supplied over 45 per cent. of the total output of heavy bombers and more than two thirds of the total output of the Blenheim light bomber. As for the Spitfire, had the Castle Bromwich factory remained within the shadow industry more than half the peak output of Spitfires would have come from the shadow industry. The contribution of shadow firms to the production of other types was for the most part very small—a few hundred Hurricanes and Beaufighters compared with the many thousands produced by the aircraft firms. In the grand total of over 53,000 light bombers and fighters the shadow firms produced less than 5,000. In the total of over 30,000 trainers the shadow firms produced less than 3,000.

(ii)

The Expansion of the Aircraft Industry

Despite the contribution of the shadow industry, much the larger task of expansion had to be undertaken within the aircraft industry. Between 1939 and 1945 the aircraft industry supplied 88 per cent. of the total output of aircraft and the same proportion of the peak output in the first quarter of 1944. Even assessed on structure weight the industry

[1] The exclusion of the Castle Bromwich factory from the shadow industry greatly reduces the total output of the shadow industry: had that factory remained under the shadow industry the total output from the shadow industry would have exceeded 30,000—22 per cent. of the total output.

supplied 78 per cent. of the total output of aircraft. Of the total of 26,461 aircraft produced in the United Kingdom in 1944, over 23,000 were produced by the aircraft industry. In 1935, the production of military aircraft was 893 and in 1936 it had risen to only 1,830. Even allowing for the small production of civil aircraft the numerical output of the aircraft industry increased by 1944 to twelve times that of 1936. Measured in structure weight the deliveries of the aircraft industry increased about 40 times (from 3.75 to 150 million tons). Taken in terms of labour employed on aircraft construction and final assembly, the capacity of the aircraft firms increased almost tenfold between 1936 and 1944 (27,000 in 1936 and 250,000 in 1944 on aircraft production under aircraft firms). In 1944 the shadow firms employed about 45,000 on aircraft production but the aircraft firms had expanded their employment on aircraft construction by at least 220,000.[1]

The contrast was not merely in quantity. The types of aircraft manufactured by the aircraft industry in 1936 were all out of date before the outbreak of war; in construction and weight they were comparable to war-time trainer aircraft. In 1944, for each of the aircraft produced in 1936 the aircraft industry produced at least twelve aircraft, of very different types.

3 Heavy bombers or transports
1 Medium bomber
5 Light bombers and fighters
1 Naval aircraft
2 Trainers

This expansion of output and of final assembly capacity was due almost entirely to the expansion of capacity under the firms manufacturing aircraft in 1936. Of the twenty-four aircraft firms in production in 1944 all but two firms were aircraft manufacturers in 1936; although only seventeen of the firms were then manufacturing aircraft for the Air Ministry. In August 1939, twenty firms had contracts for aircraft production and employed about 100,000 on this work. By November 1943, these firms employed well over 200,000 on this work. Only four other firms came into the assembly of aircraft after 1939. Three of these firms were already in the industry but only one had previously undertaken the manufacture of complete aircraft. The total labour force of the four firms in 1944 was less than 8,000 out of a total for the aircraft firms of over 250,000.

Great as it was, the expansion of the aircraft firms was less than would have been needed if the industry's organisation of production had remained unchanged. In particular, after 1938 aircraft constructors depended far more on subcontractors. This is largely obscured by the much greater number of aircraft dealt with by each aircraft firm and

[1] This excludes some employment on repair, propellers and undercarriages.

by the very large increase in the size and complexity of most types of aircraft. Moreover, the aircraft firms remained responsible for the final assembly of the aircraft and in consequence for the success of the several stages of production needed for the manufacture of a complete aircraft. Thus in addition to a very large increase in manufacturing capacity there were far reaching extensions in administrative and technical responsibility.

It was not until May 1938 that extensions to the aircraft firms at direct government expense were arranged. Private expansion of the aircraft industry then came to an end until the last few months of the war. The extensions approved in May 1938 and the earlier extensions undertaken by the aircraft firms may well have doubled the productive capacity of the aircraft industry between 1935 and the end of 1939; but it was not until war potential was planned in the summer of 1938 that really large scale schemes for expanding the aircraft firms were adopted, at a total cost of well over £3 million. Three major schemes were approved under the aircraft industry; all of which required the construction of factories larger than the 1936 shadow factories. From two of these schemes were eventually to come major supplies of heavy bombers; the third was to provide a major supply of Hurricanes. It was now accepted that aircraft firms should be able to manage large scale agency factories. A notable example was the result of a direct approach to Vickers-Armstrongs, who in 1938 took over the management of their subsidiary companies Supermarine Aviation Works (Vickers) Ltd. and Vickers Aviation Ltd. and also undertook the management of an agency factory for aircraft production to be constructed at Chester. The operation of Vickers-Armstrongs in the aircraft industry in a much more direct manner than before marked the beginning of one of the largest expansions within the industry.

After 1938 and throughout the war, the largest expansion schemes were those in the aircraft industry. Out of about 7,000,000 square feet factory floor space under construction or approved from August 1938 to August, 1939 about 5,000,000 were under schemes with the aircraft industry. Between the summer of 1938 and March 1940 ten new factories were approved under the aircraft industry, in addition to several major extensions to existing factory units. At the peak of war-time employment the ten new factories employed about 62,000. Including the employment at the Nuffield Organisation shadow factory at Castle Bromwich, which was transferred to Vickers in 1941, the total in the new factories under the aircraft industry was about 75,000. In addition, the aircraft firms employed about 180,000 in other factories —mainly their pre-war factories greatly extended. All the new factories came into operation after the end of 1939 when the aircraft firms employed about 100,000. Thus about half their expansion of labour after 1939 was employed in the new factories.

By 1941, the distinction between the expansion under the shadow industry policy and by the aircraft industry became generally unimportant; the schemes for further expansion were applied to shadow or to aircraft firms as the facts of the situation and the practical possibilities seemed to warrant. Despite the absence of schemes for major factories after the summer of 1940, floor space under the aircraft industry and the shadow industry continued to expand throughout the war. For probably all firms, the addition to factory floor space after the end of 1941 amounted to at least 25 per cent. while for some firms it was very much larger than this. For most firms employed on heavy bombers the increase in total floor space was at least 50 per cent. and for two of these firms the increase was about 100 per cent. By no means all this was for aircraft manufacture. At some firms there was a large increase in the floor space required for repair and for spares production as well as for storage.

Up to 1941 the figures of productive floor space provide a good yardstick of the expanding output.

Total productive floor space at all aircraft factories*

August 1938	4,900,000	square	feet
March 1939	6,800,000	,,	,,
September 1939	8,150,000	,,	,,
June 1940	11,160,000	,,	,,
October 1941	22,150,000	,,	,,

* Productive floor space includes only floor space on which manufacture and final assembly is undertaken, it excludes storage and administrative and all other areas not used for production.

After 1941, the correspondence between floor area and output was no longer as close as before. As we have already seen, a large part of the manufacture was now undertaken by subcontractors and overall efficiency increased. Thus although productive floor space increased by about 30 per cent. between October 1941 and March 1944, the numerical output of aircraft in the same period increased by 50 per cent and included a greater proportion of larger aircraft.

The figures of labour employed in the same period also illustrate the very large increase in efficiency of production. In this period the total employment on M.A.P. orders for complete aircraft in the engineering and non-ferrous metal industries increased by only about a third. Thus in October 1941 with a labour force of 1,200,000 the output was 1,800 aircraft, in March 1944 with a labour force which in January had reached 1,700,000 the output was over 27,000 even though much more labour was employed on spares and on repair and ancillary equipment. Even more striking, the growth of the labour force at the aircraft factories and firms was much smaller than in the other capacity and at subcontractors.

(iii)
Factories and Firms for Subcontracting

Some subcontracting of airframes developed between 1935 and 1938 but this was a spontaneous development. Experience of the 1914–18 war had raised some doubts about the possibilities of subcontracting major assemblies of the airframe; but new methods of construction were already removing many of the difficulties. Airframe construction had now many more contacts and analogies with the metal working industries. Between 1935 and 1938 several new firms were formed primarily to manufacture airframe components and many existing firms started to take an interest in this type of work. The large airframe constructors began to explore, and by 1938, to exploit the possibilities of subcontracting. Even so, most aircraft constructors had not ventured far in this field and the only subcontracts for major airframe assemblies were with other aircraft constructors. Indeed, in 1938 deliveries of aircraft were held up because of difficulties in obtaining deliveries of wings from other aircraft constructors who were also in arrears on their own programme for another type of aircraft. Nevertheless, despite the formation of what were essentially aircraft component firms, the work of most subcontracting firms was in the spring of 1938 confined to minor sub-assemblies or to ancillary equipment—propellers and undercarriages. Progress among aircraft firms in subcontracting was uneven. Over the industry as a whole subcontracting of airframe construction in the first half of 1938 did not amount to more than 10 per cent. of the total, though it was higher than this at one or two firms.

In the spring of 1938 events took a new turn when a clear departmental policy was declared. A survey of capacity for airframe construction to meet the aircraft programme of the next two years, led to the conclusion that the aircraft firms could not recruit and absorb the total labour force that was necessary. It was quite clear that a large part of the airframe construction must be undertaken by labour employed or recruited by outside firms. Speed was important and this meant subcontracting rather than the erection and planning of new factories. The aircraft firms were told that the aim should be to subcontract at least 35 per cent. of airframe construction and the Air Ministry itself decided to take direct action to increase subcontracting in any further expansion of aircraft capacity.

Planning of large scale subcontracting required a strong technical and commercial organisation. In 1938 several large industrial firms were asked to take part in the expansion of subcontracting; some of these firms it was suggested might become major subcontractors to an aircraft firm and at the same time organise large scale subcontracting in support of their production. Of the firms approached in the summer of 1938, only Metro-Vickers undertook a scheme of roughly the original form. English Electric preferred to undertake the responsibility of complete aircraft production and assembly, and initially to find subcontracting capacity at their other factories. At the end of 1938 an agency scheme under Vickers-Armstrongs was planned to provide a final assembly factory at Chester for major sub-assemblies to be supplied by firms in that region.

Deliveries from these 1938 expansion schemes were not intended to begin before 1940, although some of the subcontracting contracts were already bringing results in 1939. The immediate increase in subcontracting came from the extension of subcontracting by the existing airframe factories; by the end of 1939 this was estimated to have reached 30 per cent. of the labour employed on airframe construction. Subcontracting had not been stipulated as an essential feature of the two early shadow factories, Austins and Rootes, but at the end of 1939 it was reported that airframe construction at one of these factories was subcontracted to the extent of 40 per cent.

The outbreak of war brought a new impetus and stronger official support for subcontracting. All airframe constructors were asked to subcontract at least 50 per cent. of the total work on airframe construction, (excluding proprietary items such as undercarriages, radiators etc.). Subcontracting would also help dispersal; contractors were enjoined to avoid the heavily loaded areas, e.g. London, Coventry, Birmingham and Manchester. Many small firms were now employed as subcontractors and the problem of the aircraft firm in maintaining contact and providing technical details greatly increased. Each firm was therefore required to appoint a manager for subcontracting who was to consult with the Director of Subcontracting at the Air Ministry. As early as December 1939, major subcontractors were also asked to subcontract a large part of their work. This, it was thought would absorb many more smaller firms and relieve aircraft firms of some of the organising of subcontracting. With all this encouragement, the target of 50 per cent. airframe subcontracting, set in October 1939, was substantially met; indeed for many firms the extent of subcontracting was much higher.

All new aircraft factories after the end of 1938 were planned on the basis of a very large degree of subcontracting; several were planned as assembly factories. In December 1939, Vickers-Armstrongs undertook the construction of a second subcontracting centre at Blackpool.

The Bristol agency factory at Weston-super-Mare was also very largely dependent on supplies of subcontracted components and sub-assemblies. For a factory under A. V. Roe, subcontracting up to 75 per cent. of the total capacity was proposed. The important shadow scheme, the London Aircraft Production Group,[1] eventually received direct contracts but it was the result of an attempt to organise a major group of subcontractors. For all new airframe factories sub-contracting to the extent of 40 per cent. was required. The extent agreed for many factories was much higher than this.

Subcontracting on this scale was only possible by the division of the airframe structure into sections; these had to be inter-changeable and therefore manufactured to accepted limits. Subcontracting of airframe construction involved the prefabrication of minor assemblies as well as the assembly of major sub-assemblies. Thus not merely doorframes and doors were prefabricated but also the complete wings and fuselage. Indeed it was proved that all the major sections of the aircraft could be assembled outside the final assembly factory. As a result the man-hours for the work done in a few of the assembly factories amounted to less than 20 per cent. of the total construction man-hours required for the construction of the airframe. The division of aircraft construction in this way was possible for some aircraft in 1936 but its extension to almost all types of aircraft, the technical development of a system of interchangeability, the necessary fixtures and measuring instruments, were all achieved in a very short time.

The outcome of extensive subcontracting was reflected in the limited amount of sub-assembly work undertaken at many aircraft factories. Only a few types of operational aircraft were not heavily subcontracted, and as a result some of the aircraft factories were only undertaking the construction of the fuselage and the final assembly of the airframe and aircraft. For most types the construction of the fuselage certainly involved much less work than the total for all the other assemblies and components. Sometimes even the construction of the fuselage was subcontracted. Many of the subcontractors undertook a wide range of components, but it was quite a limited number of subcontractors that undertook the major assemblies, main planes and centre-section of the airframe.

Subcontracting reduced the need for the construction of new factories for airframe manufacture and also reduced the floor space required at the new aircraft factories for a given output of aircraft. The total building work at subcontractors was comparatively small. Thus although airframe subcontractors employed about as many as the aircraft factories, the total expenditure on building work was very much

[1] See p. 221 above.

less than the total expended on the construction of new aircraft factories and extensions to aircraft factories. Most of the early subcontracting schemes did not call for any additional factory building. By 1939 however some building had become necessary and throughout the war there was a small but steady demand for building work at subcontractors' factories or occasionally for the construction of a new factory building. Some of the building schemes were fairly large. Thus the two subcontractors with the largest employment in this work both had building schemes which in the aggregate exceeded £300,000. A few other schemes exceeded £100,000 but the cost of most of the building schemes for firms with more than 1,000 employed on subcontracting work were a good deal less than this amount.

No very accurate figure can be given of the number of subcontractors employed on airframe work. The total ran into several thousands but this included many sub-subcontractors and small firms or firms employing only a small labour force on this work. About 140 major subcontractors accounted for a labour force of over 120,000 and this was about 60 per cent. of the total employment on airframe subcontracting. All these major firms employed over 100 on this work and more than 30 firms employed over 1,000. Prominent among the firms employing over 100 on airframe subcontracts, were motor body manufacturers. One of these firms had three main factories employed on this work with a total employment of over 8,000. Another motor body firm employed over 5,000 and a leading motor car firm over 4,000. These were all firms in a closely related manufacture. But the list of firms also included several textile machinery manufacturers, two of whom employed well over 3,000 on aircraft subcontracting; railway locomotive and carriage shops, manufacturers of furniture, lifts, boilers, electrical fittings as well as several airfield service firms. The few firms specialising in aircraft subcontracting increased their employment considerably but only one or two had war-time employment exceeding 1,000.

(iv)

Factory Development and Construction

Many of the aircraft factories in use in 1936 were factories that had been used for aircraft production in the First World War. Their main feature was inevitably the large assembly sheds. These, with an adjacent airfield were for long the essential characteristics of an aircraft factory. The specialisation and systematisation of the assembly line and component manufacture which were by 1936 common features of motor car factories, were not much in evidence in the aircraft factories.

There the limited production as yet allowed them little scope. Structurally, the aircraft factories built immediately after 1935 were not very different from those of the early period; but in the internal organisation many improvements were possible. The planning of shadow factories in 1936 was based on the construction of aircraft factories, undertaking a full range of manufacture and assembly work. Internally, it was hoped to adopt something of the production line methods of the motor car industry. Although subcontracting was eventually important at all factories, it only directly affected the planning of the later factories. For example at the Vickers factory at Chester, approved in December 1938, manufacture was to be subcontracted to the extent of 80 per cent. This meant that the factory was completely dependent upon subcontracting. In other factories it was rarely possible to obtain quite such a high proportion of subcontracting.

After 1938 the insistence on a large measure of subcontracting prevented the planning of completely balanced factory units. But only a few factories which were almost entirely dependent on subcontract work became, in effect, just assembly factories. Other factories, though their assembly capacity was larger than their capacity for machining work and component and sub-assembly manufacture, were equipped to undertake the main processes of aircraft manufacture as well as assembly. To an increasing extent however the assembly capacity became the main characteristic of aircraft factories; final assembly and the preceding manufacture of component and sub-assemblies tended to be dealt with as two separate problems.

There was an increasing tendency for the assembly work and the earlier stages of production to be at different locations. A typical factory was thus often in two separate sections. Wherever they were situated, the assembly sheds were the largest structure and they had to be even larger with the increased size of aircraft. As time went on there was a notable increase in the equipment used in the assembly of the aircraft and a much greater organisation of assembly lines. The engineering and manufacturing sections of the aircraft factories also had to be greatly enlarged and but for the extensive use of subcontracting they would have had to be even larger. Dispersal increased the tendency to separation, for it was usually manufacture rather than assembly that was dispersed. Similarly, since new locations often had to be found for the additional capacity of large firms there was a tendency to develop new manufacturing factories and to extend the existing assembly capacity, or to provide assembly capacity at the nearest airfield. Most aircraft factories up to 1934 were located on their own airfield or near an airfield which they used for flight testing. With the larger scale factories required after 1936 this was not always a practical arrangement. It was usually necessary to have the factories in engineering centres which were often some distance from the nearest airfield or from a site suitable for the airfield. At first only the flight assembly and testing were undertaken at the airfield but there were, as we shall see, advantages in undertaking final assembly of the airframe at the airfield. This became the arrangement at some firms particularly for heavy bomber production; airframe assembly sheds as well as flight sheds were erected at the airfield and manufacture and final assembly were separated by several miles.

As a result of all these factors—subcontracting, dispersal and separation from airfields—the aircraft factory unit tended to be a group of related factories and not a single self-contained factory. For most units there was one main factory, this was usually the main manufacturing factory but not always the final assembly centre. In general the effect of subcontracting and some dispersal was to limit both the functions and the size of the main factories. Nevertheless, the main factories were much larger than the 1935 factories and most of the new factories approved from 1936 onwards were larger than most if not all aircraft factories in operation in 1936. For many firms however it was the total capacity of the manufacturing unit including many factories which gave the real measure of the scale of operation and capacity in war production. The manufacturing unit for these firms was a constellation of factories.

The structure and design of aircraft factories although in outline simple, had a number of features which increased the cost of construction. By far the most expensive and unusual sections were the assembly shops. For these, particularly for bomber construction, very large spans and large height clearance were necessary. Furthermore the steel work structure required was expensive and by no means easy to obtain. Nor, as the misfortunes in the erection of one large shadow factory showed, was it always possible to obtain a design that would provide a stable structure throughout all the stages of construction. Related to the cubic capacity of these large assembly shops was the comparatively high expenditure for heating and lighting. An equally exacting problem in size and design were the large doors for the assembly buildings. The design and construction of aircraft factories before 1936 were largely theoretical problems but by 1939 a good deal of experience had been obtained. Exceptional features though there were, the construction of the aircraft factories was not generally beset by many exceptional difficulties. Responsibility both for design and for the placing of contracts for construction was invariably given to the firm which was to manage the factory in production. Many of the firms acquired a high degree of efficiency both in the planning and in the progressing of construction and a great deal of confidence and independence could be exercised.

The main problems of aircraft factory construction were solved between 1936 and 1939 and no great difficulties were encountered in carrying forward this knowledge and experience into war-time construction. The financial authorities at the Treasury and at the Air Ministry also learnt in the earlier period the costs of construction that were to be expected. In the main, there was little cause for dissatisfaction with the progress and cost of construction of the aircraft factories. Although it may well be, as indeed happened later in the war, some restrictions as to materials and design might usefully have been imposed and some reduction in costs obtained even before 1939. All pre-war costs reflect to some degree the comparatively high quality of building work which was normal in peace-time. The balance between assembly buildings and engineering shops greatly affected the cost of building work and of equipment. As would be expected, a factory largely devoted to assembly work had a higher building cost and lower cost for plant than a factory undertaking a large part of the machining and detailed engineering work. With the extensive use of subcontracting the greater part of the costs were usually incurred for building. Floor space to be provided ranged from about 500,000 to almost 2 million square feet. War-time building costs ranged from £¾ million to almost £2 million, the cost per square foot from about 15/- to £2. At none of the factories was the cost of equipment and services equal to that for building work. At a few factories it was a good deal less than half but at most it was a little below or a little above half the cost of building work.

The construction of aircraft factories was usually completed in less than twelve months from the start of building work. It was exceptional for building to take more than twelve months. In consequence it was possible to achieve deliveries within two years of the approval of the scheme; for some factories the time was brought down to little over twelve months or even less. For example the two agency factories for the production of Wellingtons made deliveries in 10 months after approval. Both these factories had the advantage of an extensive outside supply of sub-assemblies and components and were managed by the parent firm. For new shadow firms, at least 20 months proved necessary from approval of scheme to the first deliveries.

Quite apart from the strategic problems, the provision of sites for aircraft factories was often very difficult. The main trouble was to find airfields not too far away from the main manufacturers and subcontractors. The difficulties were especially great when it was decided that an airfield should be constructed at the same time and adjacent to the new factory. Then a site had to be found for both the factory and airfield and an area of level land of at least 400 acres was required. It was by no means easy to find a suitable site of this size within the general area decided upon for reasons of management and subcontracting. In fact very few airfields were constructed for new aircraft factories. The most frequent solution of the problem was to choose a site adjacent to an existing airfield which could, if necessary, be extended to take the flight tests of the aircraft to be manufactured. Another solution which as we have seen was adopted more and more after 1938 was to separate the factory from the airfield and to erect flight and final assembly sheds at the airfield.

When a factory had if possible to be adjacent to an existing airfield, the number of suitable airfields proved very few. Nevertheless, none of these schemes failed for lack of an airfield. Indeed, it was easier to site the factory adjacent to an existing airfield than to find a suitable site for a new factory and new airfield combined. A combined site for new airfield and factory was unusual; one example was the Vickers' factory at Chester. There was of course a large demand for new airfields and all were put to other uses apart from flight testing—the new airfield at Chester was constructed by the Air Ministry for use for an aircraft storage unit as well as for use of Vickers' factory. The work of some factories increased beyond the capacity of specially constructed airfields. This happened for example when the Austin shadow factory went over to the production of bombers.

The construction of the aircraft factory adjacent to the airfield was the most economical arrangement but as we have seen there was a growing tendency to separate the factory from the airfield. Even before 1935 the manufacturing factories of several aircraft firms were some distance away from the airfields where the erection and flight assembly was undertaken. When Fairey Aviation acquired the Heaton Chapel factory at Stockport they used the Manchester Airport at Barton. Later they used the new Manchester Airport at Ringway. This separation of factory and airfield was to grow. When English Electric and Metro-Vickers came into aircraft production similar arrangements were made. The manufacturing factories were located adjacent to their commercial factories and the airfield used was some distance away. This arrangement also made it possible for the same airfield to be used by more than one firm. The Manchester Airport was used by at least three aircraft firms. As the use of airfields at some distance from the factory increased, it became the general practice to undertake the final assembly of the airframe at the airfield. The flight sheds were thus used as final assembly shops and consequently had to be enlarged to accommodate more aircraft for a longer period. Alternatively, separate assembly sheds were constructed and used as both assembly and flight sheds.

There thus developed a clear division in many factory units between the factory undertaking the manufacture up to and including the assembly of the main sections of the airframe and the assembly and flight sheds at the airfield where the airframe was erected and the engine, propellers and armament were installed. Aircraft structures had developed in a way that made possible this subdivision between the manufacture of the airframe main sections and the erection of the airframe. It was the same development that made possible the general subcontracting of the manufacture of main sections. These main sections were often inspected at a subcontractor's works; this and the adoption of interchangeability standards meant that many main sections were delivered direct to the airfield without passing through the main factory. The erection of assembly sheds at an airfield was often a ready means of securing a significant expansion of capacity. The policy of dispersal brought an even greater division of the manufacturing and assembly units. Most of this was a dispersal of manufacturing but there was also some dispersal of final erection. Thus flight and assembly sheds were provided at several airfields so that all the erection work of Armstrong-Whitworth should not be concentrated in Coventry. All these developments simplified the problems of finding sites for many of the aircraft factories and ancillary factories. The siting of factories for flying boats and seaplanes was of course exceptional but again the subdivision of manufacture made it possible to provide much of the additional factory accommodation inland. The location of factories was of course also influenced by wide considerations of strategic vulnerability, management and labour supply.[1]

(v)

Size of Factories and Firms

Before 1934 the floor space at many aircraft factories was far beyond the current needs; at the beginning of rearmament most firms had some reserves of factory accommodation that could be brought into use. By the summer of 1938 this process of consolidation was complete and there remained considerable variation in the size of the factories. Judged by the Air Ministry criterion of productive floor space most factories came within the range of 100,000 to 300,000 square feet of productive area.[2] Only two firms had productive space exceeding 400,000 square feet and for one firm, this was the total of two quite separate factories. Only one other firm had floor space of over 300,000. By March 1939 there were five aircraft firms, including the first two aircraft shadow firms that had over 400,000 square feet of pro-

[1] See Chapter IX below.

[2] Productive areas include only the area available for manufacture and assembly, it excludes offices, design and administrative sections as well as storage space. In the pre-war factories it was usually about half the total floor space. In war-time factories it tended to be less than half the total; mainly because of the increase in the proportion of storage space.

ductive area, although only for three firms was this at single factories. One of the 1936 shadow factories had been increased to close on 600,000 square feet productive area and had the largest productive area of any factory. By March 1939 most firms had increased the productive floor space. With several firms the floor space had been doubled and no firm now had less than about 100,000 square feet.

The two shadow factories in 1936 set the pace for larger aircraft factories, but they themselves were soon seen to be too small for war-time requirements. By 1941 both these factories had more than ¾ million square feet of productive area. From 1938 onwards most of the new factories were planned to provide over ½ million square feet of productive area and several to provide at least ¾ million square feet. As productive area tended to be less than half the total area, at least two new factories of over 1½ million square feet were constructed. The first of these was the Castle Bromwich Spitfire factory in 1938 and the second, the A. V. Roe factory at Yeadon approved in 1939. Two other factories planned in 1938, the A.V. Roe factory at Chadderton and the Vickers factory at Chester, were planned to exceed 1 million square feet in total area. Several other factories grew by extension to at least 1 million square feet of total area. There was no general reduction in size due to war-time conditions. Most of the factories approved in the first year of war exceeded ¾ million square feet in total area and one or two exceeded 1 million square but after the summer of 1940, no new large factories were planned. The policy of dispersal and the necessity of making use of available buildings resulted in the use of a large number of factory premises of medium and even small size.

The conversion of existing premises or the erection of smaller new factories as ancillary factories were by no means unknown before 1939, but from 1940 especially with the stimulus of dispersal these practices became general. In consequence, as we have seen, the factory capacity under most firms became a constellation of factory premises. Including employment at dispersal units under direct management of the parent factory, many of the existing parent factories had developed into constellations employing over 10,000 or even 12,000. Usually but by no means always the larger part of the total were employed at the parent factory. Thus despite the effect of dispersal and the frequent adoption of a multiple manufacturing unit, the size of most separate factories was very much larger than in 1935 and all firms had at least one factory on the larger scale. Many separate factories exceeded an employment of 10,000, and only two had an employment of less than 1,000. The main aircraft factories were all several times larger than the aircraft factories of 1935 but the increase in the total aircraft manufacturing capacity under each firm were much greater than this.[1]

[1] See below, p. 240.

The actual size of new factories was determined by a wide range of factors. Where final assembly was included the size of the aircraft was an important factor affecting both floor space and height in a large part of the factory. The floor space occupied by different types of aircraft was largely dependent on the overall size and a change from one type to another might mean a very large change in the floor space needed.

	Length and Span in feet	*Net area required*
Mosquito	48 × 34	1,600 sq. ft.
Spitfire	37 × 30	1,110 sq. ft.
Hurricane	40 × 32	1,280 sq. ft.
Lancaster	102 × 70	7,140 sq. ft.
Whitley	84 × 72	6,046 sq. ft.
Anson	56 × 42	2,352 sq. ft.
Sunderland	112 × 85	9,520 sq. ft.
Halifax	104 × 71	7,384 sq. ft.
Beaufort	58 × 44	2,552 sq. ft.
Blenheim	56 × 44	2,464 sq. ft.

The difference in size of fighter and heavy bomber aircraft was of course very great but there were big differences even within the main groups. For example, the floor space required to accommodate say the change in production from Whitley to Lancasters seriously affected factory planning. Height could be an even more serious problem as roofs could not be adjusted as readily as floor space. This was often a real limitation in many of the older factories but in planning new factories account was taken of the later types which might have to be manufactured in them. The increasing size of aircraft had a very direct effect on flight shed accommodation and also on airfields and runways.

The other obvious influence on the size of each factory was the maximum output for which the factory was planned. The calculation of floor space in relation to output was a complex matter even for final assembly. Much depended on the assumptions about shift working, the length of the cycle of manufacture and assembly and the level of efficiency. In planning factories big allowances were made for these factors but in general they had to be based on current experience which was often much below the possible maximum. Similar calculations related to sub-assembly and component manufacture. Changes from one type of aircraft to another often resulted in drastic changes in the balance between machining and sub-assembly work and final assembly.

Factories varied most in the balance between final assembly and component manufacture. As subcontracting increased, assembly space tended to predominate in the productive floor space. But there was also an important increase in the non-productive floor space, for storage and administration. The allocation of floor space in 1943 at a large heavy bomber and at a large fighter factory illustrate the problem involved.

	Bomber factory	*Fighter factory*
1. Flight sheds for flight assembly .	180,000 sq. ft.	130,000 sq. ft.
2. Final assembly of airframe . .	130,000 sq. ft.	80,000 sq. ft.
3. Component assembly . . .	400,000 sq. ft.	300,000 sq. ft. (3 and 4)
4. Fitting and sub-assembly . .	130,000 sq. ft.	
5. Stores	400,000 sq. ft.	450,000 sq. ft.
6. Machine shop and tool room .	125,000 sq. ft.	100,000 sq. ft.
7. Other process work . . .	100,000 sq. ft.	120,000 sq. ft.
8. Administration and drawing office .	130,000 sq. ft.	180,000 sq. ft.
9. Factory service and engineering .	60,000 sq. ft.	..

In the bomber factory, fitting, sub-assembly, component assembly, and final and flight assembly occupied 840,000 square feet compared with 225,000 for machine shop and process work. This factory subcontracted a great deal; had this not been so the floor space allocated to sub-assembly, machine shop and process work would have had to be much greater. The allocation of floor space for the fighter production shows some important differences; for this factory it is possible to follow the expansion of floor space from 1934 to 1944.

Floor Space in thousand sq. ft.

	1934–36	*1939*	*1940*	*1941*	*1943*	*1944*
Flight sheds . .	33	95	102	114	100	130
Final assembly .	30	65	85	95	70	80
Fitting and sub-assembly . .	35	37	125	191	287	289
Machine shop and tool room . . .	29	29	58	91	92	99
Other processes. .	20	74	123	124	117	203
Stores . . .	22	96	231	459	435	448
Administration and drawing office .	38	53	118	188	182	182
Total including miscellaneous and experimental . .	314	589	1,094	1,499	1,764	1,887
Percentage productive floor space . .	46·5	43·4	38·8	37·5	34·8	37·5
Output (highest monthly average for best quarter) . .	—	54	139	162	244	162*

* Decline due to withdrawal of Hurricane from production.

Subcontracting could not reduce the floor space required for final assembly but it reduced the space required at the aircraft factories for most of the earlier stages of manufacture and often reduced the space needed for sub-assembly work almost to a token area. One major section of the factory however had to be increased as subcontracting spread. This was the non-production area for storage. As the rate of output of aircraft from a factory of a given size rose a much larger area was needed for storage of sub-assemblies and components to maintain the output and to prevent failure of supply to the final assembly shops. Further with the extensive use of subcontracting it was necessary to find storage for the incoming sub-assemblies sufficient to maintain final output. Thus, both by increasing the quantity of output and removing the source of supply away from the assembly factory, the increase in subcontracting made the floor space required for storage at some factories the largest single area.

A different problem—one of scale or spread of management rather than of scale of manufacture arose when several factories were operated by the same firm. Between 1935 and 1938, some firms acquired a second factory but this was usually operated as a separate manufacturing unit with related airfields. In war production, most aircraft firms had many factories under their management, in addition to dispersal units. A wide variety of organisation was developed in response to the stimulus of dispersal and expansion. Often the several factories under one firm were organised to form two or more fairly separate manufacturing units or, as they might well be termed, constellations. The functions of separate factories could range from assembly factories almost entirely dependent on subcontracting to a few factories, mainly for trainers, making a limited use of subcontracting and manufacturing a large part of all the aircraft assembled. Other separate factories, were confined to the manufacture of certain components and sub-assemblies or main assemblies or any combination of these. Other buildings under the control of the aircraft firm might be used entirely for the assembly of spares, for the repair of aircraft and components or merely for the storage of sub-assemblies and components. As a result, the self-contained aircraft factory of 1935 was almost entirely superseded, and the new manufacturing unit was often in the form of a single factory largely confined to the final assembly of subcontracted components and sub-assemblies or a constellation of factories with a range of functions under the one firm.

The analysis of floor space for fighter production relates to a constellation of factories with a total employment of about 10,000 which up to 1942 had been confined to the production of Hurricanes but which at the end of 1943 had three types of fighters in production. The analysis of floor space given above for bombers relates to a single factory dependent to a considerable extent on subcontractors. This factory employed about 10,000 but the same firm also had the largest constellation of factories in aircraft production with a total floor space of over 4 million square feet and a total employment of over 20,000.

In the first constellation, the need for dispersal as well as for expansion had a major part in the formation of the wide range of factories. In the second constellation the persistent need for extension to meet the demands both for heavy bombers and trainers was the major factor. In this firm the expansion of component and sub-assembly manufacture proceeded mainly by the provision of additional factories of many sizes. Eventually seven additional component factories were provided with a total floor space of little less than 2 million square feet including one new factory of more than 1 million square feet. By 1943, the 1935 area of 280,000 square feet which had been divided between two locations had been expanded into a constellation of factories at 10 locations with 4 million square feet; and of this 1 million was for final and flight assembly at two separate airfields. This was the largest constellation of factories operating as one manufacturing unity. For although this constellation manufactured two types of aircraft, the capacity was organised and re-organised as required to meet the changing demand.

Single factories ceased to be the measure of the managerial unit; they were certainly no longer a direct indication of the size of the aircraft firms. At the peak of war production and indeed long before, most firms had several factories under their direct management. This, to a large extent was the key to the large expansion of aircraft production. Several firms employed about ten times the labour force of 1935 and the floor space of the several factories under their management was often more than ten times the floor space of 1935. Even greater was the increase in the output of aircraft from the factories of each firm, despite the general increase in the size and complexity of aircraft.

Here we are mainly concerned with the firm as a production organisation—the manufacturing firm. Before 1936 there had been one combination of manufacturing firms, the Hawker Siddeley group but each of the constituent firms continued to operate as a separate manufacturing firm. In 1938, Vickers-Armstrongs had brought their subsidiaries – Vickers Aviation and Supermarine—under their direct management and by the end of 1940 they were in control of three agency factories employing several ancillary factories. By the peak of war production the employment at the aircraft factories under their management exceeded 53,000. The total employment of the several firms in the Hawker combine exceeded 65,000. But in analysing the size and expansion of the main manufacturing firms and units, the Hawker combine should be considered as several manufacturing firms. With Vickers-Armstrongs, in addition to Vickers Aviation and Supermarine, we have to identify three separate manufacturing units at Blackpool, Chester and Castle Bromwich, all of which were agency factories owned by the government and managed under an agency agreement. The rest of the aircraft firms were single manufacturing firms. Of course, aircraft work was only part of the industrial operation of the shadow firms, many of which were already very large firms; but we are only concerned here with the extent of their operation in aircraft production.

The expansion in operation of most of the firms far exceeded their financial expansion. For although many factories built at government expense were leased to the firms for operation with their own capital resources, the management of agency factories was normally undertaken entirely at government expense both for working capital and for the use of the factory and plant. Our primary interest is the increase in operating size of the manufacturing firms. Judged by labour employed there was a wide range of size and a very large increase of all firms over their 1935 size. In 1935 most firms employed less than 1,500. In 1943 there were only two firms with less than 1,500. In 1935, the largest firm employed less than 4,000; in 1944 the same firm had a total employment rapidly approaching 40,000. Vickers, included as one firm, had an employment of over 53,000 in aircraft production in 1944. But divided between medium bomber (Weybridge, Chester and Blackpool) and fighter production (Supermarine and Castle Bromwich) they were the equivalent of two manufacturing firms each employing about 26,000. A. V. Roe, a manufacturing firm in the Hawker group, employed more than 35,000.

*Size of manufacturing firms**

Scale of peak employment	*No. of firms*
35,000	1
26,000	2
17,000–20,000	3
9,500–14,500	10
4,500–8,600	7
About 3,700	2
1,400–1,800	2
Under 1,000	1

* Including shadow firms but on the basis of labour employed on aircraft production only.

Thus, whilst the size of many of the separate factories tended to be about four or five times the factories of 1935, the size of many firms was no less than ten times their 1935 size. Only one or two factories employed more than 12,000 but several firms employed over 17,000. None of the shadow firms reached anything like this employment. Both Rootes and English Electric employed over 13,000 on aircraft production but Austins, L.A.P. and Metro-Vickers employed rather less than 10,000.

The number of factories of all sizes was greatly increased by the continued process of expansion and by dispersal policy. Many firms had up to thirty factory buildings at separate locations in use at the same time. Increase in floor space under the management of each firm shows a similar scale of expansion. It has already been shown that A. V. Roe with less than 300,000 in 1935 increased to a floor space of over

Output of military aircraft by pre-war aircraft firms

	Average monthly output for 1936	*Monthly War peak output*	*Labour Force employed by the firm Nov. 1943**
1	unclassified	124 trainers	5,163
2	12 trainers	64 Lancasters	12,897
3	2 fighters	60 fighters	4,916
4	7 naval	106 naval	12,612
5	12 trainers	162 light bombers and fighters	18,068
6	3 trainers	165 light bombers and fighters	10,450
7	12 naval	64 naval 31 heavy bombers	20,726
8	10 fighters		
9	15 fighters	126 fighters	10,736
10	3 light bombers	49 heavy bombers	9,572
11	30 various	244 fighters	11,055
12	—	142 trainers	6,320
13	25 trainers	137 heavy bombers 133 trainers	33,756
14	1 reconnaissance	29 heavy bombers	13,421
15	—	41 heavy bombers	19,531
†16 (a)	2 fighters	144 fighters	9,406
(b)	—	304 fighters	13,318
†17 (a)	15 light bombers	66 medium bombers	13,698
(b)	—	217 medium bombers	16,771
18	6 trainers	64 fighters	5,265

*Labour force includes all classes of employees and the figure is the total employed by the firm on aircraft and components but excluding engine production. For some firms labour employed at dispersal factories is not included.

†For these firms it is possible to show the output at the peak from the pre-war factories (a) separate from the agency factories (b) for war production.

6 million square feet in 1944 and Hawkers with about 300,000 square feet in 1935 to a floor space of nearly 2 million square feet in 1944. Short and Harland with less than 300,00 in 1935 also increased the floor space to nearly 2 million square feet. Similar increase in floor space occurred even with the shadow firms. English Electric starting with 250,000 in 1938 increased to over 2 million square feet. It is clear that an increase of 6 times the 1935 floor space was common with the aircraft firms and where large scale production of heavy bombers was the main output, the expansion of floor space might increase to ten times that of 1935. The same picture of expansion is reflected in the increase in the output of these firms. We may indeed speculate as to what would have been the labour force and the growth in the size of the firms had they not had the assistance of so large an army of subcontractors.

The increase in total output by number between 1936 and 1944 was twelvefold, but in structure weight the 1944 output was forty times that of 1936. For most firms the increase in numbers was at least tenfold and for firms manufacturing heavy bombers the increase in structure weight of the aircraft was over seventyfold. The expansion in the number employed at many firms—usually about tenfold—showed a fairly close tally with the increase in the number of aircraft produced; the increase on basis of structure weight however shows a much wider range, largely because subcontracting was more important in the production of heavier types. Indeed the mere tally of employment and output cannot show the full expansion in the operation of some firms. Several firms became the parent firms for a group, or even more than one group, of firms manufacturing the same type of aircraft to their design. For these parent firms the increase in responsibility was much greater than the increase in the output from the factories under their management. Large and rapid expansion was a feature of capacity for war production but the expansion of the aircraft firms was unique both in its extent and in the way it applied to almost all the firms in the aircraft industry. In 1936 there was very little indication that so large an expansion was possible, or indeed that the existing aircraft firms could administer production on so large a scale.

(vi)

Scale of Manufacture and Efficiency

The wide range in size and function of factory and firm resulted in a complex structure and a wide variation in form and size of manufacturing units. If by scale of manufacture is meant the scale of production of one type of aircraft in one manufacturing unit then with very few exceptions the scale of manufacture was less than the size of the firm.

Even when one firm was confined to the manufacture of one type of aircraft for a considerable time, the firm may have employed two or more manufacturing units separately on this production. Thus Vickers had three separate factories employed on the manufacture of the Wellington and two separate factories on the Spitfire. Usually, where more than one type of aircraft was manufactured at the same time, capacity was divided between two separate factories or constellations. On the other hand, most firms had at one stage or another to undertake the manufacture of more than one type of aircraft in the same factory or constellation. Here inevitably the scale of manufacture was less than the factory unit; and a possible single manufacturing unit was subdivided. Within each firm the scale of manufacture was very much affected by the extent to which the factory or constellation was allowed to concentrate on one type of aircraft. As we shall see, many factories did specialise in one type for fairly long periods and thus for much of aircraft production it was the size of the factory or manufacturing unit that limited the scale of manufacture. Even so there were many differences in the period of continuous production of one type and this greatly affected the level of efficiency achieved.

Even in the pre-war period the main lines of specialisation between heavy, light and trainer types of aircraft were discernible. For although the numbers ordered before 1935 were small, the range of types required was fairly wide—from the light fighter to the bombers, transport and flying boats and special naval types. This range of types made it possible for the firms to specialise to a certain degree in their development work. Even where there was no obvious specialisation, the acceptance of a prototype by the Air Ministry naturally led the firm to concentrate on the development of that and similar types. Only one or two firms specialised entirely in military aircraft, but of the firms in civil production some dealt only with the light class, the single or double seater planes, and others in the heavy class—the passenger planes. For many firms, this specialisation was carried into the designs that these firms prepared for the Air Ministry. In what may be called

Number of firms undertaking production in the main groups.

	Aircraft Firms	*Shadow Firms*
Heavy and medium bombers	8	5
Light bombers and fighters	11 (7)	3 (1)
General reconnaissance	7 (3)	—
Transports	8 (1)	1 (1)
Naval	10 (2)	—
Trainers	14 (4)	1 (1)

Figures in brackets are number of firms not included in any preceding class.

the heavy class, were developed the medium bombers, the heavy bombers and the transport planes. In the light class were the light bombers and fighters most of the general reconnaissance and some of the trainers.

Despite the demands of war production and the wider range of types a good deal of this specialisation persisted. The number of firms

Firms and Types of Aircraft

Type	*Aircraft Firms*	*Shadow Firms*
Heavy Bombers		
Lancasters	A. V. Roe	Metro-Vickers
	Armstrong-Whitworth	Austins
	Vickers (Chester)	
Lincoln	A. V. Roe	
	Armstrong-Whitworth	Metro-Vickers
Halifax	Handley Page	English Electric
	Fairey	L.A.P.
		Rootes
Stirling	Short	Austins
	Short and Harland	
Warwick	Vickers (Weybridge)	
Medium Bombers		
Wellington	Vickers (Weybridge, Blackpool and Chester)	
Hampden	Handley Page	English Electric
Whitley	Armstrong-Whitworth	
Buckingham	Bristol	
Light Bombers and Fighters		
Blenheim	Bristol	Rootes
Mosquito	de Havilland	Standard Motors
	Airspeed*	
	Percival*	
Spitfire	Vickers (Supermarine)	
	Vickers (Castle Bromwich)	
	Westland	
Hurricane	Hawker	Austins*
	Gloster	
Defiant	Boulton Paul	
Beaufighter	Bristol	Rootes
	Fairey	
Typhoon	Hawker	
	Gloster	
Meteor	Gloster	
Whirlwind	Westland	

*These firms made only small quantities of these types.

engaged on the production of the larger aircraft had been less than half the number of aircraft firms but with the addition of shadow firms it reached half the number of all firms. Many firms undertook production in more than one class, but most firms were more concerned with either the heavy or the lighter types. Most transports belong to the heavy types and the firms and types of aircraft were usually drawn from that class. The large number of firms employed on trainers was mainly due to the several early operational types that were subsequently placed on the trainer list, as a result almost all aircraft firms made some contribution to the supply of trainers but the bulk of the supplies came from a few firms specialising in trainers. The number of firms on the production of each type was fairly narrowly limited. But for some types, a much smaller list of firms would have been needed to secure a reasonable scale of production. Division of orders for some types between even two factories could seriously limit the scale of manufacture. For example the production of many types of naval aircraft was divided between two or three factories; as the total requirement for most types of these aircraft was comparatively small this division seriously limited the scale of manufacture.[1]

Concentration of effort at each factory or manufacturing unit on one type of aircraft for a very considerable period was the most direct means of achieving the maximum scale of manufacture. It was also an important condition for achieving improved efficiency. From 1936, all the new factories were planned to provide for the production of one type of aircraft. When they came into operation it was not always for the type of aircraft at first planned but for at least two years all these factories were confined to one type of aircraft only. At many factories this period of concentration on one type exceeded three years. At most factories two types were in production at the same time only when an existing type had to be replaced by a new type. The production of two types was usually for a relatively short period. Sometimes however the need to find additional capacity for some types meant that a factory had to keep two types in production indefinitely. Thus the Lancaster bomber was fitted in with the Spitfire at Castle Bromwich and with the Wellington at Chester in 1943. When new types of aircraft had to be substituted and manufacturing units were divided for as much as twelve months there was a heavy loss in efficiency. The permanent fitting in of an additional type of aircraft usually meant a permanent reduction in the scale of manufacture and in the level of efficiency.

At the beginning of 1942, a very large degree of concentration was in force and this reflected the planning of factories as single and exclusive manufacturing units proceeding to a high level of efficiency attained

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[1] See Appendix, Aircraft Factories and Scale of Production.

by the sustained production of one type of aircraft. Several factories especially the heavy bomber factories were only beginning to emerge from the early stages of production of the new types of aircraft. Fortunately all these factories had at least two years of specialised production ahead. Many other factories in 1942 were however affected by the need to introduce new types additional to, or as replacements for current production. Thus from 1942 onwards many units that had been planned and previously operated as single, large scale manufacturing units had to be subdivided. This subdivision of manufacturing units was not part of the initial planning; it was forced on the authorities and on the firms by the demand for new types and the need to increase the output of heavy bombers in the second half of the war.[1]

Before the larger orders came in 1936 there was very little scope or incentive for marked improvement in efficiency in the aircraft industry, but from 1936 onwards very real progress was made at even the smaller firms and there was a remarkable reduction in labour costs. There were particularly large reductions in labour costs on assembly work when continuous production was sustained over a long period. Within twelve months of making the first deliveries labour costs could often be reduced to about half the costs for the first batches. During the next twelve months, and often within six months, a further reduction bringing the labour costs down to a quarter of the first batch costs was often obtained.[2] There were many reasons for these improvements. In the first phase, training and organisation for assembly of a new type were proceeding but after training and general stabilisation of organisation, efficiency continued to increase for a considerable period. Moreover, as the quantity dealt with increased, operations could often be further subdivided. A period of at least eighteen months was usually necessary to approach maximum efficiency. For most factories the run of production of one type was rarely more than three years. As a result the period of maximum efficiency was often as short as one year. For some favoured types, such as the Spitfire and Hurricane, at some factories it covered at least three years. Bombers were less fortunate. For example, Wellington production might well have had a full three years at maximum efficiency at all factories but for the introduction of heavy bombers at Weybridge and Chester.[3] The late introduction of the new heavy bomber types in 1941 and 1942 and the reduction of production in the spring of 1944 gave little opportunity for even as much as a year's production at maximum efficiency.

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[1] See Appendix, Aircraft Factories and Scale of Production.

[2] *Airframe Production*, Mensforth, Journal of the Institution of Mechanical Engineers, June 1947.

[3] See Appendix, Aircraft Factories and Scale of Production.

The scale of production and in consequence the size of the factory unit obviously affected labour costs. It was found that a factory dealing with a planned output rather more than three times as large as another factory had labour costs about half that of the smaller factory. In the smaller factory there was little scope for the second phase in the improvement of efficiency. It was mainly because of the smaller factory units that man-hours required for airframe production in the United Kingdom were generally higher than those in the United States. Where scale of production and continuity were similar very similar results were achieved. Thus, it was found that in British factories with a long sustained production of 50 to 60 fighters or 20 to 30 bombers a week, the man-hours required were of the same order as in the best American factories.[1] Within the limits imposed by size of factory and change of types most of the aircraft factories showed improvements of efficiency comparable with the best secured elsewhere.

In bringing the new factories into operation and indeed in expanding most of the existing factories many of the problems were very similar to those found in other engineering factories. The recruitment and training of labour was an important part of the task; the organisation and progress of subcontracting was another. Where a factory depended to the extent of 80 per cent. on subcontracting, the subcontractors' work was the essential foundation of the factory and had to be assured before production could begin. In the period of factory construction, the organisation of subcontracting was of first rate importance. At the aircraft factory, a very important problem was the balance required between machining operations and assembly work. This was clearly related to the problem of shift working. In pre-war planning it had been assumed that in war all factories would operate a full second shift and this, it was calculated, would double the output of aircraft. This calculation proved unrealistic and no serious attempt was made to re-examine the policy until 1941. Even in the hectic summer of 1940, increased assembly work was mainly secured by working a very long day shift. Indeed throughout the war a long day shift remained the only regular shift worked on final assembly. The second shift so far as it was worked was employed on pre-final assembly work —mainly machining work and some sub-assemblies.

The second shift was worked in almost all aircraft factories at the peak of war production but the size of this shift was always very much smaller than the day shift. There was a very wide difference in the extent of the second shift at aircraft factories. In December 1940, employment on the second shift was only 11.3 per cent. of the productive labour employed on the day shift and in July 1941 the proportion had increased to only 14.6 per cent. At that date, one of the

[1] Mensforth. *Airframe Production*. Journal of the Institution of Mechanical Engineers, Vol. 156, No. 1, 1947.

smaller firms had a 50 per cent. night shift but at no other firm was the second shift more than 30 per cent. of the day shift. There were seven firms in the range from 20 to 29 per cent.; but for several firms the employment on the second shift was less than 10 per cent. of the day shift. In the second half of 1941 and throughout 1942 there were notable improvements at several factories. By 1942 and up to the peak of labour expansion in December 1943, 21 per cent. of productive workers in aircraft factories were employed on the night shift; but there was still a wide variation between firms. In December 1943 more than ten factories had over 20 per cent. but only at three of these did the second shift approach 50 per cent. of the day shift. An important factor in the increase achieved in the second shift after 1942 was the removal of the ban on the employment of women on the night shift.

Productive Labour Force at Aircraft Factories

	Day Shift		*Night Shift*	
	Male	*Female*	*Male*	*Female*
January 1942 . .	82,917	30,122	15,002	3,688
March 1942 . .	83,492	34,067	15,340	4,708
September 1942 .	84,684	42,873	19,269	8,573
January 1943 .	82,247	48,219	19,520	9,868
March 1943 . .	83,782	51,574	18,840	10,512
December 1943 .	81,162	52,315	18,122	10,543
May 1943 . .	74,901	47,364	15,560	8,817

The failure to reach a more or less full second shift working at even one aircraft factory remained somewhat of an industrial enigma, at least in official discussions. For the bomber programme it was calculated that four new large factories for Lancaster production would be necessary unless it was possible to put assembly and sub-assembly work on a double shift working. In October 1941 the Defence Committee (Supply) were informed that the Ministry of Aircraft Production had decided to rely on building up the second shift for assembly and sub-assembly work; to match this, additional machining capacity had to be provided and some of the machining capacity brought up to three-shift working. Even so, these hopes of a second shift on final assembly work for the bomber programme, like the pre-war assumption of double output from double shift working, proved unrealistic. Under the pressure of the bomber programme, most though not all of the bomber factories increased their second shift, but the second shift at all factories was for the most part confined to machining and, at a few factories, to sub-assembly work. Thus, it became clear that the aircraft factories could approach the maximum output of aircraft required even at the peak of war production, with single shift working on final assembly and that the primary limiting factor was the supply of components and sub-assemblies. The implication seemed to be that there was a lack of balance between manufacturing capacity and final assembly and that there had been a considerable over-provision of final assembly capacity and indeed of other assembly capacity as well.

The explanation of this apparently generous provision of assembly capacity was in fact fairly simple. In general, it was due to the effect of two factors—the planning of all assembly factories in relation to output required on the basis of one-shift working on assembly work, and the substantial increase in efficiency that was achieved on assembly work. As we have seen, planning on a one-shift basis in the pre-war period was officially approved as providing the immediate possibility in war of doubling output by working a second shift. In war-time, planning on the basis of one shift on assembly work continued. The possibility of working an effective second shift had yet to be proved and the planning of factories on a one-shift basis for assembly work was too well established in the aircraft and other vehicle industries to be easily disturbed. Officially, it was still assumed that the adoption of a second shift would be possible, but this, it might be argued, should make it possible to increase output when required and would also provide an insurance against loss of capacity due to enemy action or indeed any other cause. Thus, although the planning on a one-shift basis generally continued without special comment, it could be justified as a useful insurance against loss of capacity and against increase in demand. In the event, losses due to enemy action were fully replaced by dispersal factories and the available assembly space and the assembly equipment proved generally adequate on a one-shift basis. With the increase in efficiency above that allowed for in planning the factories, the capacity available at some factories became more than adequate.

Increased efficiency was the other factor which made the assembly capacity at least adequate to provide the planned output on a one-shift basis. Indeed because of the changes in this factor the over-provision of capacity for final assembly in the initial phases of the planning of aircraft production was almost inevitable. In the provision of floor space and equipment for final assembly, arithmetical precision was rarely possible except on the basis of many unknown factors. An important unknown was the level of efficiency that would be achieved in assembly work on what at many stages of planning was a relatively unknown production task. In fact, important changes in the organisation and methods of assembly were to prove possible at many factories; in the assembly of some major sections of aircraft a reduction of 50 per cent. in man-hours was achieved in the first twelve months and a final reduction to 25 per cent. of the initial man-hours in a further six months.[1] Thus on assembly work, it might be argued, a double shift

[1] Mensforth. *Airframe Production*. Journal of the Institution of Mechanical Engineers, Volume 156, No. 1, 1947.

was desirable in the first twelve months of production while a single shift was sufficient subsequently. It is not surprising that the planning of final assembly capacity proceeded within, what proved to be, wide margins and that when in 1943 the peak output of bombers was likely to be reached with assembly on a single shift basis, the increased efficiency achieved in assembly work appeared to be the primary factor making this possible.

CHAPTER VIII

FACTORIES FOR AIRCRAFT COMPONENTS

(i)

The Sections of Production

AIRCRAFT production was the major example of war production based on the continuous expansion of a specialist industry. In 1935, the firms within the aircraft industry employed only 35,000 and the labour force employed outside these firms on subcontract work and the manufacture of materials would bring the total to abcut 50,000. In 1943, on the production of aircraft and spares more than 1,500,000 were employed.[1] With the labour employed on the repair of aircraft the total was over 1.6 million and with labour required for ground equipment, balloons, bombs and other requirements, the total employment reached 1.8 million.

The labour force of 1.5 million primarily engaged on the manufacture of aircraft and spares indicates the main subdivision of the war-time capacity.

1. Aircraft factories	300,000
2. Airframe subcontracting	250,000
3. Engines and accessories	265,000
4. Undercarriages and propellers	90,000
5. Guns and turrets	50,000
6. Radio and radar	125,000
7. Other aircraft equipment and subcontracting for items 3 to 6	280,000
8. Materials	140,000
	1,500,000

Airframe manufacture and assembly required by far the largest total capacity and labour force. Where subcontracting is included it accounted for at least 35 per cent. of the total labour force. The labour force in the engine and engine accessory factories was somewhat less but amounted to about 17 per cent. of the total labour force. With the addition of subcontracting the total employed on engine production may have accounted for as much as 25 per cent. of the total.

[1] This is total employment including technical and administrative staffs.

There were very wide differences both in the size of these sectors measured by the labour employed and the number of firms engaged in the work. Some of these sectors employed a large number of firms in proportion both to the cost of output and also in relation to the total capital commitment. The number of firms with government capital finance schemes as recorded up to June 1943 and including some sub-contractors, shows a very wide variation between the several sectors of production. It should be noted, however, that only firms with government financed agency or extension schemes are included.

Airframes*	665	Aircraft equipment	244
Engines and accessories	120	Radio and radar	55
Propellers	57	Light alloy fabrication	81
Bombs	123	Aluminium	16
Guns	43	Magnesium	27
Turrets	9	Engine repairs	23†
Instruments	88	Airframe repairs	146†

*Including undercarriages.
†Including many firms also included in airframe or engine manufacture.

The scale of expansion can be seen more directly from the government capital expenditure in the different sectors of production.[1] In this the three largest items were for airframe factories (£93 million) engine factories (£117 million) and light alloy materials including fabrication (£70 million). Capital expenditure on other sectors of production was with the exception of propellers (£16 million) and radio and radar (£10 million) below £10 million—guns (£8.5 million) turrets (£4.9 million) aircraft equipment (£6.2 million) instruments (£3.3 million). Even so in relation to the size of the existing capacity and to the total requirement the capital expenditure for many of these products provided a very large part of the capacity. This was definitely so for propellers, for turrets and for guns, for engines and for light alloy materials. The pattern of expansion was by no means the same in all sectors of production; for some the policy of introducing shadow firms to supplement the specialist firms was important, but for other sectors, expansion was almost entirely by an extension of capacity under the specialist firms. In the organisation of expansion and of production very important differences can be traced between those products which were purchased by the production department and issued free to the aircraft manufacturers and other products which were purchased by the aircraft firms direct from the manufacturers. Where the product was a free issue, as were, for example, engines, propellers and turrets, the Air Ministry was directly concerned throughout; capacity and production were effectively organised by a production division at

[1] See p. 214.

a very early stage. The result was a systematic development of capacity in relation to expanding requirements and a reasonably satisfactory scale of manufacture and size of manufacturing unit. Where the product was purchased direct by the aircraft manufacturers, the production department was only concerned with expansion schemes and only brought in to co-ordinate capacity and production when difficulties arose.

(ii)
The Engine Factories

Capital expenditure for engine production was as large as for airframe production. Between 1936 and 1945 the capital commitment at government expense for engine factories exceeded £100 million. In total it was virtually identical with that for airframe production; the expenditure on factory building for engine production was however only half that for airframe production.

Capital Commitment April 1936—September 1945 £m.

	Buildings	*Plant*
Engines . . .	33·2	76·6
Airframes . . .	64·3	43·4

The cost of equipping the engine factories was by far the largest single item; it amounted to 40 per cent. of the total expenditure on plant between 1936 and 1944. The amount for the building of engine factories was 25 per cent. of the total building commitment. Technically and industrially, engine production was very different from airframe production and the number of parent firms employed and types of engine in production were much fewer. Nevertheless, it was possible to apply to a very large degree the same principles and policy of expansion. Even in the pre-war period the expansion of engine capacity provided an exceptional example both of the shadow industry policy and of the expansion of the factory capacity of a parent firm. Subcontracting was hindered by the extent of specialised capacity required, and was therefore much less general than for airframe production.

Aero-engines were much more adaptable than airframes; the same engine could be used in very different types of aircraft. Concentration of manufacture and a certain inbreeding of types was thus the tendency of policy both in production and development. Whereas in the lean years the Air Ministry list included sixteen aircraft firms, only four engine firms were admitted to the list. Of these four firms, only three were to provide engines for operational types of aircraft in war and for the most part the supply of engines for these aircraft came from two firms—Rolls-Royce and Bristol Aeroplane Co. The engines of the third firm—Napiers—were used only to a limited extent. The fourth firm—Armstrong Siddeley—was the main supplier of engines for trainer aircraft but for this purpose a fifth firm—de Havilland Aircraft Co.—was admitted to supply their Gipsy engine. In the pre-war period, engines from Blackburn Aircraft were accepted for trainer aircraft but less than 100 of these engines were obtained in the war years.

*Total deliveries June 1939—December 1945**

Engines	*Deliveries*	*No. of Types*
Bristol	100,932	6
Rolls-Royce	112,183	5
Napier	5,267	2
Armstrong Siddeley	32,868	1
de Havilland	10,905	1

*Excluding jet engines of which Rolls-Royce delivered 661 of two types and de Havilland 85 of one type.

In the early stages of rearmament, it seemed likely that expansion of engine production would follow a pattern very similar to that for airframe production. The initial expansion was secured by the voluntary expansion of the capacity at the aero-engine manufacturers' factories and by the government finance of a shadow scheme for production of the Bristol type of engine. By 1938, however, it had become clear that expansion of engine production would be more narrowly specialised than airframe expansion. The expectation that any outside firms employed on aero-engine production would be drawn from the motor car engine manufacturers was confirmed; in fact all the outside firms employed on final and major sub-assembly work were from the motor vehicle industry. There were obvious advantages in using the closely related and specialised organisation in the motor vehicle industry; even so, the similarity of aero and motor vehicle engine manufacture was at first over-estimated. Up to 1938 it had been assumed in all plans for war potential that it would be possible to convert selected vehicle engine factories to aero-engines manufacture by merely replacing certain items of plant. An investigation in 1938 showed however that very little of the existing plant would be suitable for aero-engine production and the conversion would involve a very extensive substitution of plant. Thus, whilst it remained an advantage to employ the vehicle engine manufacturers, it was necessary to provide them with new manufacturing capacity.

The place of shadow firms in the total output of aero-engines and in the peak production of engines was much larger than the contribution of shadow firms to airframe production. At the end of 1943 the monthly output of aircraft engines of all types was about 6,100 and of these over 2,400 came from the shadow firms, that is from motor car manufacturers. Of the total output of over 250,000 engines, the shadow firms produced over 97,000. Most of the shadow firms produced Bristol type engines and of these they produced over 67,000, more than twice the total of 33,000 produced by the parent company the Bristol Aeroplane Co. The other shadow firm—the Ford Motor Co.—produced over 29,000 of the Rolls-Royce engines. This was a good deal less than the 83,455 produced by the Rolls-Royce Co.; but the Ford output was achieved from a factory which did not come into operation until the second half of 1941 and which at 900 engines a month had the largest monthly output of any engine factory. Even so in the same year the Rolls-Royce factories had a monthly output of over 1,600 engines. In the first quarter of 1944 when the maximum engine output was attained, the output of all types of engine from the shadow firms amounted to a monthly average of 2,483 and from the parent firms 3,007 engines.

In the 1936 programme, it was estimated that apart from the Bristol engines the requirements could be met by the voluntary expansion of the aero-engine manufacturers. To meet the large deficiency in capacity for the Bristol engines, it was decided to bring into aero-engine production seven motor car engine firms. These firms were provided with factory buildings and plant at government expense and were a part of the shadow industry both for rearmament and also for war potential. The scheme was subsequently amended to include only five firms and the Bristol Aeroplane Co.—the designers and at that date the sole manufacturers of the engine. Of the six members of the group, Austins and Bristol undertook the final assembly of the engines; the other four firms manufactured components and sub-assemblies. Each of these four firms concentrated on different sub-assemblies and components within the scheme. This exceptional subdivision of engine manufacture would commercially have constituted a new form of subcontracting but all the firms had direct contracts from the Air Ministry. The scheme was organised on an agency basis and was an outstanding venture into a group organisation for shadow industry development. The consequent concentration of capacity was accepted with much misgiving by the Air Ministry; but it seems likely that the efficiency gained by the subdivision did much to offset the losses due to enemy action.

Progress under the scheme was rapid and by November 1937 the first engine produced by the shadow group had been delivered. Thereafter, and until the end of the war very substantial additions were made to the shadow schemes for Bristol engines. In 1939 a second shadow group was formed with only four firms—Daimler, Rootes, Rover and Standard. This time as an insurance against loss by enemy action the firms worked in two pairs, each pair manufacturing the complete engine. In May 1940, both groups were brought under a joint management committee and in 1942 when both groups were employed on the Hercules engine there was a general merger of capacity and operation. The joint output of the two groups was finally set at 1,500 engines a month. With this large scale planning of shadow schemes the need for expansion under Bristol management was greatly reduced. An agency factory under Bristol management at Accrington was provided in 1939 and this factory, equipped with the latest types of machine tools and planned to produce 400 engines a month, had a larger output than the parent factory. In January 1942, approval was given for the installation of machine tools to the cost of £3 million for the production of Bristol Centaurus engines in an underground factory; but the shortage of skilled labour there meant that only a very limited use of the capacity was possible. The peak output from this factory was only 42 engines a month.

Despite the additional factories under the management of the Bristol Company, it was from the two shadow groups that the major part of the supply came. This was true from the beginning of 1939 and throughout the war.

New Engine Deliveries

*Monthly Average (2nd Quarter each year)**

	1939	*1940*	*1941*	*1942*	*1943*	*1944*
Bristol Parent Factory	233	272	270	300	288	213
Bristol Agency Factory	—	—	33	265	342	405
Shadow Groups	348	593	992	1,148	1,133	1,511

*Except that 1939 is for June and 1944 is for the 1st Quarter.

The Merlin engine was the main type of engine required from Rolls-Royce both in the rearmament period and throughout the war. It proved to be capable of greater development than any other engine and in consequence had the greatest number of improved varieties or marks. Between June 1939 and the end of the war, over 110,000 Rolls-Royce engines were produced in the United Kingdom and of these over 100,000 were Merlin engines. The only other type in continuous production was the Griffon but deliveries did not begin until 1942. Both the Merlin and the Griffon were subject to constant development; the Merlin was manufactured in twenty-four marks or definite variants and the Griffon in seventeen.

Up to the beginning of 1939, the Air Ministry requirement for Rolls-Royce engines was about half that for the Bristol engine, and it proved possible to obtain the production required by direct expansion of the Rolls-Royce factory capacity. It was not until May 1938, when the Air Ministry requirement for Merlins greatly increased the output required, that it was necessary to consider a government financed expansion scheme for Rolls-Royce. The scheme eventually approved was entirely under Rolls-Royce management and did not involve any resort to shadow firms. But it was not until May 1939 that a major duplication of Rolls-Royce capacity was necessary. To meet a virtual duplication of demand, Rolls-Royce suggested the construction of a large agency factory under their management in Scotland. It was clear that what was needed was a factory free from demands of development work, located in an area where new resources of labour and sub-contracting capacity would be available. This, the first scheme to duplicate Rolls-Royce capacity by a shadow factory, was quickly approved in May 1939 at an initial cost of over £5 million.

At the outbreak of war there was immediate need for the further expansion of capacity. It was at this juncture that the possibility was considered of employing the Ford Motor Company as a shadow firm to manufacture the Rolls-Royce Merlin engine. This scheme promised —and indeed achieved—an exceptional combination of Ford methods of mass production and Rolls-Royce standards of quality. By January 1940 a site for the factory had been finally agreed at Trafford Park and the cost of building was estimated at £1½ million, with over £4 million required for machine tools. In October 1941 the first deliveries of Merlin engines from the new factory were made. This was the only shadow industry factory for the Rolls-Royce engines. Initially planned in 1939 to produce over 400 engines a month on double shift, the factory was finally scheduled in 1943 for 1,000 engines a month; in the third quarter of 1944, the factory reached the largest monthly output of any single factory when a monthly average of 900 engines was achieved.

The Rolls-Royce factories at Derby and Crewe, beset as they were by development problems, by frequent changes of type and large demands for spares, had by April 1940 a combined monthly output of 600 and by April 1941 reached a combined output of over 1,000 engines a month. The Glasgow factory which had a very low proportion of sub-contracting and undertook foundry work for the Rolls-Royce and the Ford factory attained a monthly output running very close to 700 and in December 1943 delivered 763 engines. The peak output of Rolls-Royce engines was thus obtained from four large factories of which three were under the parent firm. This was an example of compact expansion which had no parallel of comparable size either in engine or airframe production.

Monthly average deliveries of Rolls-Royce engines†*

	1939		1940				1941	1942	1943	1944		
	(1)	(4)	(1)	(2)	(3)	(4)	(1)	(1)	(1)	(1)	(2)	(3)
Derby and Crewe	204	282	306	662	739	707	732	946	993	1,027	1,044	944
Glasgow							20	396	524	574	583	543
Ford Shadow Factory								143	524	793	849	900

*Monthly average for quarter shown in brackets.
†Excluding jet engines.

The deliveries from the Ford shadow factory were all Merlin type engines of three marks only. From Glasgow the deliveries were also all Merlins but of no less than fourteen marks, including several variants with the two stage supercharger introduced in 1942. The range of Merlins produced at Derby and Crewe was even wider. In addition Derby produced the Peregrine, Vulture and Kestrel engines as well as several marks of the Griffon engine. Crewe also produced seven marks of the Griffon engine.

Two other factories were in production of Rolls-Royce engines before the end of the war but both of these factories were for jet engines. This production, from which deliveries started in December 1943, was quite separate from that on which the main factory expansion was based. A good deal of development work on the jet engines was undertaken at the Derby factory but the production was undertaken at two other factories. Both of these factories were comparatively small and both were obtained by the use of existing factory buildings.

There was never any prospect that the requirement for Napier engines would be on anything like the scale for Bristol and Rolls-Royce. In 1938, the demand for the current type of Napier engine—the Dagger—had almost ceased. The demand was revived in 1939 but was satisfied by production at only thirty a month; demand and production ceased entirely in 1940. For the new Napier engine—the Sabre—which was under test in 1938 and in 1939, the Air Ministry had by July 1939 decided on a war potential requirement of only 1,000 a year and proposed that a new Napier factory should be erected to provide this output. Much against the wishes of the firm a site for the factory was chosen near Liverpool. This was far removed from the parent factory and ruled out the previous intention of the Air Ministry that the two factories should be administered together. The factory was beset with difficulties from the start. In view of the quantity to be produced subcontracting was very limited and the Air Ministry had stipulated that a large proportion of general purpose machinery should be used in order to make the factory suitable for the manufacture of any type of engine. It is not surprising therefore that deliveries of engines from the factory did not start until 1942 and that far more labour was required for each engine than for any other type of engine.

Of the aero-engines required for trainer aircraft by far the largest requirement was for the Armstrong Siddeley Cheetah engine. Over 900 engines a month were needed for Oxford and Anson training aircraft. To meet the large expansion that would be necessary for war potential it was decided in July 1939 to introduce the Rover Motor Company as a shadow firm. This was an example of the direct use of a motor car factory for aero-engine war potential. The Cheetah was one of the few engines which could be produced in a motor car factory with the addition of balancing plant. The monthly output from all sources rose from less than 200 engines in 1939 to 720 engines by October 1942. Of the peak output the shadow firm supplied a third. Moreover this very large expansion was obtained without extensive building work and without the construction of a new factory.

The de Havilland Gipsy engine for training planes was the only other engine which had a real place in war requirements. During the war it was required in quantities rising up to 300 a month, but no major additional capacity was required after the outbreak of war. By November 1939 it was reported that a steady output of at least 300 engines a month could be supplied. The engine was particularly suitable for manufacture on motor car engine plant and it was proposed that as a reserve and strategic safeguard the engines should also be manufactured by a midland motor car firm. This arrangement was not carried through and in consequence supplies which rose to about 300 a month in 1940 came entirely from de Havilland. Motor car engine capacity was however used for extensive subcontracting of components. In 1942, de Havilland had to undertake pilot production of their jet engine, the Goblin, which came into production in 1945. With the decline in the demand for the Gipsy engine not much additional capacity was needed for the Goblin though inevitably additional specialised plant and equipment and test facilities had to be provided.

THE FACTORIES

At the peak of engine production there were twenty major engine factories in operation. All of these had a number of dispersal factories and most of them a number of ancillary factories. Often these ancillary factories were devoted to a specific task to relieve the main factory and facilitate engine assembly at the main factory. Thus some spares production and engine repair was often moved out to an ancillary factory, usually with substantial gain to the output of complete engines at the main factory. Most dispersal factories and the ancillary factories were obtained without extensive building.

Agency factories loom large both in the building programme and in the total capital expenditure. In consequence they tend to hide the very substantial extension of the parent factories. For the two main firms—Rolls-Royce and Bristol—government expenditure on building work on extensions to the parent factories was not much less than the expenditure on agency factories under their management. At Napiers in London additional factory accommodation was provided without resort to large scale building. Up to the summer of 1943 approved expenditure at these three firms on building extensions and additions to existing engine factory units amounted to just under £4 million compared with slightly more than £6 million approved for the construction of the agency factories at Glasgow, Accrington and Liverpool. For Armstrong Siddeley and de Havilland building construction was confined to extensions to their works or construction and adaptation of additional factories of moderate size; approved expenditure at these firms up to 1943 barely exceeded £300,000.

Expenditure on agency factories managed by outside firms was very large. In the Rolls-Royce group there was only one factory—the Ford factory at Manchester. This factory although on a very similar scale to the Glasgow and Accrington factories had slightly less factory accommodation. Nevertheless, it was in the same class of large factories and approved expenditure on building by 1943 had reached £1 million. With the Bristol shadow groups the position was somewhat different. In No. 1 Shadow Group the division between six firms and the use of some existing accommodation reduced the building work at each factory to less than £300,000. In No. 2 Shadow Group with a larger output and only four firms, the factory construction was much larger and at each factory exceeded £2 million. By 1943 the total building cost for factories under the shadow firms was £9 million for all types of engines—including Rolls-Royce and Bristol—and was not far below the total of over £10 million for the parent firms.

Production at even the largest of the new aero-engine factories began within two years from the agreement as to the site of the factory. For most factories production started in slightly less than two years. Construction was thus substantially complete within two years. The supply of machine tools presented by far the greatest difficulties but by dint of special efforts particularly by machine tool representatives in the United States and by the Machine Tool Control, production was not usually retarded for more than two or three months. Within twelve months of the start of delivery of engines from the new factory, the monthly output was usually at least 75 per cent. of the planned output. The planned output was then reached within a further three months—fifteen months from the start of deliveries and usually in just under three years from agreement about the site of the new factory. Most of the factories shewed an exceptional ability to respond to demands for further expansion of output; for this, many extra machine tools were usually needed but relatively small additions to their labour force. Even so obtaining the additional labour was often the most persistent difficulty; this was however only chronic at the Bristol factories, most of which were in exceptionally difficult labour areas.

The Ford shadow factory and the Bristol Shadow Groups 1 and 2 showed remarkable powers of expansion. The Ford factory had an advantage afforded to no other major engine factory; it was allowed to devote all resources to the production of what was substantially the same type of engine. In many of the other factories peak output was reached only to be drastically reduced by the necessity of bringing in another type of engine. Rolls-Royce and Bristol parent factories and all the shadow factories except the Ford factory suffered persistently from this disadvantage. The effect of this was seen clearly in the Rolls-Royce agency factory at Glasgow which was the largest and most fully equipped of all the engine factories. In 1943 the Glasgow factory was producing at least five types of Merlin and was preparing to produce the two stage supercharger type. In 1944, the factory produced at least ten types, of which seven included the two stage supercharger. Even more than Glasgow, Rolls-Royce factories at Derby and Crewe had to bear the brunt of the changes and diversity in the range of engine requirements. At these factories from the middle of 1943 onwards, the power and momentum for expansion, the additional capacity in the form of machine tools and factory accommodation, were largely absorbed in the much increased expenditure of resources required for the more complex and diverse engine requirements. The position of the parent factory at Derby was of course exceptional: a very large part of the resources of this factory had to be devoted to development work in the field of design and production.

The burden of development and introduction of new types and modifications fell heavily on both Rolls-Royce and Bristol; and any comparison in these onerous spheres of responsibility would be quite irrelevant and inconclusive. It can be said, however, that it proved possible to confine the impact of the Bristol changes and to avoid disturbing the flow of production in the new factories in a way which was not possible under the Rolls-Royce production programme, except at the Ford shadow factory. Bristol it is true had the major changeover from the radial to the sleeve valve engine but the impact of this in the shadow groups was lessened by starting up the second shadow group whilst the older types were taken out of No. 1 group. Similarly, it was possible to limit the effect of the introduction of the Centaurus, by confining this production to the parent factory and to the underground shadow factory. Nevertheless it may well be that development and preproduction work affected the operation of the Bristol parent factory much more than any other engine factory. After the end of 1941 output of engines from this factory remained almost unchanged although the labour force at the factory continued to expand until November 1943. In contrast, the Bristol agency factory at Accrington, the only other new self-contained factory for the complete manufacture of Bristol engines, demonstrated the advantages of full scale production. In the planning of this factory full advantage was taken of machine tools and manufacturing methods already well established in the United States for air cooled engines. Expansion of output in the first twelve months of operation was rapid but the final expansion to the planned output of 400 engines a week was delayed for at least a year, mainly by the shortage of labour.

The increase in the total capacity under each firm, as measured by labour force was very great. Rolls-Royce with the largest employment on aero-engines in 1935 of about 5,000 increased by 1943 to well over 56,000 on aero-engine production. Bristol with about 3,000 on aero-engine work in 1935 increased to over 36,000 by 1943. Napiers with a few hundred in 1935 had a total employment of about 20,000 on aero-engine production in 1943. Each of the four firms who shared in the two shadow groups had about 10,000 employed in the shadow factories and in addition all had some aero-engine work in their own factories. Employment at two of the Rolls-Royce factories exceeded 20,000—the agency factory at Glasgow and the parent factory at Derby. The Rolls-Royce factory at Crewe was closely related with Derby and only approached 10,000. The Bristol parent factory employed over 16,000, the agency factory at Accrington over 10,000 and the underground factory about 5,000. Three of the other aero-engine firms' factories employed just more or less than 9,000—the Armstrong Siddeley factory and each of the two Napier factories. The Ford shadow factory for the manufacture of Rolls-Royce engines employed over 16,000. The other shadow firms' manufacturing units were much smaller but many were attached to the firm's own industrial plant. The shadow firms in No. 1 group in 1943 had a total employment of over 16,000 and the four factories in No. 2 group reached a total of over 25,000.

For the single unit factories i.e. factories not in group schemes, the size was largely determined by the output of engines proposed and the extent of subcontracting arranged. The initial planning of most of the new factories for Bristol and Rolls-Royce engines was for very similar quantities, usually for 400 engines on a double shift or 260 engines on a single shift. On this basis, estimates and actual expenditure on building and works services were about £1½ million for each factory. It was the cost of providing the manufacturing plant and machine tools that was by far the largest item. This cost in the initial planning was never less than twice and was often at this stage three times the cost of building.

This meant initial cost of machine tools and jigs and fixtures at between £3½ million and £4½ million per factory. Moreover at all factories there were very large additions to the initial provision of machine tools. This was due not only to the increased output required, but also to the need to replace machine tools for the manufacture of a new type or even sub-type of engine. Aero-engine production was in the second half of the war not merely a major source of redundant machine tools then no longer required but also the basis of a constant demand for new machine tools. At some factories the total allocated for machine tools and plant was by the end of the war treble the amount of the initial allotment of machine tools. Thus for several factories the total exceeded £10 million for each factory although the value of machine tools in use at any period was a good deal less than this. With the shadow groups for the Bristol engine, the division of production resulted in smaller factories for each firm, but taking into account the extent of factory accommodation already available under the first expansion schemes, the total capital cost for the group production was very similar to that for the large single factories.

Comparison of labour force employed and output achieved at different factories can only be made with many important qualifications. The figures taken without qualification show a very wide range of output in relation to labour employed. The relation of labour force to the output of the factory was affected by the varying degrees of sub-contracting and even more by the extent of development and experimental work and production of spares undertaken at the factories. Thus whilst labour force provides a reasonable indication of the size of the manufacturing unit it cannot be directly used in relation to output as a means of measuring efficiency. Thus Rolls-Royce and Bristol together employed over 100,000 in the several engine factories and had an output of over 2,500 engines a month. The related shadow firms and groups employed over 58,000 and had a peak monthly output of 2,400 engines. Where extraneous items can be excluded the results tend to show a fairly consistent level of efficiency for newly planned and equipped factories. Thus the Accrington shadow factory achieved an output of 400 Hercules engines when a labour force of 10,000 was attained and the No. 2 Shadow Group reached an output of 824 Hercules engines with an employment of just over 20,000. In March 1943, when the two shadow groups were combined an output of 12,000 was achieved with an employment of 30,000. In March 1944 the labour force was over 41,000 and output for a month rose to near 1,600 engines. As in 1943 and 1944 some of the labour was employed on propeller production, a measure of increasing returns may be assumed.

SUBCONTRACTING AND ACCESSORIES

The manufacture of aero-engines had developed on the basis of some purchase of bought out components. In this, the organisation of production resembled that of motor vehicle engines, and many of the manufacturers of components were the same for vehicle and aircraft engines. The extent of the bought out items varied to some extent with the engine manufacturers but there were many components which all manufacturers purchased and the main differences came in intermediate products. For example, some engine factories had their own foundries, but others relied on foundry specialists. Most of the component suppliers were specialists in certain types of components and the manufacture of most of the components involved the use of fairly specialised plant.

In the rearmament period, the demands on the normal subcontractors were greatly increased and many of these specialist firms had to increase their capacity. For the less specialised work, such as the simpler castings, it was possible to employ capacity at a fairly wide range of foundries. By 1939, the maintenance of normal subcontracting presented quite exceptional difficulties. For example, it was no longer possible to obtain additional capacity for castings and forgings in anything like the quantities then required. For some new engine factories it was necessary to assume less subcontracting than had been the commercial practice. Instead of supplying additional plant to the specialist subcontractors or attempting to introduce other firms, the plant was installed at the new engine factories. Thus the large new Rolls-Royce factory at Glasgow was equipped on the basis of only 20 per cent subcontracting, which was considerably less than at the Rolls-Royce parent factories. The Glasgow factory also included a fully-equipped foundry plant capable of providing light alloy castings for other Rolls-Royce engine factories.

There were thus difficulties which prevented the maintenance of even the normal extent of subcontracting. The specialised nature of much of the work and the plant, made the introduction of new firms both difficult and uncertain. Several additional firms were introduced but the increase was not commensurate with the expansion of the existing firms and was not sufficient to maintain the normal level of subcontracting. The outcome in the provision of capacity for the peak war output varied considerably. Several new factories operated with a degree of subcontracting less than the normal commercial practice; but others, including some of the new factories had the advantage of the increasing restrictions on civil production and secured a higher proportion of subcontracting. This higher proportion was secured mainly not by the introduction of firms from outside engine manufacture, but by the use of several motor vehicle engine firms, not usually for components but for entire sub-assemblies. It is only here that engine subcontracting bears any comparison with the subcontracting of airframe production. Even then the similarity is limited by the fact that these subcontractors, unlike most of the airframe subcontractors, were usually specialists in a very closely-related field of manufacture. Thus the Austin Motor Company undertook work for the Ford shadow factory and for a time Bristol acted as major subcontractors for Napiers. The effect of the three main methods of subcontracting varied very much from factory to factory. All factories brought out certain specialised components but the extent of other outside work and supplies varied widely, only a few factories had the advantage of large scale subcontracting of sub-assembly work.

Three important engine accessories—carburettors, magnetos and sparking plugs—were purchased by the production department and issued free to the engine manufacturers. This manufacture was a very exacting undertaking for which highly specialised capacity was essential. Even in the pre-war period it had been necessary to provide agency factories for carburettors and for magnetos and several factory extensions for sparking plugs. In 1936, there was only one manufacturer of carburettors for each of the two main makes of aircraft engines —Hobsons of Wolverhampton for Bristol engines and S.U. Carburettor for Rolls-Royce engines. Both these firms greatly expanded their own resources and indeed it was not until 1941 that the S.U. Carburettor Company sought aid from public funds. But to meet the requirements of the shadow factory group for Bristol engines, it was decided in 1937 to establish an agency factory under the management of the parent firm—Hobsons. The demand was rising rapidly and by June 1938 it was agreed that a second agency factory for Bristol engine carburettors should be provided but this time under the management of the Standard Motor Company, who were already concerned in the Bristol engine shadow groups. Very considerable additions were made to both of the agency factories and a further agency factory was provided in 1942 under Standard management. Hobsons whilst increasing the capacity of the agency factory also greatly extended their works at Wolverhampton. In consequence, the output from their own works greatly exceeded the output from the agency factory. On the other hand the total output from the two agency factories under Standard management was only just less than the total Hobson output. The shadow firm here came near to equalling the output of the parent firm.

The supply of the Rolls-Royce engine carburettor from S.U. Carburettor Company was supplemented by production from a shadow firm a little earlier than the entry of Standards into the Bristol carburettor production. The Riley Motor Co.—a member of the Nuffield group—undertook production of the carburettors in their own premises in Coventry. It was not until 1941 that requisitioned premises were needed in addition and not until 1942 that supply of plant at public expense was required. From 1936 onwards, the parent firm S.U. Carburettor had continued to expand the capacity of the factory in Birmingham; it was not until April 1940 that it was proposed to erect an agency factory near Birmingham. In fact this scheme made use of an existing factory building at Shirley near Birmingham. These arrangements were somewhat dislocated by enemy action, which resulted in the loss of a large part of the parent works. By the summer of 1941, production was proceeding at the Shirley factory in place of the old parent factory and at two dispersal units in Yorkshire operating as agency factories. Despite this interruption of production the output of the parent firm continued to exceed the output from theshadow firm and the main parent factory at Shirley was responsible for at least 75 per cent. of the total output.

A very similar arrangement emerged for magneto production. Here again it was found that there were very narrow limits to subcontracting. Indeed it was found that in order to ensure reliability in the magnetos, almost all components had to be made in the specialist firms' factories. A very large part of the magneto production came from one firm—B.T.H. Before 1940 they carried out extensive expansion at their own expense but in 1940 further expansion was obtained in an agency factory and by further extensions mainly at government expense. When these schemes were completed B.T.H. were employing over 7,000 on magneto production at major factories in Rugby, Coventry and Leicester. The B.T.H. factory at Leicester was the only agency factory for magnetos and the new factory built for B.T.H. at Rugby was the only other large factory constructed for magneto production. Rotax the other large producer employed about 6,000 on magneto production but in smaller factories at several locations in the home counties and in South Wales. It was thus a common feature of these highly important accessories that production was very largely with the proprietary manufacturers. Only for carburettors were there shadow firms and these were highly skilled specialists in the motor industry.

(iii)

Propellers and Airscrews[1]

The production and programme planning of propellers and airscrews was very similar to that of engines. Although airscrews were much

[1] Although the designations, propellers and airscrews, are generally used indiscriminately, it is useful here to use propeller for the simpler fixed pitch types which consist of blade and hub, and airscrew for the much more complicated variable pitch types.

more difficult and costly to produce than fixed pitch propellers, they both had the advantage of a comparatively small number of types. As with engines, the same type was used for a large number of different types of aircraft. Also, as with engines, propellers were purchased direct by the Ministry production department and issued free to the aircraft constructor. As a result, the production of propellers and the planning of expansion were under direct control from the start of rearmament.

The manufacture of fixed pitch propeller blades in wood, though requiring specialised processes was a comparatively small production undertaking. There were a number of firms specialising in this work in 1935. These firms also supplied wooden blades to the manufacturers of the more complex airscrews; the output of some of the firms went entirely to airscrew manufacturers. The war-time requirement for fixed pitch wooden propellers was met by the deliveries from three firms. In fact, up to the end of 1940 all deliveries came from two specialist firms and it was only the increasing demand on these firms that made necessary the introduction of a general woodworking firm. The manufacture of fixed pitch propellers with metal blades was an entirely separate task. For some time the design and production of this type of propeller were undertaken by one firm only—the Fairey Aviation Co. The demand for the fixed pitch metal propeller increased considerably in the second half of the war but Fairey were able to more than double the supply to meet the increased demand. In the same period the demand for wooden propellers, though not for wooden blades declined.[1]

The problems of manufacture and expansion of fixed propellers were insignificant compared with the problems involved in the production of the variable pitch propellers. These propellers, more aptly described as airscrews, were of complex design. A large supply of blades were required as at least three or four blades were fitted to each airscrew; both wood and metal blades were used extensively. Manufacture of the airscrew required either a very large proportion of skilled workers or the installation of highly specialised machines. There were several major components; these could be manufactured separately, but all involved highly skilled workers or specialised plant. The airscrew was very closely linked with the aero-engine both in design and operation. It is therefore not surprising that of the two main manufacturers one—de Havillands also undertook aero-engine manufacture, and the other firm—Rotol—was formed in 1937 as a joint venture by Rolls-Royce and Bristol, with the primary purpose of manufacturing airscrews for use with Rolls-Royce and Bristol engines.

De Havilland's were the first to undertake the production of the

[1] Despite the decline in fixed pitch wooden propellers the production of wooden blades had to be continuously expanded to meet the needs for wooden blades for airscrews.

variable pitch airscrews in the United Kingdom.[1] In 1937 the Air Ministry was already planning to equip all medium and heavy bombers with airscrews and to confine fixed pitch propellers to lighter operational types and trainers. In consequence, it was decided that de Havilland's output should be expanded by the provision of an agency factory under their management at Lostock. There was to be some machining of components by subcontractors, and later, outside supply of some components, but to a very large degree the factory was planned and provided for the factory production of the complete airscrews. Lostock was in many ways the most self-contained of all propeller factories and it made the fullest use of specialised plant. The location of the factory dictated this. For to produce this type of airscrew with the use of unspecialised plant would have required skilled labour of a type only available in large numbers in an automobile manufacturing centre. To make use of the local labour it was necessary to divide the manufacturing processes into the simplest processes and make use of specialised plant operated by unskilled labour. The result was a highly mechanised system of manufacture giving rapidly increasing returns. The factory proved highly efficient and successful. Large scale factory production was clearly the right method for quantity production of propellers and large economies in skilled labour were obtained.

The main difficulties in airscrew production arose because of the necessity for specialised plant. This also made the use of outside firms extremely difficult and often unsuccessful; most of the successful subcontractors on the major components were from the motor industry. Specialised factory production did not exclude the use of subcontractors. Indeed, subcontractors were used from the start, for machining components and later for the manufacture of a few components. But these subcontractors had to be supplied with specialised plant and this made any rapid expansion of production by subcontracting extremely difficult. As a result, although the Lostock factory was assisted by two main subcontractors throughout the war period, the attempt to secure further expansion by this method failed in 1942 and 1943. Specialised plant was not available and it would have taken time to bring specialised methods into operation. The design was simplified to facilitate the use of general purpose plant and firms new to propeller production, but without success. Any attempt to avoid a high degree of specialisation even in subcontracting clearly ignored the very factor which had made for success in factory production. The extent of subcontracting should not be misunderstood. With a few exceptions the final manufacture was not necessarily dependent on the supply of components from subcontractors. The same components were

[1] Apart from the early Hele Shaw models produced in 1928.

also manufactured by the parent firm and usually in sufficient quantities to meet the manufacturing requirements for complete airscrews. Thus for most components the supplies from subcontractors were the equivalent of the margin required for spares.

The expansion of capacity for Rotol airscrews proceeded by rather different stages, but nevertheless demonstrated the same necessities as the de Havilland expansion. For both, a high degree of specialisation proved essential and this meant the provision of large batches of specialised plant not merely at the parent factory but also to subcontractors and shadow firms. In 1938, the Rotol airscrew was only emerging from the development stage. Development of variations and of other types was to occupy a considerable proportion of parent capacity throughout the war. In 1938, some expansion had been achieved by Rolls-Royce as subcontractors but as they were members of the Rotol firm and themselves heavily engaged on aero-engine production, this technically advantageous arrangement can hardly be said to have spread the load or increased the industrial capacity as a whole. It was not until August 1939 that the first expansion of the Rotol capacity was approved. Even at the beginning of 1940 the extent to which the Rotol airscrews would be used was still uncertain and the Rotol factory with the subcontracting organisation was already capable of attaining an output of over 500 airscrews a month. By 1941 the demand increased to over 1,600 a month. All the major expansions to meet this increase were centred on Rotol as the final assembly firm, some components were to be subcontracted and others produced by Rotol. At least two-thirds of these machine tools were to be installed in the Rotol factories and mainly at the factory at Gloucester. The M.A.P. became increasingly concerned at this large concentration of productive capacity. For although there were small dispersal factories at Cheltenham and Worcester and the subcontractors were fairly widely spread, the final manufacture of the Rotol airscrews was mainly at the factory in Gloucester.

The large expansion in 1941 at the parent factory had been accompanied by the introduction of a number of major subcontractors. More than ten firms were given major subcontracts and each firm was required to supply a large proportion of the total requirement for some of the major components. As a result, very few major components remained the sole production of the parent firm. In this period, the machining work on components which Bristol and Rolls-Royce had for long undertaken was transferred to new subcontractors. At the same time, factories in the No. 1 Bristol engine group were equipped to undertake the production of Rotol airscrews including the new electrical airscrew. This was the first example of the use of shadow industry firms for airscrew production. In December 1941, when a large expansion of output had to be quickly planned for the bomber programme this precedent was followed and three firms were appointed as shadow firms to provide the additional monthly output of 1,000 Rotol airscrews. This scheme at a cost of £1½ million and with more than 1,000 machine tools was undertaken by Hoovers Ltd., Vickers-Armstrongs, at Newcastle and the Standard Motor Co. As was very typical of so many large expansion schemes at this period, all the additional capacity was accommodated in vacant commercial factory buildings, including clothing and cabinet making factories. All three firms were making deliveries of airscrews within twelve months of the instruction to proceed. Thus although this was a late application of the shadow policy it was successful in securing the expansion of output required. This proved that firms with suitable commercial specialisation could with the use of a full complement of special plant make an unqualified success of airscrew production. At the peak of war production the output from the shadow firms including the No. 1 Engine shadow group came very near to the output of the parent firm Rotol.

The numbers employed on airscrew production even at the main firms was very much smaller than at most engine factories; the Lostock agency factory had a total employment of over 7,000 and including this factory, the de Havilland company employed well over 10,000 on airscrew production. The Rotol Company employed about 7,000 at their several factories. The three shadow firms introduced on Rotol airscrews each employed about 1,000 on this work. It should be remembered that all manufacture of Rotol airscrews was heavily supported by subcontractors some of whom employed more than 1,000 on this work. The labour force employed by firms manufacturing fixed pitch propellers was much smaller ranging from about 600 to about 1,700. Of the total commitment for capital expenditure amounting to £3½ million for buildings and over £10 million for plant more than half went to the main manufacturers of airscrews—Rotol and de Havilland. The Lostock agency factory accounted for over £2 million but much the larger amount was expended on extensions and additions under the management of Rotol. But de Havilland had extensions both at Stag Lane and at Hatfield and several of the shadow firms and major subcontractors for airscrews had schemes that in total exceeded £2½ million. Up to June 1943 there were only sixty firms included in the commitment for capital expenditure on propeller and airscrew production; and this included many small schemes.

(iv)

Undercarriages and Turrets

At the outset of rearmament, undercarriages were in process of becoming a specialised item. The fixed landing gear of the early period was being abandoned and a moveable, retractable undercarriage was included in all but a few types of aircraft. The fixed type had presented no serious problems and the design and production had usually been undertaken by the airframe manufacturer. The retractable type involved quite considerable difficulties both in design and production. Not all aircraft manufacturers could give these problems the special facilities required and the efforts of some were unsuccessful. The increasing weight of the new types of aircraft and the application of the hydraulic system for the operation of the undercarriage and nose and tail landing wheels, made the employment of specialist design and manufacturing capacity desirable.

Despite these new technical problems, a number of aircraft firms undertook both the design and production of undercarriages—Armstrong-Whitworth for the Whitley bomber undercarriage, de Havilland for several types including the Mosquito, Fairey Aviation for the Battle, Firefly and Albacore; but above all Vickers. In the pre-war period Vickers Aviation had developed a special section for design and production of undercarriages and had undertaken this work not only for their own aircraft but also for Supermarine and for other aircraft firms. In war production, Vickers undertook this work for more than fifteen types which included not merely their own Wellington and Warwick but the Hawker Hurricane, the Bristol Blenheim and Beaufort, the Fairey Hampden and Hereford, and the Supermarine Spitfire. Whilst the four aircraft firms were responsible for the main undercarriages they occasionally had the services of the specialist firms for the tail and nose wheels and even more frequently for the hydraulic systems. In the light and medium aircraft class the undercarriage work of these aircraft firms was considerable but by no means preponderant. Furthermore it was very largely concentrated on Vickers. Clearly there was much scope left for specialist firms even in the light and medium class; the heavy class was left entirely to them. Thus, even Vickers did not undertake heavy bomber undercarriage design.

Outside the aircraft firms, the specialist firms were Dowty, Automotive Products, Turner Bros. and Messier Aircraft. For two of these firms, aircraft work was merely one of their many activities; the other two—Dowty and Messier—were established specifically for aircraft component manufacture. Automotive Products as specialists in hydraulic and oil systems were mainly concerned in the manufacture of these components. At the peak of war production they had two large factory plants employing over 4,000 on undercarriage work. As they were responsible for hydraulic components for a very large proportion of undercarriages they employed a larger labour force on this work than any of the other specialist firms. Dowty and Messier were entirely engaged on undercarriage work and Turner Manufacturing Co. to the extent of 80 per cent. of their labour force. Thus these three firms were specialising entirely or to a very high degree in undercarriage work.

It was not until December 1939 that the Air Ministry had to take an active interest in this manufacture and a financial interest in the expansion of capacity for undercarriage production. Between 1936 and 1939 there had been commercial expansion among the specialist firms. Some expansion of undercarriage capacity had also been included in the airframe expansion schemes for Fairey, de Havilland, Armstrong-Whitworth and Vickers. But undercarriage capacity did not receive separate attention in these schemes. Later airframe expansion schemes also included capacity for undercarriage production but with the exception of Vickers and de Havilland this was relatively unimportant in the total capacity for undercarriage production. The Air Ministry investigation into the capacity was thus mainly concerned with Vickers and the specialist firms, Automotive, Dowty, Messier and Turner. There was already in 1939 an extensive system of subcontracting. It was to the expansion of capacity at these subcontractors that much of the initial financial assistance was devoted. Subcontracting on undercarriage production was very largely subcontracting for the supply of the complete undercarriage. Before the peak of war production was reached the number of firms undertaking undercarriage production as subcontractors had increased to over thirty. Of these, twenty-six manufactured at least one type of main undercarriage. Many firms manufactured several types and also the tail and nose equipment but only a few of the total number manufactured the hydraulic system. This, as might be expected, remained a much more specialist manufacture and a very large proportion of the supplies came from Automotive Products.

War requirements brought a large increase in the demand for the medium bomber types and for the large, heavy bomber types of undercarriages. Expansion for the light and medium types had its difficulties but these were slight compared with the difficulties of expansion of the heavy bomber types. These undercarriages had not only to be provided on the margin of the existing capacity but they also required heavier and more specialised plant. With one exception, the initial responsibility for the heavy types rested with the specialist firms, who had a very limited experience in quantity production. Most of these firms adopted extensive subcontracting as a means of readily increasing their capacity but in addition their own capacity was increased.

Both these developments brought greatly increased responsibilities which from time to time tended to overwhelm the administrative capacity of the firms. To avoid overloading and to relieve the strain on management it was found imperative to introduce additional firms to take responsibility for the complete manufacture of many types of undercarriage. In the end about thirty shadow firms were employed, some of whom had contracts from the undercarriage firms and others from the airframe constructors. This distinction is not of particular relevance; whatever their contractual position they were by function shadow firms—firms who undertook substantially the same work as the specialist firms.

Thus, although there had been no forward planning of undercarriage production and although war-time planning was largely determined by urgent necessity, undercarriages had by 1943 the largest group of shadow firms of any aircraft division. In addition, there were, of course, a large number of subcontractors who supplied components and undertook machining and other work. There were a number of reasons why the need for this extensive shadow organisation had not been anticipated in pre-war planning or in initial war planning. In particular, the undercarriage had remained a 'bought-out item' purchased by the aircraft constructors not by the Ministry and the development of the retractable undercarriage and the specialist firms was comparatively recent. There was no special directorate for undercarriages in M.A.P. until 1942, and more work had been placed on the specialist firms than they could undertake. Undercarriage production illustrates the difficulty of establishing the production of a major component which was just emerging from a radical change in technical development and for which there was a wide range of designs—a different design for each main type of aircraft. The total productive capacity needed for undercarriage production was not so very large. Organised on a large scale factory basis with some subcontracting of components it could probably have been dealt with by about six factories with a labour force of 5,000 each. The essential industrial problem was that the basis of manufacture was precision engineering with a high proportion of skilled workers. It was this that made the expansion of specialist firms difficult and also made it inevitable that the general policy would be to take the work to available precision engineering firms.

No precise comparison of the contribution of the specialist firms and of subcontractors is possible. If the aircraft constructors' production is excluded it seems probable that at the peak of war production the subcontractors were supplying about half the total quantity of the main undercarriages and tail and nose equipment also, but a much lower proportion of the hydraulic equipment. If the Vickers-Armstrongs munitions factories at Barrow, Openshaw and Newcastle are classed as subcontractors within the Vickers group, then it is possible that in the total production of undercarriages, subcontracting of the complete manufacture accounted for about half the peak output.

Despite the extensive use of subcontractors as shadow firms, the expansion of the specialist firms was still quite considerable. Nor could the provision of new factories for these firms be entirely avoided. In addition, most of the shadow firms and their subcontractors required additional plant and for some schemes additional building. An approximate total would be about £800,000 for building and £4 million for plant but this total may well underestimate the cost of additional capacity provided at the works of the airframe constructors. At least two of the specialist firms had additional factory accommodation which amounted to a new factory unit but apart from this the bulk building work was for the extension of existing factories. The provision of plant was much more general. All firms needed large additions of plant, not only to increase their capacity but also because types of machines were required that were not available in the existing plant. The machine tools, which included a large proportion of heavy types, went, not only, to equip complete new production units but also to balance the existing plant.

The labour employed on undercarriage production in the aircraft firms varied considerably but except at Vickers the total was not very large. Of the other firms, Automotive Products employed well over 2,000 at one factory and over 1,000 at another factory. Of the three specialist undercarriage firms, two employed at least 2,000 but at the other firm peak employment on undercarriage work was less than 1,000. Of the many other firms employed none had 1,000 employed on undercarriage production. The range was from about 750 to less than 1,000. The result of the widespread system of subcontracting and shadow firms was a very wide range in size of manufacturing unit. The scale of manufacture at most firms was a good deal less than at the four specialist firms but even there the scale of manufacture was substantially reduced by the administration of subcontracting and by the variety of types that had to be dealt with.

The production of aircraft gun turrets may well be considered here in contrast to undercarriage production. For turret production had the advantage of a limited number of types and the concentration of manufacture at a few firms and factories. For war-time operational aircraft, three aircraft firms were mainly concerned with the design and development of turrets—the Bristol Aircraft Co. who developed a number of turrets for Bristol aircraft, Parnall Aircraft formed in 1935 primarily to develop and manufacture the Frazer Nash type of turret, and Boulton Paul who also designed and manufactured aircraft turrets. The Bristol Aircraft Co. placed most of the manufacturing work with other firms, and almost all the Boulton Paul turrets supplied during the war were manufactured in factories under Joseph Lucas Ltd. Thus only one of the firms—Parnall Aircraft—was a major manufacturer of turrets for war production. Even then at least half of the supply of Frazer Nash turrets came from two other firms—the Daimler Co. and Brockhouse Engineering. These two firms were also the main manufacturers for Bristol type turrets and were already undertaking this work for Bristol in 1939.

It was clear in 1938 that to secure adequate war production of the Boulton Paul and Parnall turrets, it would be necessary to provide for manufacture by other engineering firms. By the outbreak of war it had been arranged that in addition to the expansion of capacity under the Parnall Aircraft Co., the two firms already employed on Bristol turrets—Brockhouse Engineering and Daimler should undertake production of the Parnall turrets and that for Boulton Paul turrets large scale manufacture should be undertaken by Joseph Lucas Ltd. Wartime production was to come almost entirely from the two aircraft firms and the three shadow firms. Boulton Paul confined most of their activities on turrets to design work, and the war production of the Boulton Paul turrets came almost entirely from the shadow firm. But the peak output of the Parnall turrets came in almost equal quantities from the parent firm and from the combined output of the two shadow firms. Of the total peak annual output of over 22,000 for all types of turrets more than 65 per cent. came from the shadow firms. With the early introduction of shadow firms capable of large scale production the wide spread allocation of capacity so often necessary for precision engineering was avoided. As a result 99 per cent. of the peak war production came from four firms and a large part of the manufacture was organised on the basis of large scale manufacturing units. One of the shadow firms employed over 6,000 on turret production, though this was in two main factories. The two other shadow firms employed over 1,000 and over 2,000 on this work. The parent firm Parnall Aircraft employed about 5,000 on turret manufacture but, largely as a result of heavy bombing, the labour force was dispersed to a fairly large number of small factory units. Despite this dispersal, a very large part of turret production continued in fairly large scale factory units. The allocation of capital expansion was similarly concentrated, for all but one of the shadow firms government expenditure of over £1 million was necessary and considerable factory building was undertaken for at least two of these firms. Turret production thus had the advantages of concentrated or closely linked capacity and of fairly large scale production units. A very important factor in promoting the rational organisation of turret manufacture was the direct responsibility of the Air Ministry and later of M.A.P. for turret production. This followed from the direct purchase of turrets and their supply to aircraft manufacturers as a free issue for incorporation in the aircraft.

(v)

Radio, Radar and Equipment

Three sections of specialised equipment for aircraft were heavily dependent on the electrical engineering industry. Radio and radar equipment for Air Force requirements as well as for the other services was produced entirely by electrical product manufacturers. Aircraft equipment also included a very large proportion of electrical equipment. Moreover a number of electrical manufacturers in addition to the specialist firms had in the inter-war period undertaken both the development and manufacture of aircraft instruments. All these demands came within what is usually described as light electrical engineering production in which many electrical firms, for example many radio firms, are entirely engaged. But some of the leading heavy electrical engineering firms also undertake and are indeed leading firms in light electrical engineering.

The electrical industry between the wars was expanding rapidly. In pre-war planning it had been estimated that the industry should be able to meet the war demands of all Services, not only for general electrical apparatus for aircraft but also for the specialised radio equipment and the even more specialised and increasingly complex radar equipment. This assessment proved substantially correct for the first year of war. It is true that even then there was some government expenditure for the provision of buildings and plant but a large part of this was required to duplicate capacity which was dangerously concentrated in vulnerable areas or limited to one or very few factories. There were also firms which had not sufficient capacity to meet the requirement for which they were most suitably equipped. The provision of additional capacity could not, even in the first twelve months of war, be avoided; but much the larger capital expenditure came after 1940. Expansion schemes for instruments and equipment followed rapidly after 1940 but the largest capital expenditure for radio and radar did not come until after 1941.

The additional capacity that had to be provided remained for the most part under the existing specialist firms. For radio and radar production there was never any suggestion of a shadow industry. Capacity was entirely within the radio sector of the light engineering industry. Pre-war calculations indicated that the existing capacity in the specialist firms should be adequate. Two agency factories for valves were approved before the outbreak of war, but these were intended as an insurance against the danger of air attack. There were also a few small extensions of existing factories before the end of 1940. Further agency factories were provided in 1941—again to duplicate and disperse valve capacity. By 1942, requirements had leapt upwards and every expediency had to be adopted to meet them. A good deal was achieved by working existing capacity to the limit by special managerial measures. In addition, there was now a general provision of extensions to existing factories where this could be done quickly. Capital expenditure from public funds increased rapidly from 1941 onwards and the final total for the war years was over £7 million. The story of the expansion of radio and radar production has been told elsewhere.[1] The pattern is very similar to that for other major production where general reliance on the existing specialist industrial capacity was necessary. Despite all that was done to increase production and expand capacity and although most of the suitable specialised capacity was allocated to radio and radar production from the start of war production, an increasing supply of radio and radar equipment had to be obtained from the United States. More extensive expansion of capacity in the United Kingdom was restricted by the need to meet the expanding requirements very quickly and by the heavy demands made on other sectors of the light electrical industry, especially for aircraft equipment and instruments.

Taken together the capital assistance for aircraft equipment and instrument production did not exceed £10 million and of this, aircraft equipment had the larger share. There were in fact many points of contact in this capacity, even though instrument production brought in many firms specialising in instrument work and though some firms in equipment production were undertaking work very similar to their normal manufacture. Whilst radio and radar were entirely within the light electrical engineering industry both aircraft instruments and aircraft equipment had very important capacity outside that industry. For aircraft equipment this was inevitable as there was a considerable range of equipment which was not electrical; and some aircraft instruments were of the kind manufactured by the optical and mechanical instrument industry.

The range of products coming within the classification of aircraft equipment increased rapidly. By no means all the items were for use in aircraft construction. Some were for personal use of the crew and others were ground equipment. The most important for aircraft construction were electrical equipment, bomb carriers and bomb release gear. Stores for operational use included parachutes and heated clothing.

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[1] *British War Production, op. cit.*, pp. 358-370.

Ground equipment included most of the items required on the ground except vehicles and weapons. It is not surprising that by June 1943 no less than 244 firms had schemes providing government capital expenditure on plant and many of these included some expenditure on buildings. Most schemes were small; the average expenditure both for plant and for building was barely more than £10,000 and for most schemes the expenditure was a good deal less. Up to June 1943, only five firms had schemes exceeding in total over £100,000; of these, four were electrical manufacturers and the fifth was a firm of precision engineers. For the most part firms were employed on production very similar or even identical with their normal peace-time production and in consequence the need for additions to building or plant was relatively small.

Aircraft instrument manufacture was a very specialised sector of war production. The development of aircraft instruments proceeded very rapidly during the rearmament period and throughout the war. The total weight of instruments in each aircraft became an important factor in the general increase of the weight of aircraft. Early instruments had followed many of the functions of nautical instruments and some of the first firms supplying instruments were long established nautical instrument manufacturers. But the special needs of aircraft navigation soon became dominant and in addition there was the rapidly increasing need for indicators for measuring a large number of operational factors and the development of automatic control of many aspects of navigation and operation. In all this came the use of electrical devices and the development of many of the instruments by electrical firms. Thus by the outbreak of war the capacity for aircraft instrument production included not only optical and scientific instrument makers but also several electrical, radio and telephone manufacturers. The list of firms with government capital expenditure schemes consisted almost entirely of specialist firms—instrument manufacturers, clock, watch and camera manufacturers and electrical manufacturers.

For many aircraft instruments there were specialised firms with commercial products basically similar to the special demands of aircraft requirements, e.g. clocks and cameras. It was for the more exceptional requirements in the form of navigational instruments and automatic controls that the large electrical firms had an important share. Most of the large schemes for capital extension were needed for these firms although an important item of expenditure was for duplicate sets of plant installed for highly specialised optical instrument production. Much of this work was so specialised that duplication of plant under the same firm or partial dispersal of the firm was the only means of ensuring the maintenance of the production. Although in war-time a few firms with similar specialised production were added, the bulk of expansion of output was achieved by a very large increase in the output of the firms already undertaking some production of aircraft instruments before 1939.

(vi)

The New Basic Industry

In the First World War aircraft were mainly constructed of wood and canvas; in the Second World War most types of operational aircraft had a metal structure and many of them were covered entirely with metal sheet. Steel was used for some components but the bulk of the structure and all the external sheeting were usually in light alloy metal—aluminium or some alloy of aluminium. Several trainers were constructed of wood; canvas was still used as the skin of some operational types as for example the Wellington, but the main operational type of wooden construction was the Mosquito. Thus, almost all the types of operational aircraft introduced after 1935 had metal structures and most of them were of all metal construction. But it was not only for the aircraft structure and covering that light alloys were required; an equally difficult and rapidly expanding demand was for propeller and engine components and also for undercarriage parts. To meet all these requirements a very large expansion of the light alloy industry was necessary. As by far the greater part of the output of the expanded industry was for aircraft production, this expansion can best be described as the creation of a basic industry for aircraft production.

The essential basis of the effort was a large expansion in the supply of the main raw material—aluminium. Deliveries of aluminium to industry in the United Kingdom rose from 78,000 tons in 1939 to over 293,000 tons in 1943. After 1940 more than half the total supplies of aluminium came from Canada; in 1943 these imported supplies amounted to 202,000 tons. The output of virgin aluminium in the United Kingdom was at least doubled between 1939 and 1943, but a much larger source of aluminium in the United Kingdom was from the melting down of scrap metal mainly from crashed aircraft—in 1943 this provided over 93,000 tons compared with a production of 55,000 tons of virgin metal.[1] The other light metal needed in greatly increased supply was magnesium, but in most years much the larger part of the requirement was for incendiary bombs. Even so the demand for aircraft construction could not be met without a substantial expansion in United Kingdom production of magnesium and this was true even in the rearmament period. Moreover until 1943 we were very largely dependent on United Kingdom production of magnesium.

[1] The expansion of the supplies of aluminium is dealt with in *The Control of Raw Materials*, *op. cit.*

Much the greater part of the greatly increased supplies of aluminium from all sources was for aircraft production and this is the main requirement reflected in the figures shewing the production of light alloy fabricated material.

Fabricated Aluminium or Aluminium Alloy
Production for M.A.P. and other government departments

(Tons—Monthly average for 1st quarter of each year)

	Sheet and strip	*Extrusions*	*Castings*	*Forgings*	*Total**
1940	3,233	2,000†	2,031	840†	8,500†
1941	5,349	3,318	2,487	1,671	12,016
1942	5,756	5,418	3,404	2,251	15,674
1943	8,506	7,459	4,864	3,320	21,637
1944	10,014	9,337	5,398	4,109	25,691

*Net total—excluding the extrusions which were used to provide a large part of the forgings.
†Estimated.

This expansion in all sectors of the industry was only possible with a large capital expenditure from government funds from 1938 onwards. With the large additions needed for war production, the total capital expenditure exceeded £60 million. Of this, £24 million was needed for developing bauxite and ingot production and a very large part of this was for development schemes in Canada. In all about £7 million was for schemes in the United Kingdom. In addition there was over £11 million needed for magnesium production and all but a very minor fraction of this was for overseas development. The same was true of the £28 million for the provision of light alloy fabricating capacity; this was almost entirely for factories and extensions in the United Kingdom. It was for the fabrication of light alloys that by far the largest number of firms were employed and received capital assistance in plant and buildings. Some of the primary metal producers were only concerned with the production of aluminium billets and slabs but many of the firms also undertook the fabrication of the material into sheet, strips, extrusion and forgings. In addition, there were many more firms that undertook fabrication from billets and slabs supplied by the primary metal producers.

The main specialist firms were those already operating in 1935. In that year the United Kingdom output of aluminium was only 15,000 tons and the total amount used less than 30,000 tons. In the fabrication of light metals for aircraft production up to 1935 it was the manufacture of castings and forgings for aircraft engines which had developed furthest. With the fairly recent general use of metal construction for aircraft there were many requirements for which current manufacturing techniques and plant were not entirely suitable. A specialised industry was in operation; but after 1936 and more especially after 1938 the demands were to grow both in quantity and complexity. From then on the light alloy industry had to concentrate more and more on the special requirements of aircraft production.

In all sections of the industry and at all firms a very large expansion of capacity was necessary from 1938 to meet the almost continuous increase in the requirements for aircraft production. It was of course not merely an increase in quantity that was required but also a change in the range of size and variety of product. For some production there was a large increase in the smaller parts required and the danger of using large product equipment uneconomically. For other products there were increases in size and complexity for which there was very limited experience and serious deficiencies both in plant and technique. The main expansion was in the firms within the light alloy industry. These firms accounted both for the greater part of the expansion and the greater part of the peak output, but some firms from outside the industry were employed as early as 1939. Almost all of these additional firms operated similar manufacturing processes in other metal industries e.g. iron and steel rolling mills, or steel or non-ferrous foundries, or steel forging plant. No less important were firms in other industries, notably in the motor engine industry who operated their own casting plant. Most of these firms were provided with additional plant to be used for light alloy fabrication.

The number of firms, the provision of additional capacity and the employment of outside firms differed considerably in the main sections of fabrication. Sheet and strip with the largest tonnage employed the fewest firms. Throughout the war sheet and strip accounted for more than a third of the total tonnage and finally rose in 1944 to a peak monthly output of over 10,000 tons. In 1939, the bulk of the production was undertaken by five or six leading light alloy firms including two of the main producers of aluminium. The greater part of the expansion was achieved by increased output from these firms and by the provision of additional plant and for some firms of additional factories. In addition, two iron and steel manufacturers were introduced to undertake this work. By the end of 1941 a steady monthly output of over 5,000 tons of sheet and strip had been achieved. The bomber programme brought a very heavy increase in requirements. Not only were the aircraft large but all the heavy bombers were entirely covered in metal sheets. Two major expansions of capacity had to be planned in 1942. The essential basis of the first expansion was a more or less equal expansion at all the main firms attained by provision of additional plant operating on a seven day week. For the final major expansion the main addition was obtained by the construction of a new factory in Scotland for the production of over 1,000 tons a month. Location of this factory in Scotland reduced the high concentration of sheet and strip capacity in the Midlands and South Wales and the factory was equipped to produce 6 ft. wide sheets instead of the 4 ft. wide sheets which had been the maximum width so far. Hitherto all efforts had been devoted to expansion of quantity of output; this was the first major change in the product and it was to be followed by other improvements in the later stages of the war.

Although the peak tonnage of extrusions was slightly less than for sheet and strip, the increase in output between January 1940 and January 1944 was much greater. Moreover, the manufacturing task was much more complex. Extrusions were required in a range of main forms each of which was subdivided into a variety of specifications. At the peak of production only about a third of the tonnage was required in the form of bar from which forgings of aircraft component could be made. The remainder of the extrusions were in the form of various sections or rods, tubes or wire and in a variety of sizes. Similarly, the extrusions in the form of sections had to be provided in a variety of sections, shapes and sizes; also in a range of weight and tensile strength culminating in the huge spars for the Lancaster bomber. The bar produced for forgings was required in a variety of sections and sizes closely related to the design of the component e.g. propeller blades, undercarriage and engine components. The manufacture of extrusions was dependent on the use of special extrusion presses. These highly complicated and costly presses were of various sizes and an important problem was to ensure the most suitable proportion of the different sizes. In January 1940 the number of presses in operation was 21; by 1944 the number had increased to over 70 with a very considerable increase in the medium and heavier presses.

A large part of the extrusion work was undertaken by the firms employed on sheet and strip production; the six leading firms on sheet and strip were also the main firms for extrusion manufacture. The other firms employed on extrusions were mainly concerned with special requirements e.g. three firms employed on radiator tubes, another firm on a wide range of tubes, another firm on wire and rod, and another firm that specialised in bar for engine and similar forgings. The total number of firms was about twelve including the six firms employed on sheet and strip. The cost of providing plant and buildings for the expansion of extrusion was less than for sheet and strip; though the extrusion presses were costly and difficult to manufacture and many of the schemes included equipment for heating, melting and other ancillary processes.

The combined tonnage of castings and forgings was only about equal to the separate tonnage for sheet and strip, or extrusions. Even so the manufacturing task was much greater. Forgings and castings required much more labour than other fabrication and most castings required highly skilled labour. Moreover the demand was entirely for specified components of specific and often complex design. A large part of the demand for light alloy forgings were for Bristol engine components and for propeller blade forgings, while in addition forgings were required for undercarriage components and a wide range of forgings for airframe components. Many of the forgings were forged from extruded bar and a large part of the forging work was undertaken by the main light alloy firms who also produced sheet and strip and extrusions. There were, in addition, several firms that specialised in light alloy forgings and castings. One of these firms at the peak of war production employed over 8,000 in several factories on this work; this firm was responsible for a large part of the supply of forgings for Bristol engine forgings as well as undertaking some of the other major forgings. Several firms not confined to light alloy forging work also undertook this work, especially for the smaller drop-forgings and stampings. Even so the greater part of the manufacture was with the specialist light alloy firms. As for extrusions, the main trend of expansion can be measured by the provision of additional units of the main equipment required—the forging hammer and press. For some forgings, notably the propeller blade forgings where forgings were from extruded bar, the expansion of extrusion and forging capacity was combined in one new factory equipped with a 12,000 ton forging press and a 5,000 ton extrusion press at a cost of over £¾ million. This factory was required entirely for the production of propeller blade forgings at the rate of 6,000 a month.

It was only in the manufacture of castings that a large number of firms were employed. But here again the most important castings were manufactured by less than a dozen firms. In 1939, there were over 500 foundries undertaking light alloy casting but many of these were small and only about a dozen of major importance. By far the greater number of foundries could only be employed on comparatively simple castings in the less exacting alloys. Of the aircraft production requirement for castings about 75 per cent. were engine castings and 25 per cent. for airframes. The castings required for engines were of great complexity and very few firms could undertake them. As early as 1939 difficulties in obtaining engine castings had led Rolls-Royce to expand the facilities for this work and later to include foundry capacity at the Glasgow shadow factory. This mechanised foundry was frequently extended and with existing facilities at Derby enabled Rolls-Royce to meet the main part of the demand for Rolls-Royce engine castings.

Thus the main burden of the manufacture of castings for aircraft production was borne to an increasing extent by the main highly specialised firms most of whom were also the major firms in the light alloy industry. The increasing use of magnesium alloy further increased the importance of the major firms. A very large casting in this alloy was for the large landing wheels for bombers; only three firms could undertake this work. The hundreds of small foundries were confined to comparatively simple casting much of which was required for other production. With the increasing demand on the few major firms a scheme had to be adopted in 1942 for the transfer of labour from some of the smaller light alloy foundries to the major firms. At the same time labour was transferred from iron casting foundries. A number of new foundries were erected for operation by some of the major firms but expansion was largely secured by increasing the operation and to some extent the equipment at the existing foundries. The cost of foundry facilities was much less than for other processes. The major factor in expansion was not equipment but labour.

The greater part of the capacity in the basic industry of light alloy production was concentrated in a few firms. There were about ten firms with a combined total employment of over 60,000, all of whom employed over 3,000 on light alloy production. The employment at one firm exceeded 13,000 and of the total 99 per cent. were employed on work for aircraft production. In addition there were eight firms employing about 1,000 and three firms employing about 2,000 on this work. Two of the firms, both employing over 3,500, were metal smelters and refiners only but all the other firms undertook at least one form of fabrication. All other firms with over 3,000 employed undertook at least two forms of fabrication, while many of the firms produced all forms—sheet, strip, extrusions, as well as forgings and castings. In addition to these firms, about 40 firms received some issue of plant for light alloy fabrication but for the most part the expenditure for each of these additional firms was comparatively small. By June 1943 the total capital commitment for light alloy fabrication was over £27 million and of this more than £24 million was for schemes with 22 main firms. These firms were also the main participants in the capital expenditure in the United Kingdom for aluminium and magnesium production. With these added, the total commitment for schemes with these 22 main firms amounted to £30 million. Of this total the greater part, at least £22 million, was with the eleven firms with over 3,000 employed on light alloy work. Some of these firms had as many as 20 major expansion schemes and most of the firms had several additional factories. More than any other sector of aircraft production, the expansion of light alloy capacity was secured by the expansion of the existing specialist firms who were almost entirely confined to this work. Moreover it was the only basic metal industry in which output was trebled in the course of war production.

CHAPTER IX

THE STRATEGIC LOCATION OF FACTORIES

Before 1936, the economic depression had brought the problems of industrial location into sharp and indeed gaunt relief. As the worst rigours of the economic blizzard began to retreat it was clear that several areas would remain relatively depressed and some largely derelict. These depressed areas included some that had been the basis of the heavy engineering industry of Great Britain. Indeed almost all had been important for their contribution to armament and naval shipbuilding production before and up to the end of the First World War. There were other more general reasons for this chronic depression; but it was significant that a large part of the employment between 1900 and 1918 in some of these areas had been in armament and naval shipbuilding or related manufacture. For some industries in these areas renewed activity was not to amount to real revival until the naval and army rearmament programme had added the pressure of their demands to the limited revival in civilian demand.

The fate of the depressed areas was accepted as a national responsibility. The government firmly avowed their intention to give assistance to these areas and to seek a means of bringing economic revival. By 1939 there had been a large exodus from many of these areas but they remained areas of relatively high unemployment. In some of the areas the revival of civilian trade and the rearmament production accounted for something but it was not until 1939 that the advent of war production brought final relief. In the placing of orders for rearmament requirements, the Service departments undertook, whenever possible, to place a proportion of their orders in the special areas, but as they had no authority to give preference to these areas, the undertaking could have little effect in securing additional orders except in so far as new factories were allocated to these areas. This was important in a few areas. But the fact that most of these areas did get a considerable proportion of the orders of the War Office and the Admiralty was mainly due to the pre-1914 concentration of armament and shipbuilding capacity in them. In addition under-employment of other existing capacity also led to the placing of rearmament orders in these areas. For example the War Office, when it sought skill and suitable capacity for the construction and to some extent the operation of new shell manufacturing machinery, found many suitable firms among the under-employed textile machinery manufacturers in Lancashire.

What was usually described as the southward drift of industry, had important implications for the military authorities as well as for economists. An increasing proportion of industry was concentrated around London and hence within easy reach of continental airfields. With the exception of Durham and Northumberland all the depressed areas came within the list of relatively safe area. This gave double force to the policy that the Service departments should take into account the desirability of bringing employment to these areas. In 1934 when the position of the special areas was being generally investigated the Service departments were examining the problem of the location of new munitions and aircraft factories in safer areas. The designation of relatively safe areas was decided by the Air Council. In 1934, the relatively safe area was described as bounded on the south by the Bristol Channel and by a line drawn from a point near Weston-super-Mare and Stow-on-the-Wold northwards through Stafford to Stockport, and thence to Haltwhistle (Northumberland) and afterwards north westward to Linlithgow. The inclusion of South Wales was at times the subject of reservations, and it was usually held that it would be in danger of attack from France. Between the relatively safe area and that classed as dangerous i.e. South, South East and Eastern England, there was a central area—chiefly the Midlands including Birmingham which was classed as unsafe and not regarded as free from danger. This classification of vulnerability remained in full force until October 1940.

The pre-war conception of vulnerability had to be drastically revised when enemy aircraft began to operate from the continental coastal areas. In the summer of 1940, the Industrial Capacity Committee sought an alternative ruling on vulnerability from the Chiefs of Staff in the light of the new circumstances. The Committee were particularly anxious to know whether factories and labour available in London and in towns in the eastern counties could now be used for war production and whether there was still objection to location of armament factories in the East Midlands, Yorkshire, North Durham and to the east of Glasgow. The Chiefs of Staff, giving their opinion before the heavy raids of September and October 1940, gave little grounds for relaxation of the general avoidance of the eastern regions. They made this more definite by stating that it was desirable that vital war production should be excluded from the region within twenty miles from the coast. This coastal area was considered much more vulnerable than the Midlands. It was also considered that new factories either located in the coastal area or in rural areas were much more vulnerable to attack than factories located in urban areas away from the coast. Further, the use of existing commercial factories had the military advantage of not attracting the enemy attention inevitably given to new constructions, particularly near the coast. This ruling whilst it was restrictive on the coastal fringe did put the rest of the country on more or less equal footing, and the sharp division between east and west was no longer essential. London, which came outside the coastal fringe, could now be used where premises and labour were available.

The prohibition on the coastal areas remained in force until February 1941. In the west, it included many areas in which several factories had been already established, as at Preston, Blackburn and Chorley. Much more restrictive for current development was the effect on Durham and Northumberland which had been generally avoided up to 1940 and now offered the largest area with supplies of labour both for construction and operation. In addition, many factories were now available in towns in the eastern counties and there would be great economic advantage in making use of these for war production. The Chiefs of Staff were greatly impressed by the economic considerations and decided that the prohibited coastal area should be limited to the coast from Lands End to the Wash. This decision released a considerable area but still left many important areas in the eastern counties out of war production; this limitation became increasingly irksome as the surplus labour came to be most evident in the east coast counties. In November 1941, the Ministry of Supply asked that this restriction should be reconsidered and premises in these areas used for the less important work. The Chiefs of Staff accepted this proposal and agreed to the use of several areas in the eastern counties. Thus by December 1941, it was possible to extend war production in most areas of the British Isles with the exception of the south and south east coasts.

Although in war, the policy of strategic location continued to restrict the choice of areas for new factories and indeed the use of existing factory accommodation, there was no general policy in favour of the pre-war depressed areas. In many of these areas after 1940, there was no longer a large unemployed labour force and for many production schemes there was usually a definite requirement for a substantial proportion of skilled workers. In the summer of 1940, the location of available labour was very different from what it had been in the pre-war years of widespread unemployment. By July 1941, when the total unemployed had fallen to ¼ million from ¾ million in 1940 and 1¼ million in 1939, the problem of finding sufficient available labour in any one district had become exceedingly difficult compared with 1938 and even 1939. This problem of the location of labour was to dominate the location of capacity and of factories from the summer of 1940 to the end of the war. From the last few months of 1940, the difficulties of locating available labour in almost all regions for any but the smallest factories made it imperative that the Ministry of Labour should provide or check in detail a short list of towns and districts likely to provide the labour required. Even in South Wales, the location of several new factories in that area, the increased production in coal mining and migration from the area, had by 1941 greatly reduced the labour available for factory work. Thus in the pre-war period the problem of location was often reduced to a choice between two depresssed areas but in war-time it became increasingly important to seek out localities in which a supply of suitable labour could be found.

In 1936, greatly concerned as the Air Ministry was with the problem of vulnerability to air attack, it found any action on industrial location of the aircraft firms largely forestalled by the immediate necessity of maintaining and expanding production. On the hypothesis of vulnerability as set out in 1934, a large part of the aircraft industry should have been removed to safer areas. Of the main aircraft and engine firms ten were in the most vulnerable area, four in the central unsafe area and only three in a safe area. There were thus strong grounds for recommending that a large part of the aircraft industry should be moved. The problem was considered by a committee at the Air Ministry in 1934 and 1935 and the views of the ten firms in the danger area were sought and discussed. The Committee came to the conclusion that the removal of the ten firms to the safer area though attended by serious difficulties was feasible, but if it was to be achieved in a relatively short time, financial assistance would be necessary.

It was however impossible to contemplate any general removal of aircraft firms before 1940 both because undisturbed production was necessary to meet the rearmament programme and because some firms had already been assured on the authority of the Air Council that there was no intention of pressing for the removal of their works before April 1940. This assurance had been given in 1935 to firms undertaking expansion of their existing factories. In consequence the valuable survey undertaken by the Committee became, in the words of the Secretary of State academic. In fact, with the policy to go all out over the next four or five years to increase the equipment of the Air Force, the best that could be expected would be extensions to factories in the least dangerous areas. There proved to be very considerable obstacles even to the policy of new factories in the least dangerous areas. With very few exceptions all the commercial extensions of the aircraft firms were erected adjacent to the existing factories. The same applied to the increasing number of factory extensions at government expense. Fortunately, some of the larger extensions were at factories outside the danger area particularly in Lancashire.

It was to be expected that the approval of new complete factories would do something to improve the strategic location. Even here less was achieved than might have been expected. It is true that none of the new factories approved between 1935 and 1938 were located in the dangerous area but the greater number of them were in the central area and, what was even more important, several were located in or near the highly concentrated industrial targets of Coventry and Birmingham. Up to 1938, with the solitary exception of the Bristol engine factory near Bristol—which in the event was one of the earlier targets of enemy attack—all the engine shadow factories were located in Coventry or Birmingham. The aircraft shadow factory under Austin management was constructed near the large industrial plant of the Austin Motor Company on the outskirts of Birmingham, and later, in 1938, the large shadow factory for Spitfire production under Nuffield management was constructed in the Birmingham area at Castle Bromwich. The position of these factories had been determined by industrial factors, primarily management and skilled labour. Many of the factories were adjacent to the factories of the firms who were to undertake management and in the areas in which the kind of skilled labour required was known to be available. Because of these primary requirements, the disadvantage of adding to the concentration of industrial capacity was accepted.

But for the policy of meeting the claims of the depressed areas even less would have been done to improve the location of aircraft capacity up to 1938. The conflict of circumstance and policy was fully expressed in the controversy which developed over the location of the Rootes airframe shadow factory. On the 21st January 1937, the Secretary of State announced in the House of Commons that it had been definitely decided to erect an aircraft factory at White Waltham near Reading in Berkshire. The House was not slow to express surprise at the apparent violation of the main tenets of location—vulnerability to air attack and the claims of special areas. The critics were indeed on strong ground: the claims of the special areas had been ignored, the proposed site was in easy reach of enemy air attack and was set in the rich agricultural land of Berkshire; the site was not very near either of the firms concerned—Rootes, and the Bristol Aeroplane Co. Clearly, proximity to an airfield was no doubt essential but there were scores of airfields in other parts of the country; moreover it was supposed to be the policy of the government to encourage industries to avoid the south. The Secretary of State in defending the decision made it quite clear that the main factor in determining the general location of the factory had been the proximity of management. He went so far as to describe the shadow factories as essentially satellites which should normally be adjacent to the factories of the managing firm. Indeed the Air Ministry would have been justified in choosing a site in or adjacent to Coventry; instead of adding to the existing industrial congestion there the Minister had chosen an isolated position behind the defences of London. Criticisms of the site as within the danger zone were, it appeared, to be discounted as with the existing range of modern aircraft there were very few sites that were not vulnerable. Vulnerability, as the remarks of the Secretary of State showed, was clearly capable of new interpretations on the score of isolation and possible protection afforded by heavily defended areas. This was an argument on which opinion might differ but which could be sustained against the criticism of the House. The claims of the special areas could not be so easily ignored. These had a more definite place in the opinion of the country and of Parliament than the increasingly hypothetical problems of vulnerability. Within a few days, the government had accepted the claims of a depressed area though not a scheduled special area; and before the end of January[1] the Prime Minister announced that the Secretary for Air was taking immediate steps to find a suitable site for the factory in Lancashire. In the same year, sites for two other shadow factories were chosen in Lancashire although the factories of the parent firms were in London and in Wolverhampton. These were the propeller shadow factory at Lostock, managed by de Havilland and the carburettor shadow factory at Oldham managed by Hobsons.

By 1939, there was a more general improvement in the location of new aircraft capacity. Extensions continued to be constructed at the existing locations but a very large proportion of the new factories approved from the summer of 1938, were west of the line. Some of this westward location was due to employment of firms already in that area. Thus, the adoption of English Electric and Metro-Vickers as shadow firms led to the use and extension of their factories in Preston and Manchester. More significant was the selection of sites for new shadow factories in the western area. The claims of management were no longer decisive; labour supply was becoming a much more difficult problem and capacity for subcontracting had to be sought in new areas. Managements realised that the time for new ventures and new locations had come. In this, the choice of Glasgow for the new Rolls-Royce engine shadow was a notable example. After an attempt to find the resources of labour and subcontracting capacity near the factories at Crewe and Derby, the firm courageously decided to venture into Scotland and chose a site near Glasgow. This was indeed a leap over the Border, with much uncertainty as to the supply of labour; only a small fraction of the skilled labour was available and extensive training schemes were necessary. The firm had some qualms whether a name that was synonymous with luxury—Rolls-Royce—might not arouse the antagonism of the Clydeside workers.[2]

Almost equally distant from the headquarters of the management was the site adopted at Chester in January 1939 for the Vickers airframe factory. Throughout 1939, the greater use of the north west continued. In September 1939, a site at Accrington was adopted for the

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[1] H. of C. Deb., Vol. 319, Cols 753-754.
[2] For firm's account see Nockolds H., *The Magic of a Name*, (1949).

construction of an engine shadow factory to be managed by the Bristol Aeroplane Co. They had originally proposed a site much more accessible from Bristol but coming within the danger zone but sites in the south west had to be abandoned because of lack of labour. Bristols, faced with the alternative of South Wales or Lancashire preferred the latter, although South Wales was nearer. The choice was mainly due to the kind of labour available in Lancashire, where the habit of factory work was well established. The problems of management at a distance were now having to give way to the problems of finding large enough aggregates of available labour. But there were still occasions on which the claims of management had to take precedence, though usually the location of management and labour coincided. Thus the approval of a second set of aero-engine factories adjacent to the first group in Coventry and Birmingham was contrary to all rules of vulnerability. But this was really unavoidable as it was intended to draw the management and the labour required for war expansion from the motor car factories of the managing firms.

The choice of Lancashire for airframe factories continued and at the end of 1939 was firmly extended to engine production. Here, very significant was the decision to locate a large new aero-engine factory at Trafford Park, Manchester, to be managed by Fords of Dagenham. This presented most of the basic problems again. The position of the Ford works at Dagenham, described in the first few days of hostilities as the most attractive target in an area which is strongly defended simply because it is expected to be strongly attacked, made it impossible for the Air Ministry to entrust them with any major part of the production for any requirement. The decision that the Ford Company should conduct and manage a factory for the production of Merlin engines meant finding a site far removed from Dagenham. The problem was to find a position close to a big centre of population and west of the line; Fords already had factory property in Trafford Park and this disposed them to consider Manchester. There were many competing claims for labour in Manchester and the difficulties of assuring sufficient labour for a factory to employ at least 15,000 men even led the Director General of Production to recommend reconsideration of the London area, somewhere west of London close to the electric railway. For in the opinion of the Director General of Production it was no longer possible to disregard London—the area containing 20 per cent. of the total population. The management would have been favourable to a London site but the Air Council could not consider the proposal and the Trafford Park site was adopted. It was soon to be proved that engine factories could function efficiently at distant locations—Rolls-Royce at Glasgow, Fords at Trafford Park and Bristol at Accrington—and that the managements of the parent firms were equal to the task.

In the early months of the war all new airframe shadow factories were located away from the parent factory and in strategically acceptable areas. A Vickers shadow factory was located at Blackpool, a Bristol factory at Weston-super-Mare, a Handley Page factory at Stoke-on-Trent, and an A. V. Roe factory at Yeadon in Yorkshire. Thus from the beginning of 1939, the location of new aircraft factories showed a very great improvement on the previous tendency to concentrate capacity in highly vulnerable areas. Expansion of the engine shadow factories in the midlands continued but apart from this, matters did improve as the new factories were completed. Even so, in 1940 the greater proportion of aircraft production was still in highly vulnerable areas. This vulnerability was disastrously proved in the first few weeks of air attack and gave an urgent impetus to the policy of dispersal which was then extensively adopted.[1]

In pre-war planning, the War Office location of factories satisfied to a very high degree the claims of the special areas and the need to avoid vulnerable areas. A large number of the factories were under direct government management; the disadvantages of isolation from other government factories were not sufficient to determine location. Many of the War Office agency factories were under I.C.I. management and with the major exception of Billingham, all the existing I.C.I. factories concerned were outside the danger zone. In consequence, proximity to existing I.C.I. factories could be achieved almost entirely within the safe zone. For many of the War Office factories in this period very little skilled labour was required; filling and explosives factories had the largest labour requirement but they would have to train their labour to the processes to be used. These factories also had to be located in fairly isolated positions and away from industrial concentrations. The War Office thus had many advantages in considering the problems of location, and in consequence they were able to approach the matter with a rigour which was rarely possible in the Air Ministry. Further, the War Office in 1934 had been authorised to proceed with the removal or replacement of some of the more vulnerable factories—at least part of R.O.F. Woolwich and all the Royal Gun Powder Factory at Waltham; in addition, the Committee of Imperial Defence supported the necessity of providing an alternative to Billingham as a source of supply of materials for explosives.

The War Office in this period was able to follow a rigorous policy of strategic location, very much in accordance with the zones of vulnerability as laid down by the Air Council in 1934. Sites were found for most of the new factories in the safe westerly zone. In the three years, 1936 to 1938, only one factory was approved within the danger zone

[1] Chapter VI, Section (iii).

and this was a rehabilitation of an already existing government factory and had the merit of location in a depressed area. Three factories were approved in the central zone—the gun R.O.F. at Nottingham, an agency gun factory at Coventry and the I.C.I. explosives factory at Huddersfield—but all these new factories made use of existing buildings or installations. All the other new factories were located in the safe zone, including a filling factory and a fuze factory in Lancashire, two filling factories and a cartridge factory and explosives factory in Wales.

There was no doubt about the vulnerability of the Royal Arsenal at Woolwich, of the Waltham Abbey Gunpowder Factory and indeed the Royal Small Arms Factory at Enfield. A War Office committee in 1934 had come to the conclusion that if uncertainty of supply in war-time was the only factor of importance, no manufacturing capacity should remain at any of these factories. The committee recommended the removal of the entire manufacturing capacity from the Waltham factory and of the filling factory and gun factory from Woolwich. New sites recommended by the committee, at Queensferry, Gretna, Oswestry and Glasgow all satisfied the Air Ministry zoning of vulnerability. There was a considerable choice of sites for the filling factory in the safe zone and the Cabinet were anxious that the claims of the special areas should be given special consideration. In consequence, a site at Chorley was accepted by the Cabinet in July 1935 as preferable to the Oswestry location and a second committee was asked to consider the possibility and desirability of a further filling factory in South Wales and the best site for an explosives factory to replace Waltham.

The Cabinet in requesting an examination of a factory for South Wales were pressing the claims of the special areas. The committee responded by recommending the location of a filling factory in South Wales and the investigation of sites for an explosives factory in another special area—Lanarkshire—and by recommending a site at Bishopton close to that area. It was difficult to please all areas. The choice of Chorley had left South Wales disappointed. The Minister of Labour strongly pressed the claims of other areas before Bishopton was chosen. The location of all filling and explosives R.O.Fs was based on very similar principles. In 1937, a second filling factory was approved for South Wales. Ease of transport between filling factories was of some importance and three factories—the two new factories in South Wales and the rehabilitated factory at Hereford—had fairly short and direct access. Proximity to other filling factories and to the supply of empty components was now to have a larger place in location. The deliberations of the committee on Billingham also resulted in a rigorous application of the policy of replacement in the safe zone. This inter-departmental committee made quite clear their considered objection to any reliance on Billingham for war-time supplies of explosives and explosive materials. The outcome of the work of this committee from June 1936 to the summer of 1939 was the duplication of the Billingham capacity at new locations. These, with one exception, werein the safe zone and also in the special areas.

This process of locating new filling and explosives factories in the safe zone and usually in special areas continued in 1939 and indeed applied throughout the war. For example, of the seven major explosives factories and three filling factories approved in 1939 there was only one possible exception to the policy. For the first time in 1939, one of these factories was placed in the special area of Cumberland. There were of course advantages to be obtained by grouping some factories in the same regions; this helped to perpetuate the policy now well established. As a result of this policy mainly based on the claims of the special areas and the problems of vulnerability, the filling and explosive factories were by 1939 located in several definite regions. By the end of 1939 there were (either completed or under construction) four factories in South Wales with one across the Bristol Channel in Somerset; five factories in the region radiating from the Wirral peninsula, mainly in South West Lancashire; and seven factories in the South West Lowlands of Scotland. This pattern of location in these two main regions was augmented by the engineering R.O.Fs that were approved in rapid succession in 1939 and 1940. Two gun factories were located in South Wales and four gun factories, a fuze factory, a small arms and a small arms ammunition factory in the Lancashire-Cheshire region. Scotland had not fared so well with engineering R.O.Fs but a gun R.O.F. and a shell factory were established on Clydeside.

The location of some of the other engineering R.O.Fs; brought some variation but only a few were placed outside the initially defined safe western region, although as early as 1936 there had been one significant departure from policy. Then, the reconstruction of an existing factory at Birtley, County Durham, had been approved as a R.O.F. for cartridge case production. This proposal had been previously abandoned in 1935 due to Admiralty objections on the grounds of vulnerability but in 1936 the Committee of Imperial Defence decided that the urgency of requirements warranted the use of an existing building with suitable installations even though this was in the north eastern danger area. Similar reasons had led to the reconstruction of the factory at Nottingham in preference to development of a new site in Scotland; but in 1938, a gun factory was located on Clydeside with the extensive use of an existing building. In 1939 some attention was given to the claims of the West Riding of Yorkshire which might well have felt neglected in view of the attention given to south west Lancashire. A gun R.O.F. was located at Leeds and a small arms factory at

Maltby; this was but a limited incursion into the fringe of the danger area. It was not until December 1939, that a new factory was approved for the North East; then a small arms ammunition factory was approved in County Durham, with a related filling factory to follow early in 1940. The rapid approval of factories at the end of 1939 and in the early months of 1940 had made it necessary to spread the burden both for construction and industrial operation. Thus the North East and Yorkshire could no longer be left out. Even so, the limited approval of factories did not disturb the preponderance of the western regions in the location of the new Royal Ordnance Factories and of the explosives and chemical agency factories.

Far less could be done about the location of the engineering section of the armament industry. Here the main firms had factories in the Thames estuary, on Tyneside, in Birmingham, in the Midlands and near Manchester. These locations were either in the danger zone or within large industrial targets in the central zone. Most of the extensions of capacity during the rearmament programme were at the existing locations. Though there was no large expansion in the Thames estuary, there was a very large re-equipment of armament works on Tyneside and extensions were approved to B.S.A. works at Birmingham. With the introduction of outside firms for shell and gun work a large proportion of the orders were placed in the North West. In war-time, this trend was to continue despite the employment of outside firms in all regions; but as the use of existing capacity was pushed to the limit, the predominance of the North West and the Midlands was reduced by the increasing employment of existing factories in other regions.

In the pre-war period, the Admiralty gave full support to the policy of locating new government factories outside the vulnerable areas. In 1936 they strongly opposed the choice of the site of Birtley in Durham for the new cartridge case R.O.F. the new Royal Naval Propellant Factory was constructed in North Wales. As far as possible they followed the same policy for the sites of the few new inland factories for naval production. There was, however, very little opportunity for improving the location of the shipbuilding industry without heavy loss of resources. There were few large shipbuilding yards on the south coast but the Royal Dockyards at Portsmouth and Devonport were clearly highly vulnerable. Some of the largest shipbuilding yards were on the west coast but there were very important yards on the north east coast. Shipbuilding continued throughout the war in the private shipyards on the south coast but in 1940 the Admiralty decided not to undertake further new construction in the southern Royal Dockyards. Repair work continued there but this was reduced by the removal of floating docks and equipment to repair depots on the west coast. This and the reopening of Rosyth brought an important change in the location of repair facilities in the government dockyards. Apart from these changes the shipbuilding and repair work continued in shipyards at all shipbuilding areas around the coast and the main balance of location was unchanged.

Part II

CHAPTER X

THE EQUIPMENT OF FACTORIES AND FIRMS

(i)

The Demand for Plant and Machine Tools

CAPACITY for some war production was provided entirely by the provision of new factories; other production was entirely from existing factories and workshops. Between these two extremes there were many stores for which production was from both kinds of capacity. Provision of manufacturing plant was thus a complex matter. For some stores there was very little doubt that self-contained factory production was the only economical method and indeed often the only practical method. It is true that the manufacturing unit rather than the factory was often the essential denominator but where a number of specialised manufacturing units had to be provided some grouping into a factory unit was an obvious advantage. This was clearly true of explosives and chemical warfare production and to a large extent of ammunition filling; in addition, safety considerations made segregation essential. For explosives and chemical factories the manufacturing unit was usually a process plant. Some factories consisted of one or more units for the same process and commodity and others of several units for different stores. Most of these factories, and particularly the explosive factories were isolated self-contained factories but some were constructed adjacent to existing factories; all the large filling factories were also isolated, self-contained factories.

The manufacturing plant at explosives and chemical factories was specialised plant. Some parts of the plant might be available as standard chemical process plant but for the most part the plant had to be designed and constructed for the specific purpose of the factory. For constituent materials a standard process plant was sometimes available e.g. nitric acid plant. Whether this was available as a standard unit or not, the manufacturing unit constructed was essentially a special purpose process plant. In filling factories, the position was more complex as the extent of process plant was small. Indeed until the limited introduction of mechanisation, the amount of process plant in filling factories was extremely small. There was however a considerable amount of general equipment, storage equipment, conveyances and measuring equipment. The supply of plant for explosives and propellant factories and also for filling factories was dealt with primarily as the provision of plant for each factory. To a very large degree the plant had to be built up at the factory. Although there were many standard items in the plant it was the integration, usually the plumbing of the several parts, which brought the process plant into existence. For the supply of most items of plant there were fairly large manufacturing resources in the engineering firms normally undertaking the supply, of plant for the chemical, gas and oil industries. Many of these firms could in addition resort to extensive subcontracting. A large part of the equipment for filling factories was suitable for manufacture by general engineering firms and, in the main, capacity was found without great difficulty. There were, of course, difficulties in organising the supply of plant but they were never such as to warrant the formal control of the supply or general allocation of the equipment required. It was only in the supply and allocation of machine tools that government control was established.

Machine tools are both unique and ubiquitous. Many types of machine tools were needed for almost every expansion of munitions capacity which made use of engineering processes; they were also required for the maintenance of other factories including explosives and filling factories. In many ways the demand for machine tools is the most exacting demand to satisfy, the demand is usually for a fairly wide range of specific types of machine tools in certain definite quantities and the scope for substitution is very narrow. The difficulties are much more specific than in the supply of labour. There might indeed be problems of balance between skilled and unskilled labour, but even in the early stages of war production, a point is soon reached at which almost all new supplies of labour have before long to be trained and the supply of skilled labour has to be distributed to facilitate the training. The scope for substitution has to be and can be made very wide indeed. With buildings, there is usually very wide scope for substitution and adaptation; in order to avoid the provision of new buildings. Moreover, as production changes occur, and this occurred frequently in war production, the same labour force and the same buildings can be used again. In contrast, very few production changes are possible without important changes in the machine tools and plant and many of these changes require an almost complete replacement of the existing machine tools by different types.

Both the trend and nature of the requirements for machine tools are exceptional. The trend is affected not merely by the size of the production programme but also, and often even more so, by changes in the products or merely in the designs of the products required. The demand is more persistent than for any other factor; for with a labour force at the peak and with existing buildings available, it might be, and often was, necessary to provide additional supplies of machine tools. In fact, the shortage of labour might be an important reason for obtaining additional supplies of labour-saving machine tools. The detail of the demand is more important than for other factors; the kind of machine tools and the right proportion of each type is peculiar to the kinds of production that have to be undertaken. Thus the demand for machine tools in war production is essentially persistent and specific.

The classification of machine tools and in consequence any schedule of demand is a very complex matter. The great bulk of machine tools are classed as standard machines and are divided between the main engineering methods—turning, boring, drilling, milling and the many other processes.[1] Thus the normal list includes more than twenty main groups identified by the main processes but within each group there are many types varying in their scope in respect of size and also specific operation. Even so, as the classification implies, all these machine tools can be used within limit of size for any type of engineering product for which the process is required. In contrast with standard machines it is usual to denote others as special purpose machine tools. For munitions production a more significant, though somewhat narrower, classification might well be special product machine tools. These are especially important for munitions production and include machines specially developed for ammunition and weapon production. Special product machine tools are also used in peace-time production and include many machine tools developed for the motor vehicle and aircraft industry especially for engine and propeller production. Earlier examples are special product machines developed for locomotive manufacture and shipbuilding. As the term implies, special product machines are designed for use solely in the manufacture of a certain type of product. Some, a comparatively small though growing proportion, are limited to the particular design and size of one component. They may be fairly simple in design and may occasionally be obtained by adaptation of standard machines. Some special product machines especially those which combine special purpose with multiple operation are highly complex and extremely difficult to develop and manufacture. For most special product munitions machine tools a significant demand usually only arises in rearmament or for war production and, in consequence, new capacity has usually to be found for the manufacture of these machines. Even so, for a given programme of munitions production, calculation of the requirements in terms of these machines can be fairly direct and precise.

It is much more difficult to formulate demands for the wide range of standard machines. For not only are there many major processes but

[1] In the classification and description of machine tools given in this volume no account has been taken of developments in machine tool design after 1945.

the subdivision of processes results in a wide range of subsidiary types of machine tools, any one of which may be essential to efficient operation on a specific task. Indeed, the possible degree of specialisation of type within the range of standard machines is very great. Differentiation by size is only one aspect of this. Two stages in specialisation are of particular importance. The first, when separate machines are designed for subdivisions of the main processes; the second, when this fairly specialised machine is developed to give automatic production at a greatly increased rate. Thus at one end of the scale of standard machines is, for example, the general purpose lathe suitable within limits of size for all lathe operations; at the other end is the fully automatic lathe capable of doing one or a series of specific operations. At this end of the scale there is an intensive development of automatic machines to provide a greatly increased rate of output. Usually, this is finally achieved by the design of multi-automatic machines which do the same operation or different operations at several points simultaneously. When this level of specialisation for quantity production is reached it is usual to describe the machine as a high quantity production machine tool. The same kind of development applies to other processes, for example from the general purpose milling machine to the automatic high production milling machine.

These highly developed machine tools are not necessarily outside the range of standard machines; they are not usually restricted to any specific product or component.[1] The degree of specialisation does however bring certain difficulties in the transfer of these machines from one production task to another. Very complex tooling is usually required for the type of work undertaken and the transfer of these machines to other work may take a good deal of time and require provision of fairly expensive tooling. War production greatly increased the scale of manufacture of all types of machined components and in consequence the demand for these highly specialised machine tools was quite disproportionate to the normal peace-time demand. For peace-time requirements it was only for the manufacture of fairly small components that there was any general development of fully automatic machines. For larger components there was often only one or two machine tool manufacturers in the world offering a suitable type of high production machine tool. Indeed for almost all types of automatic and high production machine tools the United Kingdom was very seriously dependent on foreign types.

Not merely was the demand for machine tools persistent but it was persistently competitive. For although the requirements were specific for each sector of production and indeed for each expansion scheme, in the aggregate they were for very similar ranges of machine tools.

[1] Post-war developments of machine tools have brought many changes here.

Every specific demand was very largely a demand for a special assortment of specific types of machines from the common range. There were exceptions to this; some manufacture, notably weapons and ammunition required a considerable number of machines peculiar to that production. But even this did not substantially affect the competitive demand as there were also many competing demands for these special machines. Indeed, as many of these special machines had to be obtained from the producers of standard machines the competitive pressure on common capacity was increased. Thus extreme competition for limited supplies persisted throughout the war. Even when supplies of many types were more or less sufficient to meet the demand, and when the acute competition for special munitions machines had been satisfied, competition was still severe for many high quantity production types—standard machines which were always in very limited supply.

In quantity the requirement of machine tools for the Ministry of Supply and the aircraft programmes were about equal and this was to

*Estimated requirements and actual supplies of machine tools to supply departments**

Number of machine tools

	Ministry of Aircraft Production		Ministry of Supply		Admiralty	
	Requirements	Supplies	Requirements	Supplies	Requirements	Supplies
September 1939 to December 1940	40,000†	30,000†	45,000†	33,000†	6,000†	3,500†
1941	38,611‡	32,000†	27,723	29,000†	6,063	4,500†
1942§	32,928	30,631	38,000‖	38,154	2,400¶	5,478
1943§	24,650	21,498	25,560‖	23,641	6,000	6,644
1944§	16,363	15,790	24,180‖	15,514	7,000	5,987

*This table does *not* include requirements and supplies for private purchases, exports and machine tool production.

†Approximate retrospective estimate.

‡This figure includes some of the requirements under the 1942 bomber programme. Before September 1941 the requirements ran at a monthly rate of about 2,500 per month.

§From 1942, all estimated requirements are first month of year estimates except for Ministry of Supply (1942) where a later estimate including a large War Office demand is used.

‖A large part of the Ministry of Supply requirements for 1942 onwards were for machine tools for the Army. These were mainly different from those in demand for munitions production and a very large proportion were portable low-cost machines.

¶This figure was much increased in the course of the year.

remain the position for most years of war. The requirement for Admiralty schemes was always less. This was no great advantage, for it left the Admiralty often dependent on the good will of the two main competitors and often forced the Admiralty to make do with inadequate supplies and existing plant of very limited value.

A large part of the requirement under the Ministry of Supply in the second half of the war was for low cost machines for army workshops. Even with production machine tools, number is not an accurate guide for there was a very wide range in cost for different types. Thus although the demand for machine tools for the Ministry of Supply production programmes continued into 1944, it was the M.A.P. demand for production machine tools which then proved the largest and most costly. The total annual requirements for machine tools show the persistence of the demand but they do not reflect the important changes in the proportion of types required. It is not possible to show even the main differences between the demands from year to year or the nature of any aggregate of machine tools without relating this to the sectors of production for which machine tools were required. Responsibility for calculating the requirement for the several sectors of war production rested with the three production departments. The real significance of the requirements can only be shown in relation to the main sectors of departmental production programmes.

(ii)
Munitions Production

The demand for machine tools for the production programme of the War Office and later of the Ministry of Supply was exceptional in that a large proportion was for special product machine tools. Moreover some of the machine tools were new types developed during the rearmament period. The War Office and later the Ministry of Supply had to take a direct interest in the development of more efficient machine tools for many sectors of munition production and in consequence, in the pre-war period the War Office was in much closer touch with the development and manufacture of machine tools than the other two production departments. In 1936, the most urgent task was the development of more efficient plant for shell forging and more efficient machine tools for the machining of the forgings and other finishing work on the shell cases. The expansion of ammunition production in the First World War had shown the enormous task presented by the demand for shell forging and machining, and the consequent need for maximum efficiency in plant and in methods of production. In the development of machine tools it was possible in 1935 to benefit from significant developments that had been made before 1918 in the machine tools for some types of shell.[1] But in shell forging technique an entirely new development was sought in 1935 and finally achieved by 1938. At the beginning of the rearmament period British technique for shell forging and machining was far behind continental and especially German methods. Before the outbreak of war, the War Office with the co-operation of a number of engineering firms had introduced methods and plant for forging and machining which were a definite advance on continental methods and far in advance of those available in the United Kingdom in 1936.

For rearmament an immediate improvement for current production of shell forgings had to be obtained by the importation of German shell presses but at the same time development work on a much larger capacity forging plant of an entirely new type was undertaken by Stewart & Lloyds at the request of the War Office. By 1938 the first plant under this development had been erected and the trials showed that the new plant offered the most efficient means for the mass production of shell forgings. Furthermore, it was capable of providing forgings at a rate far in excess of any shell forging plant known to be available in Germany or elsewhere, and the new forging plant could be adapted to provide all types and sizes of forged shell. The much smaller capacity presses had to be used in the interval and some continued to be used for small batch requirements; but from 1940 onwards the bulk of United Kingdom production of shell forgings came from the new forging plants. Between 1939 and 1942, forty-two of these plants were erected in the United Kingdom and ten were manufactured and supplied for overseas production including seven which were supplied to the United States. In addition, ten plants were built or partially built but not installed for use. This wide margin in the provision of plants was partly due to reductions in the ammunition requirements but it was also due in part to the very large output obtained from the plants installed. The average output was far in excess of the original target of 180 forgings per hour. On subsequent 3·7 in./25 pdr. plants, with some improvements but with no fundamental change in design, an average of at least 300 forgings per hour was attained.

In 1936, the machine tool requirements for the machining of the forgings had to be stated in terms of general purpose lathes with the addition of specialised thread milling machines and banding presses. By the outbreak of war, complete production units were available consisting of special purpose shell lathes, heading and banding presses and thread milling machines. This change had been brought about

[1] *The Hydraulic Operation of Lathes for the Production of Shells*, by W. Littlejohn Phillip, O.B.E., M.I.Mech.E.; Proceedings, The Institution of Mechanical Engineers 1944, Vol. 151, No. 1.

within a period of less than three years under the direction of D.O.F. and later D.I.P., at the War Office and with the collaboration of a few engineering firms many of whom were not machine tool manufacturers. As a result of these developments a complete set of special lathes was on order in 1938 for medium shell machining and only two types could be said to be direct adaptations of conventional lathes. At the same time, similar principles of development were being applied to the design of special machines for the larger shell from 4.5 in. to 9.2 in. By the beginning of 1939 a sound foundation had been laid for the expansion that was soon to be urgently required.

As the developments proceeded, manufacturers had to be found for the initial requirements of the special machines. In the early years of rearmament it proved difficult to interest machine tool makers in the development of these special machines and much of the development was undertaken by firms not then undertaking machine tool production. After the manufacture of the early models, several other firms including general engineering and textile machinery manufacturers were approached, and some of these formed the main source of supply for the special shell lathes for medium shell. A number of similar firms were also introduced for the manufacture of other types of machines and plant for the medium shells. Some 38 firms were eventually engaged in manufacturing the twelve types of major machines. Of these firms, 19 were not normally machine tool manufacturers and they supplied much more than half the total number of machines. An important result of this use of outside firms was that all supplies of machines and equipment for the medium shell were obtained from United Kingdom production, despite the fact that war-time production of medium shells rose to over two million shells per month.

For the machine tools for 4.5 in. and 6 in. shells a valuable source of supply came from Canada. A Canadian firm of general engineers after examining the latest developments under the War Office, prepared designs for this type of shell machines to be produced in Canada. Some pre-war supplies were obtained from Canada but this connection was even more important in 1940 when 22 units of 4.5 in. plant had to be obtained. By this time machine tool manufacturers in the United Kingdom were unable to offer supplies of the special lathes and all these had to be obtained from Canada. The total number of shell machines ordered from Canada was more than 2,000. For both 5.5 in./6 in. and 4.5 in. the Canadian machines provided the bulk of all supplies of special shell lathes. Clearly, without the Canadian machines the progress of the production programmes for 4.5 in. to 6 in. shell would have been seriously restricted.

The use of special product machines for the manufacture of small arms ammunition was of very long standing and as we have seen capacity was provided in the form of mass production factories equipped with specialised plant. After 1936, there was some improvement in existing types of plant and the development of some new machines for new types of S.A.A. Even so the manufacture of S.A.A. plant was firmly established both in the United Kingdom and in the United States, and most of the new developments were undertaken by the existing plant manufacturers. There were two firms in the United Kingdom who specialised in the production of S.A.A. plant and supplied the full range of machines with the exception of weighing machines, furnaces and annealing plant. There were also suitable firms available for the manufacture of this plant. It was, nevertheless, quite impossible to meet the large war requirements of machines from the few firms normally available. Additional firms—most of them outside the machine tool industry—had to be introduced. Production of each firm was concentrated on a few types of machine or, in some instances, on one type only. As a result of this expansion, at least half the total requirement of these machines was obtained from United Kingdom supplies. The remainder had to be obtained entirely from the United States. In the first twelve months of war the shipment of this plant from the United States was a matter of very great urgency. The bulk of the United States supplies were for factories under I.C.I. management; a very large part of the plant for the R.S.A.A. factories and other S.A.A. factories was however obtained from United Kingdom suppliers.

The other sectors of Ministry of Supply production for which special product machines were a significant part of the manufacturing unit were small arms and gun production. For all weapons from heavy guns down to machine guns it is possible to make an initial generalisation as to the requirements for special and standard machines. For most small arms and guns, the manufacture of the barrels required several types of special weapon machines in addition to a number of standard types. For the other parts of the equipment, breech mechanism, mountings and carriages, the work was mainly done on standard machines adapted for each particular store. The general requirement of machine tools for weapons therefore consisted of a considerable number of special barrel machines with the addition of a much greater number of standard machines covering a wide variety of types. On the average the special machines amounted to about one-fifth of the total number required for gun production. This placed a large demand on the limited resources for special machines but the demand on resources for standard machines, mostly of types in very short supply was frequently even more serious.

For the special machines it was necessary to find new manufacturing capacity even in the rearmament period. This led to the employment of several firms not then engaged in machine tool manufacture. All the United Kingdom production of the special gun machine tools came from six firms. Three of these firms were textile machinery manufacturers and only one of the firms in 1936 was a machine tool manufacturer. Three of the firms made all the types of the special machines, except for one type obtained entirely from the United States. The special machines for guns were of a large and heavy type, mostly beyond the size of normal machine tool production but nevertheless in a class for which there were considerable technical resources in the United Kingdom. This was particularly true of the boring machines, turning lathes and rifling machines. The requirements for gun boring machines were in the main fulfilled from United Kingdom production and it was found possible to supply a number of gun boring machines to the United States. Rifling machines for the heavy guns were supplied from United Kingdom production and the bulk of these machines for medium and light guns were also from the United Kingdom; but a fair proportion were supplied from the United States, when the United Kingdom resources proved inadequate. In total, the United States may eventually have provided at least 30 per cent. of the total supply of the gun turning lathes.

For small arms weapons and 20 mm. guns the general distribution of special machines and standard machines between the barrel and other parts was much the same as for the larger guns and again there was considerable variation in type and in size. The requirement for standard machines was also much the larger. Supplies of special types from United Kingdom production were much less adequate than for gun production and a very large proportion had to be obtained from the United States; though the position varied between types of machines and types of weapons. The greatest dependence on United States machines was for the 15 mm. and 20 mm. weapons. It was also for 20 mm. weapons that there was intense competition between production departments for the standard machine tools. It is clear that the production of small arms weapons in anything like the quantity required would have been impossible without the supply of special product and standard tools from the United States. This was true even of the rifle.

Except for shell cartridge cases[1], in no other sector of munitions production was manufacture based on the use of special product machine tools. Thus 20 mm. shells, gun carriages and mountings, tanks and fuzes were manufactured with the use of standard machine tools without any general exception. The main distinction was when a fairly standard manufacturing unit was adopted. This was particularly true of fuzes and 20 mm. shell production. Here, as we have seen, it was possible to develop efficient manufacturing units by the careful selection and equipment of standard machines. Although as far as

[1] See Chapter V, pp. 165 and 180.

possible production units included plant available at contractors' factories, fuze and 20 mm. production required a very large supply of standard machines most of which were also in very heavy demand for other production, notably aero-engine manufacture. The most important machines and the most difficult to obtain were several types of automatics, semi-automatic lathes and centreless grinders. The greater part of the supply of these machines had to be obtained from the United States. The other large requirement for fuzes was for capstans lathes and here dependence on the United States was, for the greater part of the war, very extensive. It is estimated that many schemes were dependent on the United States for 100 per cent. of their automatics, and for no less than 50 per cent. of many other machines. This was the position for the main production machines and for some bench machines, but all ancillary equipment and banding presses were supplied from the United Kingdom.

Gun carriage, mounting and tank production were, as we have seen, based as far as possible on the use of existing plants but despite this a very considerable supply of machine tools was required specially for tank production. A few special machines were developed mainly by the contractors or at R.O.Fs but in total these were insignificant and the bulk of the requirement was for standard machines. The demand covered a wide range but there was a special demand for heavy duty machine tools. There was also a large demand of machine tools for tank engine and other automotive component production. Some of these machines were only available from the United States but in the main the fairly large supply of United States machine tools for tank production was due to shortages in the United Kingdom supply of many standard machine tools.

Under the War Office in the rearmament period, the total amount approved for machine tools and plant for armament production excluding explosives, chemical and filling plant, amounted to about £14 million; of this about half was for equipment of the engineering R.O.Fs. With the outbreak of war there was a rapid increase in the provision of machine tools and plant for installation in contractors' factories. This proved to be by far the largest sector of machine tool requirements for munition production under the Ministry of Supply. By the end of the war the total expenditure on plant for installation in contractors' factories was not far short of £100 million and of this about half was for the production of gun ammunition—empty shell, cartridge cases, fuzes and other ammunition components. Guns and carriages accounted for £15 million and tanks and other armoured vehicles for over £20 million. The total expenditure on plant for engineering R.O.Fs was about £30 million and for agency factories about £20 million. All these figures exclude expenditure on explosives, chemical and filling plant and are therefore very largely for machine tools.

In war, the total demand for Ministry of Supply production programmes exceeded 100,000 machine tools. In addition the Ministry of Supply had also to deal with the War Office demand for about 50,000 machine tools mostly of workshop bench types. The largest annual requirement was in 1940 when the estimated requirements reached 50,000 but although this level was not maintained the requirements for 1941–42 were very large. No drastic fall in production requirements came until the end of 1942 and in that year and in 1943 the War Office requirements increased to more than balance the decline—in numbers though not in cost. The approximate tally of requirements and deliveries for Ministry of Supply production programmes (excluding the War Office requirement) shows that it was not until 1944 that the large annual deficiency was eliminated.

	1939/40	*1941*	*1942*	*1943*	*1944*
Requirements . .	45,000	26,000	26,000	11,000	4,000
Deliveries . .	30,000*	29,000*	31,000	13,000	7,500
Cumulative deficiency .	15,000	12,000	7,000	4,000	500

*estimated

(iii)

Aircraft Production

The great bulk of machine tools for most sectors of aircraft production were standard machine tools. This large demand for standard machine tools brought the bulk of M.A.P. demand into direct competition with the general demand for standard machine tools from all departments. Moreover, though a considerable number of high quantity production machine tools were required, particularly for engine and propeller production these were for the most part machine tools developed as part of the standard machine tool manufacture, mainly in the United States. Thus both for the more common standard machine tools and for many of the highly specialised standard machine tools the aircraft demand was in continuous and very direct competition with the main demand for standard machines from the other production departments.

Although none of the main sectors of production were dominated by any demand for special product machines there were of course, notable differences between the sectors in their requirements for types of machine tools. Both in quantity and range of types the demand for machine tools for engines was by far the greatest.[1] This was not merely the largest in aircraft production, it was the largest demand for machine tools in all war production. Moreover it included a very high

[1] See table on p. 214 above for the division of M.A.P. machine tool commitments.

proportion of expensive machine tools and a very high, indeed probably the highest, proportion of United States machine tools. Automobile engineering in the United Kingdom between the wars had relied heavily on machine tool developments in the United States. In consequence there was a strong preference for United States machines even where United Kingdom alternatives were available. In addition the United States had developed many high capacity production machines and some special product machines for engine production. Thus, for the Bristol air cooled aero-engines the new factories were encouraged to make the fullest use of United States special machines and high capacity production machines. In contrast, liquid cooled engines were not in production in the United States until the Merlin was introduced there in the middle of the war; for Rolls-Royce engines it was the demand for high capacity production machine tools that was the main requirement from the United States. In addition, there were many other machine tools in which the United States had catered for the demands of automotive engineering and for these there was a strong preference.

The supply of machine tools required to produce a quantity of engines was much greater than for airframe construction and had the extent of shift work on engine production been no greater than was achieved on airframe production the demand for machine tools for engines would have been even greater. Even so, for a factory to provide 400 engines an initial supply of machine tools in the value of about £3 million was required. A very large part of the total requirement of machine tools for engine production was for the introduction of new types of engines to replace the earlier types or for major modification in design of the existing types and also to meet the increased demand for spares. Any change in programme, any new demand and even the maintenance of the existing programme usually meant a fairly constant demand for additional machine tools. By 1944, government expenditure on plant for engine production had reached at least £60 million and schemes were in hand which would bring the total by 1945 to over £70 million. These are the cumulative totals from 1936 onwards. The total government plant in use was less than this because of the withdrawal of some machine tools with the changes in types of engines and with major modifications.

The use of machine tools in airframe manufacture and final construction of aircraft was subject to considerable development between 1935 and 1945. Prominent in most of the aircraft factories in 1930 were the woodworking machines; but in 1936 the expanding section was for metal working plant. The construction and fabrication of metal aircraft raised many new problems and there were significant developments in manufacturing technique and in manufacturing plant. Most of the exceptional problems in metal working were in relation to the longitudinal metal structure and the many sheet coverings and pressings. For the most part for machining operations and milling, turning and grinding, general purpose machine tools were used but for the machining of long light alloy sections considerable innovation was necessary. The most notable introduction was the very large and costly heavy duty plant for milling of light alloy spars. These provided excellent results but were very large machines taking many months to construct and at a high cost. It was in sheet metal working that the most difficult problems arose. Here there were exceptional problems of cutting to shape as well as forming and pressing. For all these processes there were a number of important developments and improvements in technique and in the design of more suitable machines. Again some of these, like the rubber platen presses were large and expensive equipments. Indeed a large part of the expenditure was on shaping, forming and pressing of light alloy sheet metal and of light alloy strip. This added many new machines to a section not normally very prominent in the list of machine tools.[1] Thus the employment of machine tools and particularly of special tools for light alloy sheet metal work in airframe manufacture tended to increase throughout the war as new methods were devised for work on the metal structure and skin of aircraft. This was a further cause of the persistence of machine tool requirements in the second half of the war. The proportion of large aircraft required, meant a much larger requirement for large and expensive machine tools often of special design. Generally included in the total for airframes is the demand for machine tools for undercarriage production. This was quite separate in manufacture; and was in the range of heavy precision engineering. A wide range of general purpose machine tools were required for undercarriage work; many of them were of heavy duty type and in very short supply.

Next in total expenditure on machine tools were propellers. The total exceeded £12 million and compared with the total cost of the propellers manufactured this expenditure was in very similar or even higher in proportion to the provision of machine tools for engine production. With the much wider use of the more complex airscrews the cost in machine tools became extremely high. It has been shown that airscrew production required the use of large quantities of carefully selected machine tools. In this there was a very large dependence on United States machine tools of special design; as with engines, the technique of airscrew production was further advanced in the United States and several special purpose machine tools were in use there. In

[1] Very closely related to this were the machines required for light alloy fabrication at the light alloy manufacturers.

addition a number of processes required United States type high capacity production machine tools for economic production. In addition to these special machines, propeller production required a considerable supply of general purpose machines in heavy demand. By far the largest demand for machine tools for propellers came with expansion for the bomber programme of 1941; even in 1943 the demand was higher than it was before 1941. Another sector with a large increase in machine tool requirements in the second half of the war was radio and radar production. It has been shown that very extensive capacity for this production was obtained by use of the existing resources of the radio and electrical industry but by the middle of the war the demand for valves and for radar equipment exceeded the available capacity. The demand for machine tools at government expense up to the end of 1942 had been usually less than £½ million a year. For the last three years of war the average annual demand for machine tools for radio and radar production was well over £1½ million.

Most of the other sectors of production reached their largest demand for machine tools in 1942—the first year of heavy bomber planning. Two notable exceptions were guns and bombs. Both these had a share in pre-war expansion and their largest demand was in 1939 and 1940. Although production of guns was for 20 mm. and machine gun production only, the total commitment for machine tools and plant exceeded £6½ million. This places this production on a very high capital cost basis. The main features of the machine tools required were similar to those for 20 mm. and machine gun production in the other departments. It was for the 20 mm. gun production that extreme competition with the Ministry of Supply and the Admiralty developed; there was also direct competition with United States firms which were manufacturing this gun for United Kingdom requirements. In 1940, M.A.P. obtained a major share in the machine tools intended for the French production of these weapons and also reduced M.A.P. demands in the United States for supply of machine tools, in favour of an increase in supply of guns from the United States. Even so the demand remained at a fairly high level and in constant competition with the demands for the same types of machine tools for the Ministry of Supply and the Admiralty light gun production.

By far the largest commitment for machine tools and plant apart from engines and airframes was for the fabrication of light alloys. This was separate from the production of aluminium and magnesium as raw materials. This raw material production accounted for over £20 million of plant but not all this was in the United Kingdom. The fabrication of this metal into sheets, strips, castings and forgings accounted for a separate total of £17 million in schemes with at least eighty firms. A good part of this was for furnaces and heat treatment plant and other equipment not coming within the fabricating plant nor within the normal classification of the machine tools. This classification was indeed extended to include much of the fabricating plant, mainly because of the extremely difficult problems of supply. The plant used in fabrication included rolling mills, extrusion presses, stretching and straightening presses and a variety of sheet metal working machines. These were for sheets, strips and extruded sections and bar and were all special machines for this work. For castings, stamping, and forgings a range of standard stamping, forging and die-casting plant was required. Most of the manufacturers of both sections of plant were outside the machine tool industry but the many difficulties of supply and the vital necessity of the plant led to the inclusion of this plant within the responsibility of the Machine Tool Control. This was another sector in which more than half the demand came with the heavy bomber programme and was maintained at a high level in the second half of the war.

Until the beginning of 1939, the Air Ministry had not found any reason to be seriously concerned about the supply of machine tools. This general satisfaction was no doubt mainly due to the fact that the orders for machine tools were placed by the Air Ministry contractors and at this stage mainly by aircraft and engine manufacturers. A very large part of the machine tools were obtained from overseas especially from the United States, and by 1939 the Air Ministry was greatly concerned about this very large dependence on imported machine tools. Until late in 1940 the main responsibility for machine tools orders remained with the contractors. The engine manufacturers had special representatives in the United States in direct contact with the United States machine tool manufacturers. Lord Beaverbrook, when he became Minister of Aircraft Production also made direct arrangements with the United States for the supply of machine tools for aircraft production; and M.A.P. received a considerable share of the supplies of machine tools from the United States, previously intended for France. Throughout 1940, M.A.P. representatives in the Inter-Services Machine Tools Committee pressed very strongly for a very large share of the current allocation from all available supplies. Supplies for 1940 from the United States appear to have been more than 10,000 machine tools for M.A.P. production, yet despite this and the supplies from United Kingdom sources, there was inevitably a large deficit at the end of the year.

A large part of the total requirements for 1941 was the deficit left over from 1940 and the M.A.P. Supply Board was satisfied that in many production schemes the lack of machine tools was a limiting factor. During 1941 the position improved to some extent; by August it was found that about 7,000 machine tools were overdue but by the end of the year this deficiency was substantially reduced. It was estimated that in 1941 about 32,000 machine tools were delivered for M.A.P. requirements including about 10,000 from the United States. The new aircraft programmes launched at the end of 1941 maintained the M.A.P. requirement at a very high level in 1942 and 1943; the requirement for 1942 would have been even higher but for the time needed to introduce some of the later expansion schemes. The division of requirements from 1942 onwards indicates the continuing importance of machine tools for engine production.

M.A.P. Machine Tool Requirements for Main Products

	Number of Machines		
	1942	*1943*	*1944*
Engines, propellers and accessories	16,612	11,299	10,734
Airframes, undercarriages and materials	9,761	7,703	2,318
Armament	3,296		
Equipment	750	6,879	2,468
Radio and instruments	2,642		

The requirement of machine tools for the 1941 programme presented the most concentrated demand that had yet been placed by M.A.P. In quantity it was not so much larger than the 1941 deliveries to M.A.P. but it was additional to some 10,000 machines outstanding at its inception. More important, machines for engine and propellers formed the greater part of the demand and both these involved a considerable number of special types and machines for which the supply was very difficult. Again, the unusually large requirements for airframe manufacture and undercarriages, involved, quite apart from some large special machines, a large proportion of heavy machines which although of standard type were in short supply. These various problems were the subject of continuous discussion between M.A.P. and the Machine Tool Control throughout 1942. The Machine Tool Control stressed the importance of concentration on special and critical machines to ensure that supplies were allocated where they could be put to maximum use and that every effort should be made to work these machines on three shifts. For these and for all machines it was important there should be full utilisation. In April, M.A.P. had agreed that the Machine Tool Control should undertake the technical examination of all M.A.P. machine tool requirements to ensure that the best scheme of production was adopted and that the requirements for machines was in strict accord. This had most beneficial results, as apart from possible reduction in requirements by adoption of better utilisation, it was important that the Machine Tool Control should be assured of the reasonableness of the demands that had to be dealt with under great pressure.

It was in fact, the problem of the 1941 programme that brought M.A.P. into full co-operation with the Machine Tool Control. The machine tool requirement appeared to some as open to charges of extravagance, and could only be justified on the basis of the closest check on utilisation. An extreme view was taken by Lord Beaverbrook, Minister of Supply, who in December 1941 stated categorically in a memorandum to the Defence Committee (Supply):

> No more machine tools are needed; over 30,000 new tools were directed to M.A.P. factories in 1941. The machine tool plant must be worked night and day. Some special purpose machine tools must be provided. The flow of replenishments and renewals must be maintained. But the main jobs are all completed and in fact some consignments of tools remain unused and even unpacked.

This implied that of the M.A.P. demand for 32,000 machine tools for the bomber programme in 1942 at least half were unnecessary. In the subsequent discussion the M.A.P. insisted that increased capacity was essential and that requirements for machine tools must be based on a double shift of 165 per cent. utilisation of machines which was the only realistic level for double shift working. It could indeed have been added that many of the additional machine tools were needed for new types or for modified designs. In the end it was decided that whilst the M.A.P. requirements should be subject to very careful examination by the Machine Tool Control, it was of utmost importance that the aircraft production programme should not be jeopardized because of any limits imposed on the supply of machine tools.

In 1943 and 1944, the M.A.P. requirement for machine tools continued on a large scale and was mainly for major production machines. This, when an increasing proportion of the Ministry of Supply requirements was for smaller machines for War Office maintenance and workshop requirements. The M.A.P. requirements for delivery in 1943 was mainly a continuation of the 1942 programme production and an increasing supply of machines was now available from surplus machine tools arising from discontinued production. Despite the general improvement in supplies, the M.A.P. continued to be seriously concerned with any loss of machine tools to other production. The large number of machines allocated to the Ministry of Supply was a matter for comment and in August 1943 the Chief Executive at M.A.P. insisted on investigation by the Machine Tool Control. As a large part of the Ministry of Supply allocation were small machine tools required by Army units they were of no use to M.A.P. production and the M.A.P. apprehension was unjustified. Even so, the production of many items, propellers, undercarriages and even engines at many factories was capable of considerable improvement were it possible to fulfil the orders for certain types of machine tools. It was in this period that the value of special machines in reducing the demand for labour was of vital importance. Even though labour was often the most serious shortage it was true that the supply of certain key machines could greatly improve output from the available labour.

(iv)
Admiralty Production

The demand for machine tools for Admiralty production programmes was very much smaller than the demand from the other two departments. Unlike the other two departments the Admiralty had a large part of the manufacturing capacity already available in the existing shipyards and marine engine works. It was only for the production of armament and ordnance that the Admiralty had to provide extensive additional capacity. Moreover, in heavy armament and ordnance a very large part of the expansion was undertaken in the rearmament period. Indeed up to 1938 the Admiralty demand for machine tools and plant was not far behind the demand of the Air Ministry and the War Office. In 1936, the accelerated pre-war naval construction programme called for a big increase in the production of armour plate, gun mountings, guns and ammunition. Additional capacity was built up by providing machine tools and plant at those firms already in production and to certain new firms. The total value of plant approved for major schemes between 1936 and 1939 exceeded £6 million and of this almost half was for armour plate. Well over half the provision for armour plate was made in 1936. Most of the approvals for plant for gun mountings also came in 1936. In the field of armament and ammunition, pre-war approvals for provision of plant and machine tools were mainly concerned with building up capacity for medium calibre guns, howitzers, cartridge cases and fuzes.

The total Admiralty expenditure on plant and machine tools in the war years was at least £27 million. More than half of the total was for armament production, including guns, ammunition, torpedoes but not mountings and armour plate for which by far the largest expenditure was in the pre-war expansion schemes. The war-time schemes reflected new problems: the large expansion of gun ammunition supply and also of torpedoes; the introduction of the Oerlikon guns for naval and merchant ships; and in 1942 the shipyard development schemes. With the exception of the shipyard development most of the major schemes were approved before the end of 1942. Before 1942, assistance to shipbuilders by the provision of machine tools had been limited in the case of hull construction to firms engaged on tank landing craft and in the case of marine engine works to a few comparatively small schemes. As a result of new development schemes, the peak years of capital assistance to shipyards were undoubtedly 1942 and 1943.

The expenditure so far given does not include the requirements of Admiralty establishments—H.M. Dockyards, Naval Armament, Torpedo and Mining depots, Naval Store and Victualling depots, Naval Ordnance establishments, Hydrographic establishments, Naval Repair bases and the aircraft stations and depots for Naval aircraft. During the war, expenditure on plant for Admiralty establishments was at a fairly high level. The total for the war years exceeded £12 million. Both before and during the war a large part of this expenditure was on machinery and equipment other than machine tools—for example pumping, heating, ventilating, electric generating plant, including plant for shore supplies of electricity to ships, refrigerating, air compressing, welding plants and lifting and hauling appliances; but it is estimated that during the war a total of some 6,000 machine tools were supplied to the establishments of the Director of Dockyards.

The number of machine tools required by the Admiralty to meet all their expansion schemes was very much smaller in all years than the demand for the other two production departments. The Admiralty understood the pressing demands of the other two departments and was in general ready to stand aside except when it was imperative to insist on the early delivery for such urgent requirements as the Oerlikon and torpedo programmes. Supplies of machine tools for these programmes were indeed vital to the effective maintenance of naval warfare.

The supply of machine tools for torpedo production between 1940 and 1943 demonstrated in a remarkable manner the close relation between the installation of additional machine tools and expansion of output. Between 1940 and March 1942, five expansion schemes were adopted in order to secure a rapid increase in the output of torpedoes. The total requirement of machine tools for these five schemes exceeded 4,000. In these expansion schemes some machine tools were for complete production units and others for balancing plant: of the 36 major schemes, 20 schemes could be classified as balancing plant. These schemes included schemes for the production of many components including engines but there were also balancing schemes for final assembly of the torpedoes. The schemes for complete production units included the equipment of a new factory for major production and final assembly but also other schemes for major components. The types of machine tools for which demands were heaviest were lathes, milling machines, capstans and turrets, drilling machines, grinding machines and automatics. These included a fair proportion of specialised single purpose machines particularly for engines and a smaller number of machines specially designed for torpedo production. Some of these special machines were designed by firms introduced for the war production of torpedoes. Admiralty records show that the torpedo expansion programme was almost completely fulfilled; from September 1941 the output of torpedoes approximated very closely to the output planned to fulfil the Admiralty requirements. This was achieved because the expansion of capacity was planned well in advance; at least twelve months were allowed for completing each expansion scheme and the supply of machines was completed at least by the date scheduled for maximum production.

The manufacture of Oerlikon guns was another programme for which the supply of machine tools was an urgent necessity and for which on several occasions the Admiralty had to press their need against the direct opposition of the other departments. This was particularly necessary towards the end of 1940 when a number of outside firms were brought into this production and had to be supplied with machine tools, and again in March 1941 when a new expansion was planned. At this stage the First Lord of the Admiralty told his colleagues:

> We have less than 100 Oerlikons and we require 10,000 as a start and later 20,000. To put it another way, we require an immediate production of 300 Oerlikons per month as at present planned and an expansion to reach 600 per month. Our actual production at present is 6 a month, rising at best to 100 by June.
>
> I need 40 machine tools a week for the next ten weeks to complete my existing programme and a further 100 per week for the following 12 weeks for the proposed expansion.

Competition between departments for machine tools for 20 mm. weapon production was very acute and the completion of the Admiralty expansion scheme proved to be much more protracted than for torpedoes. The third scheme for expansion in 1941 had to be reduced and deliveries of machine tools on a modified scheme were not complete even by the end of 1942.

A large proportion of the machine tools required for the Oerlikon were special product machines which had to be imported from the United States. Some special machines were also required for torpedo manufacture; but in contrast, the Admiralty demand for gun ammunition was never sufficient to justify the development of special machines to the same extent as for War Office ammunition requirements. A few special shipbuilding and marine engine machine tools were required under the shipyard development schemes of 1942 and 1943 but the main problem in the supply of more than 1,200 machine tools required for these schemes was the large number of heavy duty machine tools of various types required both in the shipyard and for the marine engine factories.

With the advantage of a high proportion of standard machine tools of United Kingdom type and the further advantage of coming at the peak of machine tool production, the schemes for re-equipment at the shipyards made rapid progress. Within a few weeks, nearly 500 machines had been allocated for delivery in the next few months. By May 1943—six months later—580 machines had been delivered out of the total of 1,170. There were however several types which were not readily available; these included special shipyard machines e.g. hydraulic presses, joggling and flanging machines, riveting machines and special horizontal boring machines and also many standard heavy duty machine tools usually in very limited production.

An important feature of the shipyard development schemes was the large requirement for welding equipment of many types. In the pre-war period only one or two firms had adopted welding to any significant extent. During the first two and a half years of the war the Admiralty maintained its attempts to encourage welding but no general progress was made until June 1942 when the Treasury authorised a scheme for the development of welding of which the total cost was not to exceed £2 million, and the Admiralty contribution £1 million. This scheme and the introduction of prefabrication for smaller naval vessels encouraged many firms to extend their welding facilities; the final cost was slightly in excess of the £2 million. Progress under these schemes was very rapid and in August 1943 the Shipyard Development Committee was able to report that 90 per cent. of the welding schemes were either complete or would be complete by September 1943. That the Admiralty demands had been largely met was due to the special action taken by the Industrial Electrical Equipment Division of the Machine Tool Control, particularly in standardising a large percentage of welding machines in order to increase production.

The increased use of welding and prefabrication had an important effect in reducing the demands for some portable power tools especially drills and riveters but tended to increase the demand for grinders. Despite this reduction in demand the supply of portable power tools was by no means easy. A substantial proportion of the portable power tool requirements had been met by supplies from America. During 1942 however supplies of these United States tools decreased seriously and special steps were needed to improve the position. The Machine Tool Control had already by 1942 secured an expansion of about 50 per cent. With the special demands of the shipyard development scheme and the fall in supplies from the United States the Machine Tool Control made further efforts to increase the United Kingdom production of portable machine tools.

CHAPTER XI

THE SUPPLY OF MACHINE TOOLS

(i)

Policy for Supply

The difficulties which arose in the supply of machine tools during the First World War were still vividly remembered in 1936. It was clear that the rearmament programme could not be carried through without a very large provision of machine tools and manufacturing equipment. The problem was only indirectly referred to in the formal announcement[1] but in the debate in the House of Commons the vital position of machine tools and other equipment in any armament programme was dramatically emphasised by both Mr. Lloyd George and Mr. Churchill. Their remarks referred specifically to the development of war potential capacity rather than to the immediate rearmament programme. Nevertheless, the two problems were closely related and Mr. Lloyd George's proposal for the manufacture by the state of machine tools and manufacturing equipment was doubtless intended to apply to both phases. The government's reply did not deal directly with the proposal but by implication showed that there was no intention of embarking on the state manufacture of machine tools.[2]

The demand for a large quantity of machine tools came at a time when the demands of industry for civil production were very considerable and increasing. Thus, it was by no means clear what response the machine tool industry could make to meet this additional demand. Several meetings were held in 1936 between the Minister for Co-ordination of Defence and the representatives of the Machine Tool Trades Association. Estimated requirements of machine tools for the three Service programmes were submitted giving a total requirement of at least £11 million's worth of machine tools for the years 1936 to 1938. This provision was taken as required within 2½ years, giving an annual requirement of about £4-5 million. Such a requirement would obviously impose a considerable strain on United Kingdom resources, as in 1935 the total United Kingdom output of machine tools was only £6.5 million. The problem was even more formidable in view of the

[1] Cmd. 5107, paras. 49 and 54.
[2] H. of C. Deb., Vol. 309, Cols. 2010-11, 2029-30 and 2089.

general government policy that rearmament should not be allowed to restrict industrial recovery nor to limit expansion of exports. Production of machine tools was an important factor in both these problems and the Board of Trade were particularly anxious that the proportion of machine tool output available for export should not be reduced. Under these conditions the provision of the rearmament requirement would require a considerable expansion of supply, either from United Kingdom production or by imports. It was accepted both in the government and in the machine tool trade that exports should be maintained and if possible increased. The only practical step was to allow an even greater reliance on imports so that more of the United Kingdom output could be available for export. This could only be done economically by allowing an increase in the imports of machine tools free of duty and this was the policy accepted by the government and the trade in July 1936.

Thus despite every effort that was to be made to expand the United Kingdom output of machine tools, an essential part of the policy from the inception of rearmament was to greatly increase the dependence on imported machine tools. This was to some extent, at least, the acceptance of a trend which had already developed as a result of the demand for machine tools for the earlier aircraft expansion programme. This and the large demands of the full rearmament programme were reflected in the increased imports of machine tools and particularly in the imports admitted free of duty because of the protracted delivery offered by United Kingdom manufactures. This had already begun towards the end of 1935 when frequent applications on these grounds were received by the import licencing authority. Up to this stage all licenses for omission of duty were for types not manufactured in the United Kingdom; this remained the largest class to receive exception of duty. But in 1937 and 1938 the value of machine tools admitted because of the protracted delivery in the United Kingdom was not far short of half the rapidly increasing total of imports admitted tax free.

The increase in the importation of machine tools followed rapidly on the introduction of the rearmament programme. In 1936, imports on a tonnage basis were almost three times the 1935 imports, in 1937 they increased even further and in 1938 they were still over three times the 1935 imports. It was not until 1938 that exports showed any signs of responding to the policy which had freed the trade from at least part of the demand for rearmament requirements.

	1935	*1936*	*1937*	*1938*	*1939*
			Tonnage		
Imports . . .	7,768	20,058	31,591	23,854	30,390
Exports . . .	16,446	13,886	11,987	24,122	17,453

In the same period there was a persistent increase in the United Kingdom output of machine tools. In 1938, when exports reached a record level, it was estimated that these accounted for little more than a third of the total United Kingdom output. For a few weeks at the beginning of 1939 it seemed possible that the increased United Kingdom output and the general reliance on imports might, despite the high level of exports, enable the demands for 1939 to be fully met. These hopes were shattered by the large increase in the demand for machine tools which followed the army expansion schemes of the spring of 1939. It was at this stage that it was agreed that the policy of encouraging exports of machine tools to expand, if possible, up to 50 per cent. of the United Kingdom output should be reconsidered. It was clear that a continuance of exports at a high level would result in a greatly increased dependence on imports and a consequent strain on foreign exchange; on the other hand a large part of the exports were for the Soviet Union and any restriction might lead to serious international difficulties. Much depended on the extent to which the United Kingdom machine tool industry had already expanded its capacity between 1936 and 1939. Before an investigation into this could be undertaken, war production had already begun and the immediate pressure of dependence on imports of machine tools was greatly increased.

(ii)
The Pattern of Dependence

This dependence on imported machine tools was a fact not merely in war but also in rearmament and not merely in the Second World War but also in 1914. This dependence had a primary cause in the much more limited growth of the United Kingdom machine tool industry and the smaller United Kingdom share of the world trade in machine tools compared with Germany and the United States. From at least the first decade of this century both Germany and the United States had a far larger share of world trade in machine tools, and in consequence a larger margin of capacity in war and a larger basis for the expansion of their machine tool industry. In 1913, the German exports were at least four times the United Kingdom exports and the United States exports were about three times the United Kingdom exports. Even then, despite the poor showing in the world trade, the output of the United Kingdom industry was in quantity more than sufficient to meet the domestic requirements in peace.[1] With the excess

[1] In 1907 the value of the output of machine tools in the United Kingdom was £2.9 million, probably about 45,000 tons. By 1913, it is probable that United Kingdom output had increased. But it seems unlikely that the total United Kingdom output in 1913 was greater than the German exports.

of exports over imports, the United Kingdom output was, in bulk, at least 10,000 tons above home requirements in 1913. Many allies were however dependent to some extent on supplies of machine tools from the United Kingdom and the large increase in United Kingdom exports of machine tools in 1909 reflects in some measure the world wide preparations for possible war.[1] A large part of the increase went to the major powers expanding their armed strength—Japan, Italy, Russia and France.

With the impact of war in 1914, the serious deficiency of the United Kingdom machine tool industry for war requirements was immediately reflected in a very large increase in imports, and, for the first two years, some reduction in exports.

United Kingdom Imports and Exports: Machine Tools (Tonnage)

	1913	*1914*	*1915*	*1916*	*1917*	*1918*
Imports .	3,852	4,833	20,742	21,983	15,860	19,379
Exports .	16,537	15,109	9,972	11,900	20,724	12,515

In war, machine tools became a vital necessity not merely for the expansion of munitions production at home but also for those Allies who in peace were dependent on the United Kingdom for supplies of some types of machine tools. Thus, after 1914, United Kingdom exports of machine tools to Russia and France, and after 1915, to Italy, had to be very substantially increased. By 1917, exports to these three countries had increased from over 5,000 tons in 1914 to over 18,000 tons.

After 1920, Germany rapidly regained the lead in machine tool exports; United Kingdom exports fluctuated below the pre-war tonnage and did not reach the 1913 total until 1932. In the early post-war years the United States exports showed little sign of the expansion that was to come. The continued ascendency of Germany and the very limited United Kingdom share in world trade is shown by the percentage of world trade in machine tools for 1933–37.

Percentage of World Trade in Machine Tools

Country	*1933*	*1934*	*1935*	*1936*	*1937*
Germany . . .	70·3	49·7	39·8	47·3	48·3
U.S.A. . . .	12·4	28·1	33·6	23·7	35·3
United Kingdom .	10·0	12·5	15·2	9·3	7·1
Switzerland . .	4·3	6·3	7·5	6·3	5·3
Total value £m. .	12·6	12·9	14·4	21·7	30·4

[1] *United Kingdom exports of Machine Tools (Tons)*

1908	*1909*	*1910*	*1911*	*1912*	*1913*
8,183	15,164	13,329	12,749	16,817	16,517

Between 1920 and 1935 the most significant change affecting the United Kingdom was the increase in the volume of imports of machine tools into the United Kingdom.[1] Over the ten years 1925 to 1935 the average annual imports of 8,000 tons was very much higher than the average of 2,449 for the years 1911-13. The United Kingdom output of machine tools lagged behind the pre-war level until 1935. Then a distinct improvement in trade brought export orders up to the 1913 level and the United Kingdom output rose to meet the improvement in trade.

The position in 1935 reflects very well the general outlook in the machine tool industry. Of the total United Kingdom output about a third went for exports; imports in that year were about half the volume of exports; and of the total supply of machine tools for the United Kingdom factories about a quarter was obtained from overseas. The excess of exports over imports could even in volume provide only a small margin in emergency, but many of the types imported were not in production in the United Kingdom. Moreover experience in the First World War had shown that to a large extent exports had to be maintained in aid of allied countries. Dependence on imports for many types of machine tools not produced in the United Kingdom was greater in 1935 than it had been in 1913. This was so despite the several new types of machine tools that had been introduced into the United Kingdom list. In general, the United Kingdom industry had not attempted to provide extensively for the many specialised machines required for automobile manufacture and particularly for mass production in this field and in light engineering. There were thus important deficiencies in specialised and automatic large scale production machines. The increase in imports between 1925 and 1935 was largely due to the equipment of the motor vehicle and light engineering industries with specialised and automatic machines from the United States and from Germany. Thus in 1935 with a very limited share of the export trade in machine tools and a large measure of dependence on overseas types, the United Kingdom was certainly no less vulnerable than in 1913. Moreover with the general mechanisation of warfare the demand for machine tools of types in which the United Kingdom production was deficient, or which were entirely lacking, was much greater.

The effect of rearmament on imports was to raise the import of machine tools to an even higher level than had been reached in the First World War. The combined total for the three years 1936, 1937 and 1938 was as great as the total for the four war years 1915 to 1918, although by no means all the imports were for rearmament. In the

[1] *United Kingdom Imports of Machine Tools (tons)*

Average 1911–13	1923	1925	1926	Average 1929–31	1934	1935
2,449	3,821	5,480	7,625	10,946	6,567	7,765

four years 1915 to 1918 a total of 77,000 tons of machine tools had been imported; by the summer of 1939 it is probable that this total had been exceeded for the rearmament programme alone. With the outbreak of war in 1939, the import of machine tools increased to quite unprecedented levels. In 1941, over 77,000 tons of machine tools were imported in that year alone. In the four years 1940 to 1943 a total of over 230,000 tons of machine tools was imported—three times the total for the four years of the First World War.

United Kingdom Imports and Exports: Machine Tools (Tons)

	Imports	*Exports*
1935 . .	7,765	16,446
1936 . .	20,058	13,886
1937 . .	31,591	11,897
1938 . .	25,539	24,122
1939 . .	31,933	27,453
1940 . .	72,261	11,397
1941 . .	77,658	7,344
1942 . .	41,296	20,265
1943 . .	39,958	12,718
1944 . .	16,895	32,262

Changes in exports were much less dramatic but they show a very similar pattern in the years 1936 to 1943 and 1908 to 1918. There was a notable expansion of exports in 1938 and 1939 due mainly to large orders for the Soviet Union. In the war years, the exports followed the 1914–18 trend even more closely with a fall in the early war years, followed by a large increase due to urgent demands of the Commonwealth and foreign allies—this time the Soviet Union without France and Italy.

Comparison of United Kingdom output cannot be stated so precisely. It is probable that the peak annual output of machine tools between 1914 and 1918 did not exceed 100,000 tons which would be about twice the 1913 output. Already by 1939 the United Kingdom output had increased to about 100,000 tons from less than 50,000 tons produced in 1935 and by the peak of war output in 1942 rose to over 200,000 tons. Thus despite the very large provision of machine tools in the rearmament period the peak annual supply of machine tools from all sources, including imports, was more than double the peak supply for 1916. The large increase in total supply provides the best indication of the large increase in total requirements. As supply, until the second half of the war never really caught up with requirements, the total requirements were clearly at least twice the requirements of 1914–18, despite the large measure of rearmament. The main sections of the requirements have already been described and comparison of the output of warlike stores in the two world wars points to the main causes of the large increase in requirements of machine tools. Whilst the output in many sectors of armament production was not so much greater, the extent of specialised and therefore new plant tended to be greater; but the largest increase in machine tool requirements was due to the general application of mechanised warfare. This was much more extensive and based on much greater automotive power, particularly in aircraft engines and tank engines. It was for greater mechanical power in the air and in tank warfare that the largest additional requirements for machine tools arose. It was also in these sectors of automotive engineering that there was a very significant dependence on imported machine tools.

Thus the same pattern of dependence emerged again in 1936 and appeared on an even larger scale in the war years. The underlying causes remained the same: a significant and growing dependence in peace-time on imported machine tools for United Kingdom factories; a substantial deficiency in the plant required for many types of munition production. To these were now added in greater measure the demands of mechanised warfare on land and in the air. The underlying causes continued despite the expansion of United Kingdom output of machine tools, which was evident in 1939 and which continued from year to year until the output reached the war-time peak in 1942. Indeed, the pattern of dependence continued up to the peak of demand and supply, with imports still accounting for nearly 25 per cent. of the much greater total supplies. But with the United Kingdom industry expanded in 1942 to the war-time peak it was able in the remaining years of the war to supply an increasing proportion of the demand. Thus in 1943 and 1944 imports accounted for only one-sixth of the total supply. The supply of machine tools from overseas was fundamental both in the planning and effective operation of war production in the United Kingdom. This was no marginal problem. Without the supplies from overseas many sections of war production would have had to be replanned at a very much reduced level of output and many programmes abandoned.

(iii)
The Necessity of Imports

Dependence on imports of certain types of machine tools was of long standing. It went back to at least 1855 when the machine tools for the equipment of the Royal Small Arms Factory at Enfield were purchased from the United States. Subsequently, the types of machine tools only available by import either from the United States or from the continent, notably Switzerland, Germany and France, had persistently increased. The essential characteristic of most of these machines was that they were designed for the large scale production of mechanical parts by repetitive, often automatic processes. Moreover, many of the machines were specially designed to cater for the needs of new industries or of old industries converted to a mass production basis. Two of the earliest manufactures affected were small arms and small arms ammunition. Outside the munitions industries, watch and clock manufacture, and other light precision engineering were soon affected. After 1900, automobile manufacture was the most general example. For all these industries, the initial development of specialised types of machine tools was mainly undertaken outside the United Kingdom. The development of machine tools with very high output, suitable for large scale production of small components, was an advantage for many sections of manufacture, for example the light electrical industry, cycle, gramophone and typewriter manufacture as well as the industries already mentioned. These machine tools also had increasing application to the light munitions industry notably for fuze and small calibre shell production.

From the turn of the century, and even more definitely between the wars, there had been a large increase in the industries and products which were dependent on some imported types of machine tools for efficient and competitive production. The growth of the light engineering and light electrical industries and the motor vehicle industries greatly increased the peace-time dependence on imported types of machine tools. When in war, the scale of production of a wide range of components was increased far beyond the peace-time production, the use of highly specialised machines with a very large output was highly desirable. Moreover, war requirements included a much higher proportion of products for which special product machines had been developed outside the United Kingdom—this was true not merely of armament but also of aero-engines and other automotive production. The peace-time demand for some of the more highly specialised machines was small and for a few it could be claimed that the world demand barely justified more than one firm undertaking the manufacture of these machines. There were other machines for which the United Kingdom peace-time scale of production provided a very small demand. For some other machines of more general application, some United Kingdom manufacture was gradually developed but the technical lead and persistent improvements of foreign designs resulted in a very large preference for imported types.

The economy of the United Kingdom machine tool industry, subject to frequent fluctuations and great uncertainty of demand, definitely favoured dependence on imports of certain types of machine tools. An economical volume of production was usually only obtained by specialising in types of machine tools for which there was a firm home demand or preferably a firm demand from the combined home and export trade. The development of a large export trade was held to be of paramount importance in affording some security from the fluctuations in home demand. It was consistent with this policy to tolerate a very large measure of dependence on imports for some types of machine tools; and moreover when there was extreme pressure of demand, to tolerate a considerable importation of many types which were also produced in large quantities in the United Kingdom. In view of the general acceptance of this policy, it is not surprising that some of the leading United Kingdom manufacturers of machine tools were also leading importers and agents for many types of foreign machine tools. Dependence on imported supplies of machine tools had become a permanent factor in the structure of the industry.

In war, exports were reduced to the necessities of allied demands; they had to be proved essential to the common war effort. To some extent some of the imports replaced machine tools which had they not been exported would have been available for United Kingdom requirements. If indeed the need for imports were entirely a quantitative problem the excess of imports over exports would show accurately the extent to which we were unable to provide sufficient machine tools for our home needs. Taken on this basis in 1935 and in 1944 the United Kingdom industry would have been able to cope with the quantity of machine tools required but in all the years between, the total United Kingdom output was inadequate and in some years very inadequate.

Excess of Imports over Exports Tonnage of Machine Tools

1935 . .	— 8,681
1936 . .	6,172
1937 . .	19,694
1938 . .	1,417
1939 . .	4,480
1940 . .	60,864
1941 . .	70,314
1942 . .	21,031
1943 . .	27,240
1944 . .	—15,367

Thus in the first two years of rearmament United Kingdom output in quantity was quite inadequate to meet the home demand. In 1938 and 1939 with an increase in output which is reflected in the doubling of export tonnage, the deficiency could have been greatly reduced. With the outbreak of war and despite the immediate reduction in exports, the deficiency for 1940 and 1941 increased to about ten times the deficiency of 1936 and was in volume about the equivalent of the total United Kingdom output for 1939. Even in 1942 with United Kingdom production of machine tools at the peak, the total output would still have been inadequate to meet the total United Kingdom requirement. Not until 1944, when the requirements had fallen far below the war-time peak and when more than a quarter of United Kingdom output was exported would the United Kingdom output have been sufficient in quantity to meet the total United Kingdom demand.

A large part of the problem in rearmament and even more so in the war was quantitative; it was not possible to expand the United Kingdom output of suitable types to anywhere near the extent required. Thus the quantitative problem remained for many types even after the peak of United Kingdom production had been reached in 1942. Despite all that was done in the United Kingdom, the quantities of many types could not be increased sufficiently to meet the requirement. This was particularly true of types of machine tools for which there had always been a large reliance on imports. In addition, there was the problem of types not produced in the United Kingdom. For some of these no alternative types were available in United Kingdom production; this was an absolute dependence unless production was allowed to fall below a tolerable level of efficiency. For other machines there were possible alternatives but often of much lower efficiency. Moreover, with the long standing policy of reliance on imports for the more efficient machine tools of these types, preferences and indeed methods of production were firmly established. Indeed, it could be argued that as imports were unavoidable there was every advantage to be gained by importing the most efficient type available.

There are many difficulties in making a satisfactory comparison between the quantity of imported machines and the total of machines manufactured in the United Kingdom. A great deal depends on the extent to which small, low price, bench machines are included or excluded. At the war-time peak of imports in 1940 and 1941, these low price machines were more generally excluded from the count of the number of machine tools imported than in 1943 and 1944. In United Kingdom statistics the reverse was true; more low price machines are included in the number of the peak output than in 1940 and 1941—partly, though not entirely, because there was a higher proportion in

Number of Machine Tools

	1939	*1940*	*1941*	*1942*	*1943*	*1944*
United Kingdom production	37,000	62,000	80,927	95,788	76,208	59,125
United States supplies to United Kingdom	8,364	33,111	32,044	24,023	20,514	8,416

the total production. Thus the figures normally given for comparison of United Kingdom output and imports from the United States tend to underrate the dependence on imports in 1940 and 1941 and to a lesser degree for 1942 and 1943. Taking all factors into account it is clear that supplies from the United States in the two years 1940 and 1941 approached if they did not exceed a total equal to half the United Kingdom output in those years. Thus at least a third of the total supplies came from imports. By 1942, dependence on imports had fallen to about a quarter of the total supplies.

Dependence on imports to the extent of at least a third of total supplies in the equipment of factories and firms for war production, was a very substantial dependence. The proportion of imported machine tools installed in United Kingdom factories was even greater because a portion of the total United Kingdom output of machine tools continued to go in essential exports. Moreover, though in the total annual supplies in 1940 and 1941, the dependence may be calculated as equivalent to about 50 per cent. of the United Kingdom output, the dependence was very much higher than this for several main groups. This is true even when the United Kingdom peak output for these groups is compared with the peak annual imports from the United States, usually in 1940 or 1941.

Some main groups for which peak United States supplies to the United Kingdom exceeded the 1942 United Kingdom output

(Number of Machine Tools)

	(I) *U.K. Output 1942*	*(II)* *Peak Annual Imports from U.S.A.*	*(II) as % of (I)*
Automatic lathes .	1,087	2,702	249%
Turret lathes . .	1,240*	3,314	280%
Vertical drillers . .	2,100*	4,181	198%
Boring machines . .	989	1,024	102%
Gear cutting . .	505	535	106%
Some other main groups exceeding the average			
Grinding . . .	11,903	11,000*	92%
Milling . . .	10,196	6,807	67%

*estimated.

The dependence in 1940 and 1941 of several of these groups was appreciably greater. Even then, comparison by numbers does not take into account the high proportion of highly specialised and costly machine tools included in the imports.

Within all these main groups there were many sub-groups and for some of these there was an almost complete dependence on imported types; for a few types, this complete dependence remained despite United Kingdom war-time development of some types as alternatives to imported types. Thus, whilst the United Kingdom output of milling machines was always greater than imports, there were several types of milling machines which could only be obtained from imports. There was no main group to which this did not apply to some extent. A list prepared in 1941 of types of machines for which there was a complete, or nearly complete dependence, on imports included over twenty types drawn from about twelve main groups. Details show that for almost all types of highly specialised, usually fully or semi-automatic machines designed for large scale production, there was a very large dependence on imported types. For some of these machines, a United Kingdom machine could be used as an alternative but at a very much lower level of production; but some imported machines were the only machines available to undertake the processes required.

(iv)
The Industrial Effort

The industrial effort to increase the output of machine tools began not in 1939 but in 1936 when the existing firms began to expand their output to meet the rearmament demand and to maintain and to increase the export of machine tools. The main outline of the industrial effort can be seen clearly in the increase in output, in the increase in the number of firms and in the total labour force employed. As a result of the pre-war effort, the output of machine tools in the United Kingdom had by the summer of 1939 reached a level about double that of 1935. This expansion had been very largely secured without any large increase in the number of firms in the industry. An even larger expansion was required in war; although the output of the existing firms in the industry provided a very large part of the increase, the total expansion of output was only achieved by the addition of a large number of firms, some of whom were employed as subcontractors.

In 1935, the output of the machine tool industry in the United Kingdom was about as large as had been achieved in peace-time. The output was certainly a good deal higher than any of the preceding years back to at least 1924. In the 1935 census, taking 1935 as 100, the volume of output for 1924 was computed as 69, the index was 72 for 1930 and 47 for 1933 and 74 for 1934. The index of output was fairly closely related to the trend of exports of machine tools. In 1936, the machine tool industry had to provide for increased orders for rearmament and also to maintain the policy of increasing exports. The result was an increase in production, in imports, and eventually in exports.

	£ millions				
	1935	1936	1937	1938	1939
Production (1936–39 estimated) . .	6·1	7·6	10·5	13·3	18·0
Imports . . .	1·7	3·6	6·2	5·0	7·7
Exports . . .	2·2	2·0	2·2	4·5	4·5
Available in United Kingdom . .	5·6	9·2	14·5	13·8	21·2

Prices rose in this period and the increase in volume was not so great as indicated by selling price. Thus expansion by 1938 in the United Kingdom output was certainly less than 100 per cent. of 1935 output and for 1939 it was a good deal less than 200 per cent. of the 1935 output. It should also be remembered that prices of imported machines were a good deal higher than United Kingdom prices. This reduces the balance between imports and exports and the total available in the United Kingdom. Despite these adjustments, the increase in supplies for use in the United Kingdom was by 1938 quite substantial and in 1939 the supply available was about three times that of 1935.

With the outbreak of war even greater expansion was required. This is best followed in the increase of the number of machine tools manufactured in the United Kingdom.[1] The output of machine tools by number in 1935 was probably between 20,000 and 23,000; thus output on a numerical basis rose by about 350 per cent. on 1935. The total value of the 1942 output of over 95,000 machine tools was £33.5 million, allowing for the increase in prices between 1935 and 1942, this also gives an additional output of about 350 per cent. There was also an increase in low price machine tools—less than £30 in price—excluded from this count. In addition, with the extensive use of machine tools the demand for replacement parts reached a higher percentage of output. Thus the total output of machine tools and parts from the firms employed on machine tool production in 1942 was about 5 times the output of 1935 and was approaching three times the 1939 output. To achieve this record output there was a considerable increase in the number of firms employed, particularly after 1939 and also a large increase in the total labour force. But a large part of the increase came from the firms already employed in 1939.

After 1920, with the end of the post-war boom, many long established firms had left the machine tool industry. Prominent among them were manufacturers of heavy machine tools for shipbuilding,

[1] See table p. 330 above.

marine and locomotive engineering and also for gun and other armament manufacture. The products of these firms were typical of the heavy machine tools that had been the foundation of the United Kingdom machine tool industry in the 19th century and had for long been the main stay of the industry. New types were to come to the fore in the post-war equipment of newer industries but for these the United Kingdom was never to approach the self-sufficiency and independence which had been achieved in heavy engineering equipment. With an increasing dependence on imported machine tools for the equipment of the expanding post-war industries, the export trade became even more essential to the activity of the United Kingdom machine tool industry; but large expansions in the export trade only came with large equipment of basic industries in other countries—notably in the Soviet Union from 1931 onwards. Despite fluctuations in demand and the increase in imports, the size of the United Kingdom machine tool industry remained fairly stable between 1925 and 1935. Output in 1935 was somewhat higher than in the previous years but even then the output was in volume probably only about the same as in 1910 although there were some significant changes in the types of machine tools produced.

In 1935, as recorded in the census of production, the machine tool industry consisted of 123 manufacturing establishments with a total employment of 21,000. Half the gross output and more than half the output sold in 1935 came from ten factories which together employed half the total labour force in the industry. Of these ten factories, the three smallest employed between 500 and 700 each; the seven largest all employed over 750 with an average of 1,250. In addition to the 123 factories in the machine tool industry, there was a fringe of firms with an output of machine tools which in value was about one tenth of the output of the industry. These fringe firms, of which there were more than fifty, provided a wide range of machine tools but were more prominent in the production of presses and sheet metal working machines. The expansion of output between 1935 and 1939 was obtained by a greatly increased output from both groups; the number of firms in both groups increased. The increase in numbers was comparatively small in the machine tool firm group; there were a number of new machine tool firms but with one or two exceptions these were very small firms. The expansion of output in the machine tool firms was mainly due to an increase in the number of workers employed and increased efficiency of production. Some additions to plant were also involved, but, especially up to 1939, a large part of the increase was obtained by making fuller use of the capacity already available. In the fringe firms there was also considerable scope for increased use of existing capacity. Many of these firms, like the machine tool firms, had considerable slack capacity. This was particularly true of the firms who were also textile machinery manufacturers; but a number of other fringe firms were able to greatly increase the use of existing capacity. Similarly, there were a number of firms who were not manufacturing machine tools in 1935 but who had suitable capacity available; many of these firms were in the textile machinery group and some had undertaken machine tool manufacture previously.

In the expansion of output from the fringe, both the increase in the capacity allocated within the firms and the increase in the number of firms were important. The existing fringe firms in the pre-war period responded to the general increase in demand for machine tools but there were some notable additions of firms who entered production to meet specific requirements for ammunition and gun machines. With the increase in demand during the rearmament period, the fringe firms with a notable increase in their number greatly increased their contribution to the total output. In 1935, the fringe firms provided about 8 per cent. of the output of complete machines; in 1939 the proportion was at least 15 per cent. Nevertheless, the machine tool firms supplied by far the greater portion of the total supply and of the total increase in that supply. In the summer of 1939 the machine tool firms appear to have reached an output double their 1935 output with an increase of about 50 per cent. in the labour employed.

After the outbreak of war and during 1940, there were further increases in the output and labour force of the machine tool firms but by the second half of 1940 there were signs that the expansion had reached the optimum for many firms. At the end of 1940 it was clear that the initial forces of expansion within the existing capacity were fairly fully extended. There appeared to be a need for creating entirely new production units. Plans were considered by the Machine Tool Control for the provision of six agency factories to produce a total additional supply of machine tools to the value of £2.5 million. The possibility of establishing new capacity in Canada was also considered. In the first two months of 1941 the plans for the agency factories were considered in detail but in April 1941 it was decided to abandon the scheme and to rely on more extensive subcontracting and the expansion of output at existing machine tool factories. Increased use of subcontracting and a further expansion of the existing factories were to bring the capacity to maximum extension in the second half of 1942.

From January 1941 to the peak between December 1942 and March 1943, 20,000 additional workers were brought into machine tool production. This addition appears to have been fairly equally divided between the machine tool firms and the fringe firms including subcontractors and at the war-time peak of 64,000 the labour force appears to have been about equally divided. By January 1943, the labour force of the machine tool firms of 1935 had increased to about 35,000.

The fringe firms had increased in number and with them subcontractors were now usually included; in fact some pre-war fringe firms had become subcontractors to machine tool firms. If however all pre-war firms producing machine tools are taken into account, their total labour force on machine tool production in 1943 would be at least 45,000 or approximately 70 per cent. of the total. This is in accord with the general impression that about 75 per cent. of the war-time peak production was obtained from pre-war firms as expanded by 1942. This appears to be true of the 1939 list of pre-war firms which, as already noted, was somewhat extended from the 1935 list. The remaining 25 per cent. of the peak output was from new machine tool firms mostly quite small in size, from new fringe firms and from subcontractors to main firms. According to the records available, the number of firms employed mainly on machine tools, to the extent of 75 per cent. of their production numbered about 190 in 1939. By the first quarter of 1942 the number of firms thus employed was over 330. In addition there was a large number of firms employed to manufacture complete machine tools as subcontractors to the main firms. By the end of 1941 the total of these firms was about 310. Thus at the peak of war production over 600 firms were employed in making complete machine tools. Thus, by the expansion of existing firms and the influx of 142 new firms and the use of 310 subcontracting firms, the output of machine tools and parts went up by over 250 per cent., from 1939 to the first quarter of 1942.

Thus there were the two main aspects in the expansion of machine tool output; the increase in output from the existing firms both in the rearmament period and in war-time; and the entry of many more firms into machine tool production. The entry of more firms into machine tool production was by no means a new departure. It had happened in the First World War and many of the first firms to undertake the work after 1935 had been engaged on machine tool work previously. In the rearmament period many of these firms agreed to undertake the manufacture and also the design of special types of gun and ammunition machines. This process continued after the outbreak of war and as a result a very large proportion of ammunition machines came from the fringe firms and from outside firms. In addition, some of the specialist firms employed firms from outside the industry as subcontractors to manufacture some of the simpler types. In many ways the continued expansion of output from the specialist firms in war-time was a more difficult task. Few of the factories were up to capacity in 1935 and in consequence some immediate expansion was possible by fuller employment of capacity. In addition, many firms, in response to the demands of rearmament and of the export trade, somewhat increased their capacity, but a large part of the expansion up to the outbreak of war came from fuller use of existing resources. By the outbreak of war there was little scope for immediate expansion except by working longer hours and by shift working. Longer hours were already being worked in many firms but shift working was not usual in the industry and in this no general progress was made until late in the war. With the formation of the Machine Tool Control more direct encouragement for expansion was to come in the form of overriding orders and production agreements and in factory extension schemes.[1]

LABOUR AND SHIFT WORKING

With the general increase in labour force at the pre-war machine tool firms there was an increase in the number of factories employing over 200. But many of the additional firms mainly employed on machine tool work were quite small firms. In consequence, in the total of factories mainly employed on machine tools, the proportion employing less than 50 in 1942 was larger than it had been in 1935. Thus despite the increase in the number of large factories and in the size of many factories, the proportion of small manufacturing units increased.

Operatives employed	*Number of Factories*	
	1942	*1935*
1—49	149	48
50—99	72	28
100—199	47	23
200—299	26	11
300—499	23	3
500—749	6	3
750—999	6	—
1,000—2,000	5	7
over 2,000	1	—
Total	335	123

In January 1942 these 335 factories employed a total of 52,000 operatives. By March 1943 the total for all firms approached 70,000. Although it was possible to secure a considerable increase in efficiency and in the hours worked, increased output on the scale achieved could not be attained without a large increase in the labour force. The expansion of the labour force proceeded to a total at least three times that of 1935, and more than double the total labour force employed at the outbreak of war. To meet the increased demand for labour, women were employed in what had hitherto been almost entirely a male labour industry.

With a rapid increase in the labour force and the entry of women many skilled operations had to be broken down; even so, in March

[1] See p. 352 below.

Labour force (operatives only 1941–45) employed in machine tool production

	Males	Females	Total
1935	—	—	21,000
1941 July	40,540	3,760	44,300
1942 January	49,230	8,500	57,730
1942 September	53,800	11,900	65,700
1943 March	54,800	13,800	68,600
1944 February	50,000	11,000	61,000
1945 May	38,880	6,120	45,000

1942, 62 per cent. of all labour was skilled and no less than 75 per cent. of the male operatives were skilled. The proportion of skilled workers was at all times higher than the average for all the engineering trades. In the first few months of war the loss of skilled workers either to the Services or to new factories, particularly aircraft factories, was a serious problem but the industry was later more definitely protected by occupational reservations and essential work regulations. The main problem was to provide for the increased employment of unskilled labour in a trade normally very much dependent on skilled labour. A special committee investigated the position at the end of 1940 and found that for 250 main firms the average proportion of skilled workers was 45 per cent.; in addition, apprentices and boys accounted for 25 per cent. and semi-skilled for 16 per cent. leaving only 9 per cent. unskilled labour and 4.3 per cent. women. In the smaller firms, those with under 500 workers, the proportion of skilled workers was from 50 to 55 per cent. and the percentage of women gave an average of less than 1 per cent. Only in the 19 large firms, with over 500 workers, were the skilled workers less than 50 per cent. of the total. In the largest firm, with over 2,000 workers the proportion was as low as 29 per cent., and the proportion of women as high as 16 per cent.

There were clearly good reasons arising from the nature of the work which justified a high proportion of skilled workers. In addition, the small size of most firms and the general absence of mass production methods were difficulties in the way of general dilution of labour and a large increase in the employment of women. Although in war, the increased demand ensured a continuity of production and increased the scale of batch production, it was only for very few types that a limited degree of mass production was possible. This was in fact limited to the production of one or two firms. Special needs such as the repair of bombed plant was also against any general reduction in the skilled labour force. In all the circumstances, the committee could not agree that there should be any reduction in the total of skilled workers employed; there was however a demand for a large increase in the labour force and this should be largely met by an increase in the semi-skilled workers employed. In this group there should be a much larger proportion of women and the committee recommended there should be a more intensive process of upgrading within the industry and a greater use of Ministry of Labour training centres to provide workers for the lower grades. Following on the report of the committee, the policy of dilution and a reduction in the proportion of skilled labour was undertaken extensively and systematically. A separate section in the Machine Tool Control was given responsibility for the matter. Very real improvements were obtained during 1941 and 1942, with the result that by the peak in 1943 the proportion of women employed had increased to over 20 per cent. To some extent the improvement was due to the introduction of firms with a higher proportion of women; some of the pre-war firms remained remarkably conservative but for most of the firms the proportion ranged from 10 to 25 per cent.

Single shift working was the general rule in the machine tool firms in peace-time. During the rearmament period no general change had been made in the position. At the end of 1939 only a few firms were working more than one shift. In the first half of 1940 the position was probably very similar to that in the engineering trades generally, where only 22 per cent. of the firms had more than one shift but where 83 per cent. of the firms employing over 1,000 workers were operating a second shift. The situation was slightly improved during the course of the year; in September 1940, of 242 major firms in the industry, about half were operating a second shift. The scope of the second shift was very limited; even among the larger firms the average for the second shift was about 17 per cent. of the firm's total operatives and 30 per cent. of the machine operatives. Of the total number of machines installed in the machine tool industry not more than 30 per cent. were operated more than one shift though the proportion varied very much with different firms, from nil to 70 per cent. The average of not more than 30 per cent. was much less than in munitions factories where major establishments had an average of between 55 per cent. for trade firms and 65 per cent. for R.O.Fs.

With the urgent need for increased supply of machine tools and the large demands made in the United States to supplement supplies it was essential that United Kingdom capacity for machine tool production should be utilised to the maximum extent. The limited extent of double shift working indicated that the position was far short of this target. The difficulties in the way of improvement were closely related to the problem of increased dilution of labour. With a high proportion of skilled labour and work basically of a precision nature, the continuance of work through two shifts brought many disadvantages. The variety of processes involved prevented the organisation of a machine unit in which all machines were fully employed. The main advantage of a second shift to many firms was to remove shortages of certain parts due to lack of balance in the output from the existing plant. Where a fuller operation on the second shift was justified the difficulty was to obtain the additional skilled and semi-skilled workers. As a result of these factors the second shift working in most firms was only sufficient to operate a small portion of the total plant. The position was subject to very critical examination by official investigators from the United States in October 1941. They found that many firms were not working a second shift and that where the shift was worked it was only a small proportion of the machine tools that were operated; in only a few firms was the extent of the second shift found to be satisfactory. In general, the United States investigators' findings gave full support to the opinion already held in the United States that the machine tool manufacturers in the United Kingdom were not making the maximum use of their resources and that the demands on the United States for machine tools could be reduced by a much fuller use of the existing capacity.

It was clear that an extension of shift working could only be attained by an increase in the number of skilled and semi-skilled workers available for a second shift; and this could only be attained by a general recruitment and training of additional labour. As late as April 1942, 40 per cent. of the firms were operating without a second shift. The flow of additional labour was shortly to reach the peak and with it the possibility of increased shift working. Thus by the end of 1942 only 25 per cent. of the firms were not operating a second shift. The scope of the second shift varied between wide extremes but some of the larger firms were able to employ 70 per cent. of their machine capacity. The average was much lower than this and it could not be claimed that the additional shift working contributed more than 20 per cent. of the total machine hours worked. On this basis the contribution to total output may have been as low as 10 per cent. Shift working thus had a comparatively small part in accommodating the large increase in the total labour force. Many of the subcontractors and new fringe firms provided an immediate addition both to the factory capacity and to the labour force.

At the existing specialist and fringe firms, a substantial increase in labour employed on machine tool production was possible without recourse to extension of the existing factory and plant. Up to the outbreak of war, expansion of output and labour force was possible by a fuller employment of existing resources, with the provision where necessary of additional manufacturing plant at the firm's expense.

After the outbreak of war most of the firms looked to the Machine Tool Control to provide the additional plant required for the further expansion of output. This was inevitable in an industry always subject to the effects of frequent fluctuation in demand and now faced with an obviously abnormal war-time requirement. Thus, a large part of the additional plant installed in the machine tool firms in war-time was on rental from the Ministry of Supply. This arrangement also enabled the Machine Tool Control to ensure that this additional capacity was definitely planned to increase the output of specified types of machine tools. The extension of capacity for the manufacture of certain types in heavy demand was the primary purpose of this capital assistance. It was only for a few schemes that additional buildings were necessary and there was only one agency factory provided. The main expenditure was for the purchase of machine tools; these were issued to the firms on a rental basis though some firms continued to obtain some additional plant at their own expense. In the first few months of war over 40 schemes requiring over £1½ million of machine tools were approved; by the end of 1944 there were over 300 schemes and over 5,400 machine tools had been issued at a cost of a little over £4 million. The effect of these schemes on the expansion of output was more substantial than these totals suggest. Not all this expansion was available for the peak output of machine tools but later schemes were mainly important in securing the production of types of machine tools not normally manufactured in the United Kingdom.

(v)
The Expansion of Types

General expansion of output of all types was not of course enough. There had to be special attention to certain types of machines either because they were in very great demand or because they were not likely to be produced in greatly increased quantity without the creation of specially equipped capacity. The largest group to which definite attention was given were the special purpose ammunition and gun machines. For these the position had been carefully explored in the rearmament period, and for some gun and ammunition machine tools additional capacity was in operation at the outbreak of war. Most of these machines, as already described, had been specially designed and developed for rearmament and war production and were not generally available from imported types. The decision taken in 1936 to design and manufacture these machines in the United Kingdom brought a very significant relief from the danger of dependence on imports. This was not achieved to the same extent for the more generally established types of munitions machines, particularly for small arms and small arms ammunition.

Pre-war preparation thus greatly facilitated the supply of some specialised munition plant. Moreover the war-time requirement for many types could be fairly clearly defined and calculated. The position of standard machine tools was quite different. The demand for most of these was the aggregate of a wide range of production, some were required for complete units, other to balance existing equipment. Up to 1941, the problem of estimating even the probable trends in the demand for the standard types was fraught with difficulties. The output of all types would need expansion to some extent but it was important to decide which should receive special attention. The problem was narrowed by the limited resources available for expansion and the policy of placing large demands on the United States. For several types not made in the United Kingdom, the United States was the only source of supply and for many other types for which it had been usual to rely on imports to a very large extent, there was little chance of expanding United Kingdom production in time to meet the immediate requirements. Even in 1940, any accurate calculation of the proportion of various types in the total demand was hazardous but it was possible to choose several for which the increase in demand would be much greater than the average increase. In addition to gun and ammunition machines, this applied especially to machine tools which were in heavy demand for several major sectors of large scale production. Prominent among these were automatics, capstan and turret lathes and milling machines. For many of these there had been a very heavy dependence on imports during the rearmament period; and the expansion of United Kingdom output up to 1939 had remained well below the average.

With the exception of special munition machine tools, the expansion achieved up to 1939 was the result of the direct response of the industry to the increased pressure of demand. The effect of this was weakened where there was an almost traditional reliance on imports. Fortunately, for certain special munitions machines there had been a direct approach from the War Office to certain firms. With the outbreak of war the direct encouragement of increased manufacture of many standard types as well as special munition machine tools was necessary. It was here that the combination of administrative and industrial effort could be most effective. A good deal was achieved, by ensuring continuity of production and by reduction in the number of types and by other measures which increased the efficiency of production. For many types, direct expansion of capacity was necessary; the list of the main groups of machine tools for which manufacturing plant was provided shows the concentration of effort on a number of groups.

The total expended by the end of 1944 amounted to over £3 million but almost half this amount was expended in 1940 and the greater part of the remainder in 1941 and 1942. Despite this expansion of

*Cost of Plant for Machine Tool Expansion 1939–45**

Type	*Cost £*	*No. of Schemes*
Automatics	624,760	21
Millers	349,410	34
Capstans and turrets	313,791	23
Grinders	295,481	28
Lathes	242,745	40
Presses	190,574	17
Borers	127,012	10
Drillers	52,450	10
Planers	48,603	6
Gear cutters	45,267	4
Broaching	33,408	2
Shaping	8,774	2
Shearing, bending and punching	5,424	2
Gun machines and shell lathes	342,624	10
Cartridge case machines	24,883	4
Other types	43,592	6
Components	136,798	12
Chucks	69,520	10
Miscellaneous	47,768	9

*Cost of purchase by Ministry of Supply; mainly issued to machine tool manufacturers on rental terms.

capacity the output of many of the groups for which most additional capacity was provided fell well below the average expansion. This was mainly due to the very limited expansion of capacity for these types before 1940 and for some types this was due to a heavy dependence on imported types in the rearmament period. Thus although there was a very large capital provision for the war-time expansion of capacity for automatics and for capstan and turret lathes, the peak output for these groups was only about three times the 1935 output. For other groups the increase in output was very much larger than this and for some groups a large measure of expansion had been achieved by 1939. An important factor facilitating the rapid expansion of some types was the extent to which fringe firms and subcontractors were able to undertake complete manufacture. This advantage rarely applied to the more difficult types and for these large capital expenditure to secure expansion was unavoidable.

With the need for immediate delivery and the many difficulties in the way of adequate expansion of the output of standard machine tools and special munition machines, there was for long little opportunity to develop or allocate resources for the manufacture of types of machine tools not already manufactured in the United Kingdom. Some approach to the problem of the supply of precision machine tools—tool makers' machine tools, required mainly for the manufacture of small tools, jigs, fixtures and measuring instruments—had been made before 1939 by the Gauge and Tool Sub-Committee of the Supply Board. As a result, at the outbreak of the war, several additional types of these machine tools were under development or being manufactured in the United Kingdom. These machine tools were not required in large quantities; the manufacture required high skill rather than a large manufacturing establishment. Progress was slow but by the middle of the war substantial improvements had been achieved in this highly specialised field of manufacture.

Prominent among other types of machine tools not made in the United Kingdom were several types of highly developed production machines. Most of these machines were capable of undertaking the work of several less developed machine tools. Some of the machines were thus not entirely indispensable but they afforded a very large saving in time and labour. Again some of the machines eliminated the need for a series of laborious machine processes. Several of these types had become the normal machines for large scale manufacture even in the United Kingdom; the alternative would be a much more extensive machine unit employing many more skilled men. With the increasing shortage of labour in the United Kingdom the pressure from official and technical authorities to make use of these highly developed machines increased. Only for a few types had it been possible to contemplate manufacture in the United Kingdom and it was not before the middle of the war that much general progress could be shown. In December 1942, the Controller General of Machine Tools reported that a total monthly output of about 66 machine tools had now been achieved of major types not previously manufactured in the United Kingdom and that this was to be increased to 250 machine tools a month. The plans provided for the manufacture of direct substitutes for at least fourteen United States types of machine tools and some were to be manufactured in several sizes. Prominant on the list were five different types of automatics in a fairly large number of sizes. In addition, broaching, automatic milling and gear shaping machines were included.[1] For most types only one firm was to undertake production, but for the automatics and for surface grinders there were five firms. The production already achieved in 1942 had allowed some reduction of the demand for these types from the United States but the further expansion of United Kingdom output of these types came too late to contribute to the peak requirement. Even so, the success of these plans and of the earlier plans for the introduction of certain types of precision machine tools did show that a substantial measure of independence could be achieved with the introduction of United Kingdom substitutes for foreign types.

[1] Most types were to be manufactured in several sizes.

CHAPTER XII

THE ADMINISTRATIVE EFFORT

(i)

The Machine Tool Control

Machine tools, it has been shown, were the only group of manufacturing plant to come under direct and systematic control. Although not appointed until the outbreak of war, the Machine Tool Control by the middle of the war provided in many ways a more rigorous and detailed system of control than for any other factor of production. The First World War had shown how important machine tools and ancillary equipment were to the defence plans of the nation. The difficulties then experienced in the supply of machine tools and gauges were still acutely remembered when the Supply Board Organisation was set up in 1929. At an early stage sub-committees were set up to consider what the position would be in any future emergency and what could be done to improve the potential supply. A Gauges Sub-Committee was established as early as 1930 and a Machine Tool Sub-Committee followed in 1931.[1] The task of these sub-committees was to survey the capacity for the production of machine tools and gauges; to assess the adequacy of that capacity in relation to current official assumptions about a possible war; to study the availability of machine tools, type by type; they also had to decide whether machines of specific types for war purposes should be designed and manufactured, and to consider the possible allocation of machine tool production between the various departments in war-time. The sub-committees made recommendations on all these points.

Useful investigations were undertaken by these sub-committees and they stimulated some action in relation to gauges and precision machine tools required for gauge and instrument production but they had no direct effect on the overall supply of machine tools. A general approach to this problem during the rearmament period was made at the meetings of the Minister for Co-ordination of Defence and the representatives of the Machine Tool Trade. In connection with these meetings the machine tool representatives were informed of the size of rearmament demand for machine tools and encouraged to expand

[1] The chairmen of these sub-committees were leading industrialists.

production up to at least the limit of their existing resources. These informal contacts with the machine tool industry were however very limited in scope compared with the control of demand and supply which became essential with the outbreak of war.

THE ESTABLISHMENT OF A FULL CONTROL

In June 1939 when the Ministry of Supply was formed, a Machine Tool Adviser to the Minister was appointed. On the outbreak of war, it was clear that a Controller, with greater authority over the machine tool demands of all production departments was needed. Thus with the issue of the Machine Tools Control Order[1] the Adviser became Controller. The duties of the Controller (or as he became in 1941 Controller General) were, broadly, to organise the supply of machine tools, cutting tools, jigs and gauges to meet the demands and to organise the repair and reconditioning of damaged or worn tools; to examine, with the Supply Departments, the demands for machine tools etc. and to allocate and distribute supplies; and to supervise and control the use made of machine tools and equipment. The necessary powers for these duties were provided in the Machine Tool Control Order and his authority with other departments was strengthened by his position as Chairman of the Inter-Service Machine Tool Committee. This Committee was set up soon after the outbreak of war and its primary functions were, to ascertain the requirements of the production departments for machine tools and to use this information as an indication of the need for establishing new sources of supply or for augmenting existing resources; to agree to substitute where possible simplified machine tools for universal types; to agree on priorities in cases of exceptional urgency; and to discuss generally any means of meeting machine tool demands more swiftly. Other committees of a similar type were the Small Tool Inter-Service Committee, the Woodworking Machine Tool Inter-Service Committee. The Control could also seek the advice of several Advisory Panels drawn from the trade.

It was most important that the Machine Tool Control should be regarded as a central independent Control and not merely as part of the Ministry of Supply. One step in this direction came in July 1940 when the Controller became responsible to the Parliamentary Secretary of the Ministry of Supply instead of to the Director General of Munitions Production. In June 1942, after the establishment of the Ministry of Production, the Controller General of Machine Tools, became responsible in the work of allocation and priorities to the

[1] S.R. & O. 1939, No. 1373, provided that every person engaged in the production, keeping, distribution, disposal, acquisition or use of machine tools must comply with any directions of the Ministry of Supply in regard to them, and keep such books, accounts and other records as the Ministry might require. 'Machine tools' included any mechanical contrivance for cutting, forming, abrading, polishing or otherwise working wood or metal and any accessory, small tool or equipment therefor.

Minister of Production, but remained responsible to the Minister of Supply for most of his other functions, including production and overseas supply of machine tools. The final division of his responsibilities was as follows:

> *Ministry of Production:* for the compilation of the demands for machine tools, including their examination, the general policy regarding procurement and relations with the Commonwealth Governments in regard to machine tools, small tools, etc., the allocation of these supplies amongst those requiring them and all work in connection with the utilisation of machine tools and equipment, in respect of which the Controller dealt with individual Ministries as heretofore.
>
> *Ministry of Supply:* for the administration of the Machine Tool Control and for the production of machine tools, small tools, etc. through the producing firms in the United Kingdom, and for their procurement in detail from the United States and any other outside source of supply.

This dual responsibility, though looking somewhat anomalous in retrospect, worked in practice quite smoothly. Indeed before the formation of the Ministry of Production the position of Controller had become accepted in all departments as, in effect, an inter-departmental authority serving all production departments.

Needless to say it was not easy for the Control to recruit the range of technical staff on which so much of the effectiveness of the work depended. But through the help of the trade, sufficient technical staff was recruited to carry out the basic functions of the Control and the important duties of advising firms on problems of layout, utilisation and so forth. For a Control whose activities affected almost every firm in the United Kingdom an efficient regional organisation was essential. The staff at headquarters grew from 33 in January 1940 to over 650 in April 1943, and the staff in the regions from 8 in June 1940 to over 160 at the end of 1942.

In the course of time, the Control assumed responsibility for equipment that could not be strictly described as machine tools—testing machines and measuring instruments (instruments used in engineering workshops for measuring or testing materials of many kinds); industrial electrical equipment other than that specially produced for use in aircrafts and ships, certain civil engineering and mining portable power tools and electrodes. The Machine Tools Order of 1939 although only referring specifically to machine tools and any accessory, small tool or equipment for use with machine tools, thereby gave the Control responsibility and powers over a very wide range of production. For, as will be shown later, the output of small tools which, in addition, to all types of cutting tools, included jigs and fixtures, gauges and fine measuring instruments, was in total value at least equal to the output of machine tools. In addition, as most machine tools were supplied with electrical motors and ancillary equipment, the eventual entry of the Control into the field of electrical equipment was by no means unexpected.

Some classes of equipment did not come under the Machine Tool Control until comparatively late and it was not until 1943 that the Control could be said to be in effective control of the wider field. Nevertheless, by the end of 1940 the Control was already organised into its ultimate pattern with the division of its work into three main sections:

(a) metal working and woodworking machine tools,
(b) machine tool equipment, cutting tools, gauges, fine measuring instruments, testing machines and measuring instruments, jigs and fixtures,
(c) industrial electrical equipment, welding machines, portable power tools, civil engineering and mining portable power tools, electrodes.

The powers vested in the Control by the first Control Order of October 1939 were very wide indeed. They gave the Controller authority to issue to firms any directions he might decide regarding machine tools and equipment. His position in relation to the departments was by no means so clear. Moreover the general use of the powers given in the Control Order was a matter for subsequent development. There was in consequence a gradual development of specific methods, such as, price control, licensing, investigation of demands for machine tools and also investigation of utilisation of machine tools in factories. Whilst all these methods were implicit in the actions of the Control in the first few months of war it was only gradually that they became the general practice of the Control and specifically mentioned in Control Orders.

In the first few months of war the most obvious factor was the lack of definite information regarding the scale and scope of the current and future demand and the possible expansion of supplies. Immediate action had to be concentrated on the points of direct conflict in demand and the most serious deficiencies in supply. In approaching these problems and in developing future methods the Control was well served by the Inter-Service Committee and by the machine tool trade panels which were set up at a fairly early stage. The Inter-Service Committee, composed of representatives of the war production departments, made it possible for the Controller to have immediate and direct contact with the main factors in demand and the competition between the departments. The trade panels served mainly to keep the Control in direct contact with the manufacturers of machine tools and in consequence with the main factors in supply. The members of the Inter-Service Committee had at first only a limited knowledge of the machine tool requirements of their departments and the main discussion at this stage centred upon points of conflict and the allocation of limited supplies. Later, most of the members were the Directors of Machine Tools in their departments and fully apprised of their departmental demands. The concern of the Inter-Service Committee could then range over the whole problem of matching demand and supply; the meetings, usually held at least every ten days, gave the Controller General a regular opportunity of informing the departments of the main aspects of the current situation. He was also able at all times to get a direct expression of opinion on all matters relating to the activities of the Machine Tool Control. The importance of the Inter-Service Committee both to the departments and to the Machine Tool Control can hardly be exaggerated.

THE CONTROL OF MACHINE TOOL DEMANDS

In the first few months of war, the large demands for machine tools were all too obvious in the order books of the machine tool industry and in the large import orders. It was even more acutely felt in the competition between the departments, particularly for any windfalls from the suspension of exports. Though the wide range of the demand was clear enough, there was no systematic information about the major sectors of this demand. Even the division of the total demand between the three departments was unknown; the requirement in terms of types of machine tools could not even be guessed at. For more than twelve months the Control had to operate without any detailed information of the requirements. Indeed it was not until the end of 1940 that the departments were able to provide fairly adequate estimates of the requirements of machine tools for the production programmes. The first determined effort by the Control to get adequate estimates of the departments' demands for metal working machines was made in June 1940, but the first tentative estimates for the demand in 1941 were not ready until the end of 1940 and they were soon revised. The estimates added up to about 90,000 machines at a cost of well over £80 million. These estimates were at first only useful in giving a general indication of the size of the demand; much more detail was required before they could be used for the planning of production. This only became available as the requirements for the major production programmes were examined and the requirement of the many sub-types and sizes determined. This more detailed information of the requirements for the production programmes under the three departments was essential for the planning of supply. It made possible an attempt to bring United Kingdom production of machine tools into line with requirements and also to determine the minimum demand that would have to be met by imports. When the detailed requirements were at last available it was very much like a release from working in the dark.

The mere listing of requirements by the types of machine tools could not bring about any reduction in the volume of requirements. Indeed some of the requirements listed were not within the control of the department and in the early stages of recording requirements the departments had no procedure for rigorous checking of requirements, although all demands were subject to general scrutiny by the production branches. The initiation of more rigorous control of requirements was to come from the Machine Tool Control and to be followed up by the departments with the formation of special directorates for machine tools in the Ministry of Supply and in M.A.P. The greater part of demands which the production departments listed were ordered by the contractors—thousands of firms engaged on war production. All schemes had to be sponsored by the department, who except for private purchases would also finally pay for the machine tools but the nominal purchaser was usually the contractor. The most important exceptions to this were the purchase of special ammunition plant by the Ministry of Supply and purchase of plant for R.O.Fs. There were very few if any exceptions in the other production Ministries.

In the first few months of war there was no control of inessential demands. The Machine Tool Control dealt with questions of priority in an ad hoc way by arranging with the Inter-Service Committee for the diversion of machine tools to meet special individual demands. In the summer of 1940 with the issue of a Priority of Production Direction which placed the sections of production in order of priority[1] the Controller was able to use the Inter-Service Committee meetings for regular advice and consultation on the details of priority and the specific application of the priority direction to machine tool requirements. Meanwhile throughout the summer and autumn of 1940 discussions proceeded about setting up a complete licensing system. This would not only have the merit of controlling and deterring inessential orders[2] but it would also give the Control, for the first time, a picture of current orders on the industry. The system eventually came into force in December 1940. The system was established not through a Statutory Order or formal Direction; in view of the wide powers of the first Machine Tools Control Order it seemed sufficient simply to issue a circular. No Order specifically authorising the licensing system was made until April 1943.

The essential function of licensing was to direct purchasers to nominated manufacturers but licensing was a valuable means of pro-

[1] See *British War Production*, *op. cit.* p. 160.

[2] Actual applications rejected amounted to 8,000 machines in 1942, 6,288 in 1943 and 2,727 in 1944.

viding records of prospective orders and also of eliminating any lingering duplication of orders. It could not however be expected to result in any large reduction in the total demand; it was only when licensing was combined with the greater control of utilisation that substantial savings in demands were made. The utilisation section of the Control did not begin operations until late in 1941. The main purpose of utilisation work was to ensure that the most suitable machine tools were employed and that they were fully employed, and in the most efficient manner. First, there was the routine vetting of demands; this took the form of regional investigation of private purchases and other small demands, and headquarters' investigation of government financed schemes. One of the main purposes of this vetting was to see that the most suitable type of machine was ordered. By insisting on this, increases in efficiency of production of up to 50 per cent. were often made. Another main function of the vetting was to see that the number of machines asked for was not excessive for the work and that existing machines were being worked for as long a period as possible. Checks were also made to see that machines were being used at their maximum efficiency, and that machines were not installed, except in special circumstances, in a region where capacity for the work already existed.

Also within the scope of utilisation work, was the special planning of specific production schemes by planning engineer teams. Thus the Control undertook the special investigation of machine tool layout and operational sequences on selected types of important stores, such as Hispano-Suiza cannon and airframes. This work could only be undertaken by experienced planning engineers, and the Control could never obtain anything like the number of engineers that were required. The normal practice was to send a team of engineers to review a given project, each member of the team being a specialist in one form of the machine tool operation, such as milling, grinding, etc., with a team leader to co-ordinate the investigation. These special investigations resulted in correction of misplaced contracts, in simplifying contractors manufacturing programmes, in drawing the attention of production departments to inefficient contractors, in re-aligning equipment between contractors with advantage to production and in providing more productive equipment for contractors. Some large savings in machines and labour employed were achieved by this procedure. Further, it was often necessary to ensure that the contractor could make efficient use of the machines supplied. For this purpose the Emergency Machine Tool Utilisation Corps was set up in September 1941 and consisted of a group of expert demonstrators and operators in different classes of machines, recruited from the machine tool trade and made available to contractors for the purpose of training labour or starting up new machines. It was maintained at an approximate strength of 120 operating in approximately 40 squads and during the year 1943, for example, it served some 130 important factories for varying periods up to three months.

Licensing and checks on utilisation between them reduced the demand for machine tools. But they were not sufficient in themselves to match demands to supplies; priorities and allocation methods for directing scarce supplies to the factories where they were most needed were still necessary. Allocation was indeed one of the earliest functions of the Machine Tool Control; for even while total requirements and indeed production were largely unknown, it was always possible to allocate available machines to meet specific urgent demands. This procedure was always necessary, for even up to the end of the war the supply of some types of machine tools was never sufficient to meet the demand. An allocation section of the Control was set up in June 1940, well in advance of licensing or utilisation. It was to some extent guided by the general instructions issued from time to time giving top priorities to various war stores; but more generally there was consultation with the directors of machine tools in the various Supply Departments and discussion in the Inter-Service Committee about the relative priority of their demands. An essential task was to strike a balance between machine tool demands for production programmes. That there were very few occasions when the Control's judgment had to be referred to higher authority was a direct indication of the efficiency of the Control and the Inter-Service Committee.

PLANNING PRODUCTION

The lack of detailed information about the requirements for machine tools was also a serious hindrance to the planning of production. Here again, the Control was able to do a good deal long before adequate information as to the requirement for types of machine tools was available. In the first two years of war, the deficiency in the supply of almost all types was so great that there was little, if any, danger that any plans for expansion of production of most types would prove unnecessary. For most types the important need was that the manufacturers should produce as many as possible and go on manufacturing the machine tools without waiting for separate orders to cover their forward planning of production.

One of the actions taken by the Machine Tool Control in the first few weeks of the war was to enable machine tool manufacturers to undertake the manufacture of large quantities of machine tools without danger of loss. This was done by the issue of overriding orders to a number of firms indemnifying them from any loss due to excess production up to an agreed quantity of machine tools. In the first few months of war Treasury approval was granted for this production up to a total value of £1 million. In June 1940, following the collapse of

France there was an urgent need to encourage manufacturers, not merely to continue the production of most types of machines, but to increase the rate of output. There was no time for the limited staff of the Control to review the production programmes of each manufacturer and determine the quantities of machine to be produced. Treasury authority was therefore given for the issue of continuity agreements which authorised the manufacturers to produce a given type of machine tool at $1\frac{1}{2}$ times the average rate for the previous few months. In similar manner to the overriding order, the continuity agreement indemnified the manufacturer against any loss due to unsold machines. The continuity order thus provided for continuous production of many types of machine tools at an increased rate. The continuity orders were used to ensure continuous and increased production in the months following Dunkirk and until it was possible to work out the definite quantities of specified types of machine tools that the leading firms should manufacture. As this became possible the continuity agreements were converted into production agreements, which specified the total quantity of machine tools of specified types which the firm was to produce.

Both production and continuity agreements proved very effective in enabling manufacturers to undertake the maximum possible flow of production. These agreements were almost entirely confined to machine tools; the value of machines covered by these agreements exceeded £10 million in 1942 and in 1943. The issue of these agreements to machine tool manufacturers also helped manufacturers in the granting of subcontracts to the general engineering firms. For the agreements clearly safeguarded them against any failure to sell these machines. Main contractors, in general, gave full co-operation to subcontractors in the supply of drawings and of general technical assistance, and it was normally left to the main contractor to arrange the form of agreement with the subcontractor under which the latter undertook not to produce the machines in question after the war. In a number of cases the Machine Tool Control had to bring pressure or persuasion to bear to secure the co-operation of both parties in the proposed subcontract, but it was only in the very rare cases that the Control ever had to make formal use of its statutory powers. It should be stressed that production and continuity agreements were indemnities not direct contracts; the indemnities were limited to the risk of failure to sell the stores, the normal manufacturing risk of profit or loss on sales was borne by the manufacturer.

Details have already been given of the capital assistance schemes arranged by the Machine Tool Control.[1] This was another method of promoting expansion brought into use in the first few weeks of war.

[1] p. 343 above.

Here again it was possible to arrange for extensive expansion without any overall picture of the position of demand and supply. The deficiency in so many types was clear enough and very large expansion could be granted without fear of creating surplus capacity. Similarly the lack of supplies for highly specialised machines only required in small quantities was sufficiently clear to warrant giving assistance to selected manufacturers for production of these machines; but the deficiency in many standard types already in production in the United Kingdom delayed action until the middle of the war on many special types which were only available from imports.

The issue of overriding orders had some bearing on the problem of reducing the number of alternative types in production. Concentration of effort was desirable in order to achieve the advantages of continued and large scale production of a number of types by the same firm. If these advantages were to be achieved to anything like the maximum extent it was essential that some firms should concentrate on a smaller number of types and that where alternative makes were available some firms should cease production of these types. This process of concentration of effort by reduction in the number of types and by reduction in the number of firms manufacturing the same type of machine tools could not be generally applied until details of requirements by types were known. Tentative efforts were made in the first months of the war to reduce the number of types in production but there were real difficulties at this stage as the balance of demand and supply could not be accurately estimated. It was only when more detailed information was available as to the total demand for the different types and when expansion of some makes had reached a much higher level that any general progress towards rationalisation could be made. Moreover the choice of makes to be eliminated was a difficult problem and it was only with the co-operation of the manufacturers and the assistance of an advisory committee of manufacturers that a systematic policy could be developed. Most progress was made in the middle of the war and by the end of 1943 more than 100 different makes of machine tool had been taken out of production.

With the introduction of licencing in 1941 and with detailed information as to requirements and the introduction of production agreements, the Control was able to achieve full scale programming of production. By the end of 1941 the Control was fairly fully informed of the types and quantities of each type in production at each firm. In accordance with current requirements it was possible to promote further production or to divert a firm's capacity to the increased production of another type. Whilst the general demand remained at the peak, regulation was not of great importance but with the decline in demand for some types and the need for expansion of other types, guidance from the Control on the scope of future production made possible a close fulfilment of requirements and a reduction in the dependence on imported supplies.

The effective control attained in 1942 was in complete contrast to the situation in the first year of war and even in the early part of 1941. The Machine Tool Control in many ways came much closer to the problems of war production than any other Control. This direct contact with war production was reflected both in the intensive and the extensive nature of the Control's work. For more than a year before the war production approached the peak, the Machine Tool Control was fully informed of all expansion schemes and was in full control of the supply of machine tools for these schemes. Moreover, control meant a full investigation into the quantities of machine tools required and often a detailed examination of the methods of production. Licensing and above all utilisation investigation gave the Control a detailed knowledge of all schemes; for many major schemes the knowledge of the Control was as direct and as close as that of the factory planning staff who drew up the scheme and were eventually to implement the scheme.

The value of this direct contact in securing a beneficial control of requirements and of supply has already been shown. There were other benefits depending on the availability of technical knowledge which the direct contact made possible. Many contractors were undertaking work which differed to a very large extent from their normal production and many were undertaking production on a much larger scale than was usual for them. In consequence, there were many technical problems relating to the use and the types of machine tools which were new to them. Here the officers of the Control were often able to give great help. They were in a position to share and exchange knowledge and to draw on the machine tool trade for technical information. For many sectors of munition production there had been an approach to standardised methods of manufacture and plant; this was especially true of ammunition production. But, as has been shown in connection with utilisation, there was a very large number of schemes for which the most efficient processes and plant had to be determined; for this kind of problem too, the Machine Tool Control was in a position to provide very real help.

(ii)
In the Departments

By the beginning of 1941 and in some respects long before this, the Control was in direct contact with the main problems of machine tools provision for the production programme. The effectiveness of the work of the Control and the eventual general acceptance of the Control as responsible and available to serve all three departments narrowed the scope of the departmental organisation almost from the start. Except in M.A.P. for a short but important period, this division of responsibility was not a matter of contention. Although limited in scope, the amount of the work remaining to the departments was for long on an increasing scale; moreover it was of great importance to the Control as well as to the departments that the departmental arrangements should be effective.

The need for an effective representative from each production department arose in the first few weeks of war with the formation of the Inter-Service Machine Tools Committee. In the Admiralty, the representative then appointed was almost from the start given the function of co-ordinating Admiralty machine tool requirements. In the Ministry of Supply, there was a direct line of evolution from the appointment of a representative to the committee and the directorate of machine tools which was formally set up in January 1941. In the M.A.P. close collaboration with the Machine Tool Control was not so quickly achieved, despite regular representation at the Inter-Service Committee. When in November 1940, a Director of Machine Tools was appointed in M.A.P. it seemed likely that he would continue to have rather wider functions than in the other departments. For some time M.A.P. retained responsibility for investigation of utilisation but in 1941 a change in M.A.P. policy brought them into line with the other two departments. Thus in 1941, the departmental administration of machine tools in relation to the main functions of the Control was very much the same in the three production departments; the main differences arose from the extent of the work undertaken for the departmental production branches. In this the major exceptions were in the Ministry of Supply where responsibility for machine tool provision was eventually transferred to D.M.T. from many of the production branches.

In the main, however, the essential functions of the Director of Machine Tools in the Ministry of Supply and in M.A.P. were the same. As they had to keep a regularly revised account of current and future requirements, they had to be informed of all demands for machine tools and of all schemes involving the use of machine tools. All these demands had to be examined technically both as to quantity and types of machine tools. When approved by D.M.T., the approval of the Machine Tool Control had to be obtained. The allocation of supplies of machine tools was the responsibility of the Control but it was the task of D.M.T. to ensure that the allocation was directed to the most urgent requirements. Thus although many of the D.M.T. functions were parallel to those of the Control, the essential difference was that the D.M.T. had the task of ensuring that within the scope of limited supplies the requirements were met in the most useful manner.

It was essential to the effective operation of the Control and the most useful fulfilment of demands that each of the production departments should be adequately in contact with the Control. Equally if this contact was to be effective it was essential that all representation should be based on a clear and accurate knowledge of the department's requirements. Well founded representation at the Machine Tool Control, in the inter-service meetings and internally within their own Ministry, were very important functions of D.M.T. Competition for limited supplies was almost continuous and it was important that all demands should be thoroughly examined in the department before allocation had to be decided.

In both the Ministry of Supply and M.A.P., the operation of the D.M.T. organisation followed more or less routine lines. Demands from contractors and the requirements of machine tools for all capital expansion schemes had to be investigated and a final requirement approved. The total current and future requirement by quantity and types of machine tool had to be computed. In the work of scrutiny and approval, the problems of correct utilisation had to be assessed for each scheme. From 1941, the investigation of utilisation both for new schemes and for existing plant was undertaken by the Machine Tool Control, and D.M.T. acted in accordance with the finding of the Control. The D.M.T. organisation at M.A.P. included production officers or at least one senior production officer for each of the main production directorates, airframes, engines, armament, equipment and instruments. This ensured that the needs of production directorates received specific attention in all phases of machine tool provision and allocation.

The D.M.T. in the Ministry of Supply had an even closer contact with the details of machine tool requirements. Production branches in the Ministry of Supply were much more concerned with the detail of the provision of machine tools, at least for some production, especially for ammunition and gun production. Eventually D.M.T. took over these responsibilities from some of the production branches—for guns, carriages, for ball bearings and for tank production. In addition D.M.T. was responsible for the arrangements for the purchase of machine tools required by the War Office for army requirements. For all these requirements, as also for some requirements for R.O.Fs, it was possible for D.M.T. to arrange for direct purchase of machine tools, and in consequence for direct co-ordination of orders and requirements. Two major sectors of machine tool provision continued to be dealt with by the production directorates—ammunition production and instrument production. Over the rest, the range of D.M.T. activities was very wide. In the second half of the war it included problems as diverse as tablet making machines for medical supplies and special production machines for tank engines.

In the Admiralty, the administration of machine tool requirements was comparatively simple but nevertheless direct and effective. It developed rapidly from the appointment in November 1939 of an engineer Rear Admiral as adviser on machine tool requirements to the Controller of the Navy and as the liaison officer with the Machine Tool Control. The appointment was made in response to a proposal from the Machine Tool Control that the Admiralty should appoint some one to deal with Admiralty requirements of machine tools. In the words of the Admiralty the officer appointed had been given powers to examine critically every proposal to obtain machine tools by every department inside the Admiralty and by contractors for the Admiralty. This remained a fair definition of the functions of the officer and the small section which was developed under his charge. The officer appointed in 1939 represented the Admiralty on the inter-service committees for machine tools and small tools throughout the war and maintained a staunch policy in support of the Machine Tool Control as the most effective organisation for the provision and allocation of machine tools. Within the Admiralty the machine tool requirements prepared by the production branches were subject to scrutiny and co-ordination by the machine tool section before transmission to the Machine Tool Control. With the formation of a utilisation section in the Machine Tool Control in September 1940 the Admiralty made the fullest possible use of the services available. The effectiveness of the machine tool section and the liaison with the Machine Tool Control was demonstrated in the success in securing the large requirements of machine tools required for torpedo and Oerlikon gun production and in 1942 and 1943 for the shipyard development schemes In 1942, the importance of the work of the machine tool section as a means of securing the fuller utilisation of machine tools on Admiralty work, was formally recognised by a change in title to Inspector of Machine Tool Utilisation.

CHAPTER XIII

SMALL TOOLS AND ELECTRICAL EQUIPMENT

ELECTRICAL equipment and small tool equipment are essential to the operation of machine tools; to ensure that these were available the work of the Machine Tool Control had to be extended in the early months of war into the problems of supply and demand for this essential equipment. This was no marginal task; the value of equipment that had to be dealt with was in total greater than the United Kingdom production of machine tools.

United Kingdom Production (Value £ thousands)

	1941	*1942*	*1943*	*1944*
Machine tools . . .	41,010	43,915	40,586	32,000
Small tools . . .	25,047	35,837	42,172	38,600
Industrial electrical equipment	23,910	30,938	36,250	39,928

The formation of industrial panels and inter-departmental committees to help in the co-ordination of the problems of demand and supply, followed very similar lines to those for machine tools. Within the Machine Tool Control, specialised branches were developed and by 1941 there was a Directorate of Industrial Electrical Equipment as well as a Directorate of Small Tools. The work on small tools and related equipment proved the more extensive. Whilst the work on electrical equipment remained under one director who was responsible for the three main sections—industrial electrical equipment, portable power tools and welding machines—the work on small tools had to be divided between three directors. The subdivision of small tools between cutting tools, gauges and measuring instruments, jigs and fixtures, each under a separate director, was placed under a controller who was responsible to the Controller General of Machine Tools. The heavy responsibility which arose in connection with demand and supply of small tools is described in the next section.

(i)
Electrical Equipment

Although it was not until April 1943, that industrial electrical equipment was subject to licensing, the Machine Control Tool had been concerned with electrical equipment from the early stages of the war. Electrical equipment was essential to all machine tools and an increasing number of machine tools were equipped with separate electric motors and equipment. Portable power tools, welding sets and electrodes were also the concern of the Control although the cost of most of these tools brought them below the range of licensing. Although some allowance must be made for an increase in the completeness of records, the official records show clearly enough that the production of industrial electrical equipment continued to increase until 1944. In the second half of the war, much greater use was made of welding equipment and a good deal of additional electrical power equipment was also needed for this and also for such developments as improved cranage in the shipbuilding yards.

Industrial Electrical Equipment
Value of Production (£ thousands)

	1941	*1942*	*1943*	*1944*	*Jan. to Sept. 1945*
Industrial electrical equipment	18,000	23,000	26,500	28,300	19,500
Welding sets	1,000	1,765	2,250	2,172	1,502
Electrodes	3,000	3,250	3,600	5,256	3,080
Portable power tools					
(engineers type)	1,910	2,923	2,900	2,800	1,900
(civil engineers type)	(*)	(*)	1,000	1,400	1,100
Total	23,910	30,938	36,250	39,928	27,082

*Not available.

Standardisation was an important factor in improving the supply of electrical equipment and enabling the supply to be generally distributed. By elimination of a number of refinements and reduction of specifications to standardised essentials, manufacture was greatly assisted. With the ruling that any suitable make of standardised equipment should be accepted by machine tool and plant users, a much easier distribution of electrical equipment was achieved. An approach to this arrangement was made in 1940 but general application of the principle was laid down in November 1941 by a Machine Tools Control Order.[1] The general adaptability of many types of industrial

[1] S.R. & O. 1941, No. 1864.

electrical equipment and the fairly large existing capacity for the manufacture of most common types, made the problem of matching demand and supply far less difficult than for machine tools. This is clear from the fact that there was no urgent need to introduce licensing until 1943. By then the demand for replacement and the growing direct needs of the armed forces made the problem of distribution more acute. Much more difficult were the problems of matching demand and supply for welding equipment and portable power tools. For these the existing capacity was extremely inadequate and the war-time demand continued to develop and expand right up to the final months of the war. Much could and was done to improve the situation both by rationalisation of demand and supply; this enabled a much closer matching of demand and supply and avoidance of wasteful use of larger equipment than was necessary. This contributed a good deal to fulfilment of two of the major demands for welding equipment in the shipbuilding and tank programmes.

(ii)
Small Tools

The classification of small tools covers a wide range of tools most of which are essential to the operation of machine tools. Although most of them are in fact small in size, they are required in such large quantities where machine tools are in full operation, that in the aggregate cost, their production is by no means small in comparison with the total output of machine tools. Indeed the cost of the peak annual production of small tools far exceeded the cost of the peak annual production of machine tools and parts. The production of small tools for sale was only slightly less than the output of machine tools and when it is remembered that in addition a very considerable supply of small tools was provided by the machine tool users in their own tool rooms, it is clear that the peak production of small tools was considerably in excess of machine tools. To reach the recorded output of small tools to the value of over £40 million a labour force of at least 54,000 was employed. Again it is clear that the total labour force employed in small tool production, including production in factory tool rooms was certainly no less than the total labour employed on machine tool production.

All machine tools have to be equipped with small tools to operate directly on the product; these may be cutting tools, form, or press tools, or other tools according to the process. In addition, there is often other equipment required for holding the tool or the work. For the successful completion of the process and for inspection and testing, gauges, measuring tools and at some stages, measuring instruments are required. For some machine work, jigs and fixtures are required and in addition large jigs and fixtures are required for assembly work, notably in aircraft assembly work. In the manufacture and setting up of these and indeed of most small tools, measuring tools and instruments are also required. Moreover, a large part of the demand is for consumable tools subject to rapid wear and reduced efficiency; in consequence with the high pressure of war production frequent replacement was necessary. Similarly, frequent changes in design made many types of small tools notably jigs and fixtures subject to frequent replacement. Metal machining and processing reached a record level at the peak of the Second World War. In consequence, the demand for cutting tools rose to an unprecedented level; frequent changes in design and requirements added further to the demand as new small tools were usually required for new designs. The large scale aircraft production and the frequent changes of type had a similar effect on the demand for jigs and fixtures; to this, the requirements for tanks and engine production added further demands. The demand for gauges for armament production was at a very high level in the First World War but in the Second World War the demand for greater precision in aircraft production added to the already large demand. Closely related to all engineering production and to small tool production itself was the increased demand for measuring tools. A comparatively new development was the large and varied demand for measuring instruments. Here again, in addition to the general demands of precision engineering, there was a special demand arising from the problems of aircraft assembly and aircraft component interchangeability, as well as from the increasing importance of testing machines for materials.

THE INDUSTRIAL EFFORT

In 1935, the specialist small tool firms employed about 10,000 compared with over 20,000 employed on machine tool manufacture. In war, the firms manufacturing for sale, employed well over 50,000—only 20 per cent. less than machine tool manufacturers. Similarly, output in 1935 at a little over £3 million, was in value about half that for machine tools; but by 1943 the output was at £42 million, equal in value to the peak output of machine tools and parts. Unlike machine tools, the imports of small tools, although well above pre-war levels, were only a small part of the total supply; in the first half of the war and even at the peak in 1943 imports accounted for less than 20 per cent. of the annual supply based on value, and substantially less than this in volume. Thus the expansion of small tools manufacture for sale was even greater than the expansion of machine tool manufacture and the dependence on imports a good deal less. Between 1935 and 1943, taking the firms employed almost exclusively on small tools, the labour force employed increased to over five times the 1935 total. The 1943 output by value was over twelve times the 1935 output but in volume it was probably about eight times the 1935 output. The total labour force in 1943 at about 400 firms was at about 54,000, only about 10,000 less than the total employed on machine tool manufacture. The number of women employed at these firms was very much greater than the total for machine tools. In 1943, with over 19,000 women employed, their proportion of the total labour forces approached 40 per cent.

The number of firms employed in 1942 on small tool manufacture was much greater than the number employed on machine tool production. By 1943 it was calculated there were over 1,200 firms employed on small tools for sale compared with less than 300 in 1935. Many of the additional firms provided a very small output; it was estimated that over 80 per cent. of the total output came from about 300 firms and these firms accounted for the greater part of the expansion in output. The greater expansion secured on small tool production is reflected to some extent in the much larger expenditure on capital assistance. The total spent on plant provided on a rental basis amounted by the end of 1943 to over £8 million. This was 2½ times the amount spent on government plant for machine tool expansion. The total by 1945 was £8.4 million provided for 687 schemes compared with £3.3 million and 286 schemes for machine tool production. Not merely was the average size of schemes larger but there were more large schemes. Moreover, all the large schemes were with established small tool specialists. There were twelve firms who received plant to the value of over £100,000 and for one of these the total was not so far short of £2½ million. In addition there were 15 firms provided with plant valued at over £40,000. Most of these firms were in production of a large range of small tools, either a range of cutting tools or a range including jigs fixtures, gauges and other tools or measuring instruments.

Included in the general classification of small tools are several quite different kinds of tools, instruments and aids to production. The main division of the varied capacity required for this production is most readily seen from the value of the output in 1944 when production had fallen only slightly from the peak.

	1944 United Kingdom output for sale (£ thousands)
Cutting tools and dies	21,414
Press tools and dies	3,047
Jigs and fixtures	8,622
Gauges	3,259
Fine measuring tools	1,070
Measuring instruments	541
Testing machines	465

By far the largest sector was for cutting tools but here large scale mechanised production of some tools was possible; the same was true to some extent of press tools. In other sectors the work was for the most part not suitable for large scale mechanised production. Very few firms undertook the manufacture in all the sectors but many firms undertook a wide range excluding measuring instruments. Throughout the whole field, the work of specialist firms was predominant and in some sectors production was entirely from specialist firms. Thus for measuring instrument and testing machines all the firms were instrument or testing machine specialists. In this field there were probably less than fifty firms all of whom were specialists. The position was similar for the more exacting types of measuring tools--micrometers and verniers; there were not more than twenty firms and all were specialists. In this sector, it was only for the simple measuring tools such as calipers that some outside firms were introduced.

In the other sectors of small tool production there was more scope for the use of outside firms but in all sectors much the greater part of the output came from specialist firms. In most sectors there were many new firms established from 1935 onwards specifically to meet the increasing demand for small tools, particularly for press tools, jigs and fixtures and gauges. By the outbreak of war the number of specialist firms had greatly increased and additional firms were formed and entered the trade in the early war years. Most of these firms were small and dealt mainly with local requirements. Despite the increase in the number of specialist firms the increased demand for war production led to the introduction of some outside firms. For press tools there were about forty specialist firms in 1935; this number was increased somewhat by the outbreak of war and still further in war, with the result that in 1946 there were about 150 specialist firms. To help meet the war demand other firms undertook this work; for the most part these outside firms were manufacturers of press products ranging from toys to metal motor bodies who had capacity for making their own press tools and who made press tools for sale to meet war requirements. In all about 250 firms including the specialist firms appear to have been employed.

The cutting tool work formed by far the largest section of the small tool trade. Although automatic production methods were possible for many types of cutting tools this section accounted for well over half the labour force at the peak of war production. In 1935, there were more than 150 firms in the sector and the number was somewhat increased for war production but it was estimated that over 80 per cent. of the peak output came from about 80 firms. Specialisation in the cutting tool trade depends to a large extent on other specialisation, thus many of the drill manufacturers were also specialist steel manufacturers and many of the lathe and gear cutting tools were manufactured by machine tool manufacturers. The work of outside firms was confined to the few types of cutting tools which were often or could be readily made by some firms in their own tool rooms. For many types of cutting tools production was entirely from specialist firms and the major expansion schemes and a very large part of the increase in output, came from these firms.

It was in the two remaining sectors—gauges and jigs and fixtures—that the outside firms had a more prominent place; though here again, a considerable number of firms entered into these trades between 1935 and 1940 in order to meet the growing demand arising from the rearmament programme. The output of jigs and fixtures was the second largest to cutting tools with a total of over £8 million in 1944. Nearly 90 per cent. of the total was for aircraft production; this was by far the largest requirement, and with frequent changes in aircraft design the demand persisted at a high level throughout the war. To meet the demand for aircraft production several firms were established or entered into this work during the rearmament period. Another cause of increased demand even before 1939 was the increased use of welding. By the peak of war production there were over 200 specialist firms and in addition a large number of engineering firms engaged on the manufacture of jigs and fixtures. In the supply of gauges there was a marked difference in the approach of the three departments. A large part of the supply for Ministry of Supply requirements was from large agency factories. The Admiralty had a special factory for inspection gauges but relied on firms for production gauges. A very large number, probably more than 50 per cent. of the gauges required for aircraft production, were made in the tool rooms of the aircraft manufacturers. For aircraft engines, the proportion was even higher. In addition, there were a very large number of firms employed on the manufacture of gauges for many kinds of aircraft work. The greater number of these firms were small tool specialists but in addition many engineering firms were also employed.

There was thus a rapid growth in the number of specialist firms in several sectors of small tool production. This process which continued throughout the war greatly reduced the need for the introduction of outside firms. Many of the new firms were very small firms; some of the outside firms were large undertakings but it was usually only the tool room capacity which was employed on small tools. The number of small firms and small manufacturing units employed was very great. Thus out of about 480 firms which were exclusively or at least 75 per cent. employed on small tool production only about 80 firms had over 100 employed on small tool production. Of the employment of about 40,000 in January 1942 in nearly 500 firms, at least 27,000 were employed in the 80 larger firms. At the peak, these firms employed more than 60 per cent. of the total for all small tool production for sale.

There was a very wide range of size in the firms who were mainly employed in small tool production.

Size by employment	*Number of Firms*
over 1,000	4
501—1,000	7
201— 500	28
101— 200	46
51— 200	84
21— 50	170
11— 20	117
Under—10	28

If, as was estimated, there were some 1,200 firms employed on small tool production, it is probable that most of the additional firms had on the average less than 20 employed on this work.

(iii)
Demand and Supply

The large expansion of small tool output was not merely a quantitative expansion; it was accompanied by important additions to the range of small tools manufactured in the United Kingdom. For several small tools there was a notable reduction in the dependence on imported types. The expansion was accompanied by a very significant strengthening of the resources and range of the small tool industry. With a large part of the expansion carried through by specialist firms the development proved a permanent advance.

CUTTING TOOLS

The annual demand for cutting tools rose to well over £20 million. Thus the industrial effort was at least half that required for the supply of machine tools at the peak of war production. By the middle of 1940 serious shortages of certain types of cutting tools had developed; the sudden increase in demand tended to overwhelm manufacturing capacity. The shortages were specially marked in special milling cutters, ground thread taps, twist drills, carbide tipped tools and carbon steel drills. There were a variety of reasons for this shortage. Milling cutters were especially affected by the shortage of highly skilled labour and the shortage of steel; production of ground thread taps was impeded by the lack of thread grinding machines and by the multiplicity of sizes and types, production of twist drills suffered through the shortage of high speed steel. The Machine Tool Control helped to increase supplies by assisting toolmakers to increase their capacity and by recruiting extra labour and also by co-ordinating supplies of small tools from America. The total financial assistance for the provision of plant and buildings for expanding the production of cutting tools—over £3½ million in the years 1940–44—proved even greater than that required for the expansion of machine tool manufacture. Of this expenditure, about 59 per cent. was in 1942 and 28 per cent. in 1941.

The shortage of cutting tools in the first half of the war was aggravated when firms tended to duplicate orders, especially for standard tools which were relatively cheap; in 1941 there was evidence that in many cases stocks sufficient for six months supply were being built up. The Machine Tool Control insisted that all duplication of orders should be avoided. At the same time production branches of the Supply Departments were urged to ensure that contractors did not order in excess of requirements; and the Machine Tool Control issued a memorandum enjoining strict economy in the use of cutting tools. In order to improve the planning of production, group buying by one firm on behalf of others making the same products was encouraged. There were also schemes for grouping together producers of similar types of tools so that each toolmaker did not try to cover the whole range of sizes and types.

In August 1941, cutting tool committees were set up in each region to examine requirements and the supply and use of cutting tools. The committees after surveying their districts reported that there was no real shortage of standard tools except ground thread taps, but that distribution was very inefficient, there was however a real shortage of special tools. The committees had already organised Mutual Aid Schemes to improve distribution; under these schemes small tools surplus to the requirements of one local user could be passed on to another local user whose demand was urgent. Later, allocation centres were established; these centres encouraged the better distribution of orders among manufacturers. To increase the output of tools by the use of standard rather than special tools, the Machine Tool Committee arranged—usually in collaboration with the British Standards Institution—standard types for various groups of cutting tools. As a result a very high degree of standardisation of size and form, both of the finished tool and of the manufacturing blanks, was achieved, for a very large number of both standard and special tools. This resulted in a very large saving both in manufacturing effort and in material. It also made it possible for toolmakers and firms making their own tools to obtain ready made blanks from which finished tools could be fabricated.

The full use of plant in the cutting tool industry was threatened by shortages of high speed steel and tool steel. The average output of high speed steel in 1941 was about 270 tons per week rising by early 1942 to 330 tons per week; total requirements in 1943 were estimated at

420 tons per week. Tool steel requirements were estimated at 725 tons per week against average production in early 1942 of 570 tons per week. Efforts were made to expand production of both types of steel to meet requirements. Meanwhile it was necessary to issue a Control Order to promote economy in the use of tool steel.[1] The Machine Tool Control also put in hand schemes for increasing the output of carbide tipped tools and dies; this resulted in a very large saving of scarce metal.

In spite of the efforts to secure expansion, home production of cutting tools was not adequate to meet requirements. Deficiencies had to be met by deliveries from the United States. In November 1940, the Treasury approved a scheme for the bulk importation of £1½ million worth of cutting tools to supplement the orders being placed through normal trade channels. The value of orders for all small tools placed in the United States for bulk imports and private orders averaged £450,000 a month during the first half of 1941; and to meet increased demand this figure rose to £500,000 a month for the second half of 1941 and the first half of 1942: of this latter figure about 72 per cent. represented cutting tools. Requirements from the United States continued at this level in the twelve months ending June 1943. Imports from the United States of tungsten carbide tips for cutting tools were also important. In December 1941 production in the United Kingdom was estimated at between 317,000 and 320,000 tips per month. Stocks were less than three months' consumption and were not uniformly distributed between different types; any serious stoppage through a breakdown of machinery, enemy action or other causes would have resulted in a serious shortage in supply. To guard against this arrangements were made to requisition under Lend-Lease 800,000 tips of various shapes and sizes representing three months' supply. Cutting tools were by far the largest item in the import of small tools; in most years from 1940 to 1944 cutting tools amounted to more than 70 per cent. of the value of the requirement for small tools placed on the United States. Out of a total of over £19 million for small tools imported in the war years, it is estimated that at least £14 million was for cutting tools.

JIGS AND FIXTURES

The demand for jigs and fixtures was very large and subject to very large additions during the course of the war. This was due in part to the employment of an increasing number of unskilled workers and to frequent changes in design but also to improved methods of production—especially in aircraft production. Unlike cutting tools, jigs and fixtures are not generally standardised products and it was possible to

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[1] S.R. & O. 1942, No. 760, 20th April 1942.

meet the demand in a variety of ways. The manufacture of many jigs and fixtures in the tool rooms of the main engineering firms reduced the load on the small tool industry; even so the demand on specialist firms was greater than ever before. Expansion at the specialist firms was achieved mainly before 1942 when the provision of additional plant to the extent of £1 million was arranged by the Machine Tool Control.

In the Supply Departments the general policy was that contractors should be responsible for the provision of jigs and fixtures, but in all departments there were notable exceptions. In the Ministry of Supply there were several schemes, especially for gun and tank production, for co-ordinating requirements and arranging for special manufacture and distribution to contractors. For example, for the Polsten gun mountings, one firm became responsible for both the design and manufacture of all the main welding jigs and fixtures; the Ministry of Supply placed contracts with this firm, and supplied the jigs and fixtures to the producing firms as free issues. A somewhat similar procedure was adopted for the jigs for the 6 pdr. A.T. gun when in 1941 manufacture of this gun was divided among several production groups. Each production group then pooled tool room resources and allocated the manufacture of jigs. Among its members the design of jigs and tools was standardised as an insurance against interference by enemy action and in order to limit the effect of delays on production. In the production of 2 pdr. carriages insistence on standardisation and interchangeability of components necessitated very complete jigging and threw a heavy load on the tool rooms at a time when the demand for skilled tool makers exceeded the supply, an interchange of jig and tool production was therefore arranged. With the formation of production groups for each type of tank it usually proved possible to concentrate the manufacture of jigs and fixtures; this rationalised both the design and supply of many of the jigs and fixtures by concentrating their manufacture on one source which was charged with the responsibility of satisfying the needs of all members of the group.

In aircraft production, jigs and fixtures formed a large part of the manufacturing equipment and accounted for a considerable proportion of total expenditure on tooling equipment; in airframe production the proportion was not far short of half the total. Many of the jigs and fixtures for airframe production were large and expensive; in the years 1939–43 the total value of jigs and fixtures made by outside firms for aircraft production was nearly £29 million. While there were a number of firms that specialised in the design and manufacture of the large assembly jigs used by aircraft firms, it was not unusual for the jigs to be made by the aircraft firms. It was necessary for some of the larger jigs to be embedded in concrete in the factory floor and although specialist jig firms did undertake the manufacture of these jigs it was often less expensive for the aircraft firms to do it, provided they had adequate measuring equipment and precision machinery available. Probably about half the total amount of jigs used in the aircraft industry were made in the aircraft firms' tool rooms. For group production the parent firms were usually responsible for the jigs and fixtures for other firms engaged on the same aircraft.

In the Admiralty production branches, it was the rule to make shipbuilders and other contractors responsible both for the design and provision of jigs and fixtures. The exceptions to this occurred mainly when the progress of production was impeded through lack of jigs and fixtures and when contractors had difficulty in securing capacity for the manufacture of jigs and fixtures. The jigs and fixtures for making torpedo components were provided by the firms holding contracts, either from their own tool rooms or by subcontracts; but the Directorate of Armament Supply often gave help in finding suitable subcontractors. For one scheme, design and provision of jigs and fixtures were contracted out by the Admiralty to a specialist firm as neither of the main contractors had the necessary facilities or experience. Requirements of jigs and fixtures for the Oerlikon gun were large, as the processes of making the components were broken down into a number of simple machine operations, so that semi-skilled and unskilled labour could be used; the tooling programme included 1,000 jigs and fixtures excluding additional designs due to modifications. For this, the parent firm—B.S.A. Guns—designed the tools and provided drawings for other firms brought in to make or assemble components.

PRODUCTION AND INSPECTION GAUGES

Interchangeability of components is essential to munitions production; the reliability of weapons, the effective use of ammunition, the assembly of aircraft and indeed all major munitions manufacture are dependent on efficient measurement to ensure complete interchangeability both in manufacture and in operational use. With the employment of thousands of firms of very different technical standards this problem was greatly increased. All firms had to have reliable manufacturing gauges and the satisfactory control of their output was dependent on the use of effective inspection gauges. This was a lesson which was slowly learnt between 1914 and 1918 when the crisis in the supply of manufacturing gauges was no less significant and indeed closely parallel to the deficiency in the supply of shell ammunition. Not merely were gauges difficult to manufacture but the technique of their design and use was for long inadequately understood. Many technical difficulties had to be overcome and in this the National Physical Laboratory gave valuable assistance; they were also responsible for testing the gauges and for this purpose introduced several new types of measuring instruments.

Many of the technical advances achieved were retained after 1918 and there were many other changes in precision engineering which improved industrial resources for gauge manufacture. The position was under review by the Supply Board Sub-Committee on Gauges from 1930 onwards and although an improvement in sources of supply was reported, the committee recommended that there should be an allocation of gauge-making capacity between the production departments, who should be responsible for their own gauge requirements for war production and also arrange for the supply and inspection gauges with the assistance of N.P.L. The committee found that there was a lack of certain precision machine tools which were essential for gauge manufacture, especially jig borers, dividing tables and thread grinders, and at their recommendation special arrangements were made to provide for the production of these machines in United Kingdom. In the rearmament period, the Service Departments took a keen interest in the supply of gauges; the War Office paid special attention to ammunition gauges and the Admiralty increased the factory capacity for inspection gauges; but the demand for gauges for aircraft production proved very uncertain because of the rapidly changing methods of manufacture.

A great deal had been done before the outbreak of war to provide specialised capacity, particularly for ammunition gauges, but with the outbreak of war the heavy increase in requirements for gauges soon greatly overloaded the available resources. There was an immediate shortage of manufacturing plant and skilled workers; it proved exceedingly difficult to avoid placing orders with unsuitable firms and to avoid a large duplication of orders with the specialist firms. Continuous action had to be taken both by the Machine Tool Control and by the production departments not merely to obtain a general expansion of capacity but also to ensure the manufacture of the more difficult types of gauges. A separate section of the Control dealt throughout the war both with the technical problems of gauge design and the expansion of manufacturing resources. The Machine Tool Control arranged expansion schemes to the value of well over £1 million; completion of many of these schemes was delayed for a considerable time owing to the lack of suitable precision machine tools.

The production of the more difficult types of gauges was a persistent problem and as early as April 1940 it was decided that the orders for these gauges should be allocated to suitable manufacturers by the Control's advisory panel of gauge manufacturers. In this way it was possible to encourage the process of rationalisation and concentration of industrial effort. As early as 1940, the gauge makers were unanimous in supporting the need for standardisation both in design and material. Gradually, as a result of co-operation between the Machine Tool Control and the British Standards Institute, a number of specifications were issued providing for standardisation of dimensional tolerances for many different types of gauges. Of even wider application was the British Standards Institute specification which laid down general dimensions for all the more common types of gauges. It was also possible to adopt a measure of standardisation in the manufacture of gauge blanks and thus to create a stock of these blanks in advance of their final use by the gauge manufacturers. Many difficulties remained throughout the war for many types of gauges; even so the very large deficiencies which had occurred between 1914 and 1918 were avoided. The range of difficulties had greatly increased but technical and administrative resources were more fully developed.

In all three departments it was the general rule for the supply of manufacturing gauges to be the responsibility of the contractors but there were important exceptions. By far the most significant was the bulk production of ammunition gauges under the Ministry of Supply. This had begun as early as 1937, under the War Office, when an agency factory was approved for this purpose. The justification for this step was of course the serious shortages of ammunition gauges in the First World War. In 1939, a second agency factory was equipped for ammunition gauges and shortly after the outbreak of war the equipment of a third factory was approved. Even the provision of these three factories was not sufficient; for despite a continuous increase in output, some further capacity for ammunition gauges had to be found with several other firms. The N.P.L. gave much technical assistance and were responsible for the inspection and storage of the gauges. The issue of gauges was under the control of the Director of Ammunition Production, Ministry of Supply, who was also responsible for the general operation of the scheme. A very high level of efficiency was achieved; standardisation of design and measurement was secured and a very high concentration of industrial effort was possible. Above all, serious deficiencies were completely avoided. It is not surprising that D.A.P. in 1941 was asked to deal with the supply of gauges for small arms ammunition. As a result the manufacture of these gauges was organised in a similar way and undertaken in an agency factory on mass production lines subject to similar inspection and storage by N.P.L.

In the Admiralty, gauges for shell manufacture remained the contractors' responsibility until towards the end of the war when special difficulties led to D.A.S. giving some assistance in the planning of supplies. Previously the Admiralty's main concern was with manufacturing gauges for torpedo production. Here difficulties arose with the introduction of new firms into torpedo production and the need to design and ensure the manufacture of suitable gauges for these firms. Somewhat similar arrangements had to be made when the Admiralty decided to introduce outside firms into the manufacture of the Oerlikon gun. For this, a common stock of gauges was made from which outside firms and subcontractors could obtain supplies. This was also arranged by D.A.S. for certain types of gauges which were particularly difficult to obtain. Except for the manufacture of weapons, the gauges for M.A.P. production presented somewhat different problems. The bulk were for aero-engine manufacture and for the somewhat exceptional problems of aircraft construction. Both required a very high standard of interchangeability and for aircraft construction this required a good deal more than direct gauge measurements; special measuring instruments and a system of alignment tests had to be introduced. Even so responsibility for manufacturing gauges and templates remained with the contractors, many of whom manufactured their own equipment for this purpose. It would of course be wrong to think of gauge production as being entirely in the hands of specialist firms. A proportion varying a great deal between different products was made in firms' own tool rooms. For example, for gun production simple standard gauges were bought from recognised gauge makers but more complicated gauges specially designed for gun production were often made in the firms' own toolrooms. In aircraft manufacture it has been estimated that about 50 per cent. of the gauge requirements both for engines and airframes were made in the firms' own toolrooms.

Attention has so far been confined to the gauges required for use in manufacture. In addition, there was a very large requirement for inspection gauges to be used by the inspectors employed by the production departments. Most of these gauges were more difficult to manufacture than production gauges and their design and calculation of dimensions presented many difficult problems. The Admiralty and the Ministry of Supply had by far the largest requirement; this was so because the general rule was for all their stores to be inspected by departmental inspectors. The number of inspection gauges required by the Chief Inspector of Armament in the Ministry of Supply in 1942 exceeded 90,000 of over several thousand different types. Admiralty requirements for inspection gauges in the same year was over 80,000. It was in the Admiralty that the most direct approach was made to the problem of the supply of inspection gauges. The Inspectorate of Naval Ordnance was responsible for the inspection of all stores produced for the Director of Armament Supply and the Director of Naval Ordnance and the bulk of the gauges required were manufactured at the Naval Ordnance Gauge Factory which had been established in 1917. This factory was expanded during the rearmament period and again in 1939 when arrangements were made to treble the output of the factory to an annual total of 75,000 gauges. Even at the peak of war production the deficit which had to be met by placing orders outside the factory was comparatively small. The Admiralty were thus at all stages of the war in full control of the supply of inspection gauges for their own use. In the Ministry of Supply the position was much less satisfactory. The several inspection branches were for the most part entirely dependent on arrangements made by them with gauge manufacturers. There were frequent difficulties and the supply of gauges was often insufficient to cope with the volume of production. This was so even for ammunition production for which it was at times necessary to make use of production gauges for inspection. Other inspectorates had similar difficulties and the Inspectorates of Electrical and Mechanical Equipment and of Fighting Vehicles eventually equipped their own workshops to deal with the repair and manufacture of inspection gauges.

In M.A.P., the Aeronautical Inspection Department system of delegated inspection made the direct requirement for inspection gauges comparatively small. Under this arrangement a large proportion of the firms inspected their own production and A.I.D. inspectors supervised the inspection and checked the firms' inspection equipment. The main items in A.I.D. requirements were for master gauges and interchangeability gauges. These were inevitably very exacting in the standards of manufacture and the relatively small demand made it difficult to attract suitable capacity. At one stage there was a serious shortage of interchangeability gauges for engine accessories and components and arrangements had to be made for one set of gauges to circulate constantly between the firms producing the same products. The A.I.D. system placed heavy responsibility on the contractors to maintain an adequate supply of efficient gauges both for manufacture and inspection. This was often especially difficult for subcontracted work. The A.I.D. had to maintain a continuous check on the position and to provide a good deal of technical assistance in order to ensure the maintenance of satisfactory standards.

FINE MEASURING TOOLS

The accuracy and excellence of workmanship is a long standing tradition of British engineering work. Despite this, the bulk of the fine measuring tools in use in the United Kingdom before both World Wars were of foreign manufacture. During the First World War the use of foreign measuring tools was very largely maintained and between the wars the preference for foreign types continued; this was true even for the basic precision measuring tools—micrometers, slip gauges and vernier gauges. It was not until the Second World War that the use of fine measuring tools and measuring instruments of British manufacture became a general practice and that their manufacture in the United Kingdom was extended to significant proportions.

During the First World War supplies of micrometers came almost entirely from two American firms but in the 1920's two British firms were successful in establishing themselves as substantial suppliers of micrometers. Even so, the danger of serious dependence on imported supplies remained and the Gauges Sub-Committee recommended that government departments should encourage British manufacture even though the prices might be higher. By 1939, the expansion of production from the two British firms made it possible to meet the bulk of peace-time requirements from United Kingdom supplies. The traditional preference for American micrometers was now the main cause of the continuance of high imports which in 1938 amounted to nearly twice United Kingdom production. To meet the large increase of requirements after the outbreak of war, two additional factories had to be provided and a third firm brought into this production. Production did not increase as rapidly as was hoped owing to various difficulties of which labour shortages were perhaps the worst. A very large supply had still to be sought in the United States; in 1943 the minimum requirement from the United States was 6,000 per month. By the end of 1942 production of micrometers in the United Kingdom was 3,000 per week and expansion schemes were in hand to increase this to at least 5,000.

In the supply of slip gauges complete independence from imports was achieved. It was not until 1920 that with the encouragement of the N.P.L. the first slip gauges were manufactured in the United Kingdom; previously all supplies had to be imported from Sweden. By 1936, two firms were in production of these gauges and to meet war requirements two additional factory units were provided under one of these firms. By the end of 1942 the supply was sufficient to meet the maximum demand. The output from the main firm was then almost ten times their output for 1939. In 1939 we were still seriously dependent on the United States for supplies of all types of vernier gauges. At that time there was only one firm in production in the United Kingdom. Three additional firms came into production in 1941; another firm in 1942 and three further firms in 1943. As a result between 1942 and the end of 1943 output had increased to more than six times the 1942 output. This was a very essential expansion; supplies from the United States were very difficult to obtain and in 1943 the Machine Tool Control had to undertake a complete control of vernier production.

There were several other types of fine measuring tools for which there was a general dependence on imported supplies but these were required in comparatively small quantities. The dependence on imports for these tools was generally continued until 1943 when it appeared that further imports might not be available and arrangements had to be made for the United Kingdom manufacture of many types.

MEASURING INSTRUMENTS

Between the wars there had been notable developments in the manufacture of measuring instruments in the United Kingdom. An initial stimulus had been the need for checking of gauges for the mass production of ammunition in the First World War. The National Physical Laboratory had done much to promote development both before and after 1918; but in 1922 there were very few firms on this work despite the war-time developments. There were only seven firms making gauge measuring instruments and only two making engineers' optical measuring instruments. In the following years interest in measuring instruments was encouraged by the N.P.L., where research and experimental work went on. Nevertheless United Kingdom engineering firms had a strong preference for foreign instruments; in consequence potential instrument makers in the United Kingdom had very little encouragement from industry. All the same a few pioneering firms with experience in making optical and precision instruments did turn their attention to the production of measuring instruments. But although some progress was made, dependence on foreign supplies was still serious. For example, one firm produced a toolmakers' microscope and were busy with work for the service departments, but in the middle of 1938 not less than 80 per cent. of the toolmakers' microscopes used in the United Kingdom were imported types. The importance of the work of the United Kingdom firms in producing measuring instruments before the war, was thus mainly in the creation of a nucleus of capacity and knowledge that could be further developed.

This was a sector in which we were largely dependent on continental supplies. Very few types were available from the United States and with the outbreak of war special efforts had to be made to increase United Kingdom manufacture. The United Kingdom output of main types of measuring instruments between 1940 and 1943 increased fourfold. In 1944 and 1945 output continued at very near to 1943 output.

Production of main groups of measuring instruments (Value £'s)

Description	*1940*	*1941*	*1942*	*1943*
Comparators	23,345	64,750	116,025	144,149
Projectors	44,380	66,720	85,900	112,810
Microscopes	1,240	2,440	15,050	24,720
Measuring machines	21,350	29,050	46,770	43,880
Indexing, levelling and aligning instruments	21,355	49,340	69,905	110,935
Miscellaneous	14,868	21,478	33,362	65,773
Total	126,538	233,778	367,012	502,267

In total cost, the requirement of measuring instruments was very small. Yet developments in measuring instruments and in their application could have an effect on production far exceeding the cost of the instruments. The cost of the measuring instruments employed in connection with airframe assembly was negligible compared with the cost of the aircraft manufactured but they provided notable savings in time and labour. It was not merely their importance in production; they had a fundamental part in the proficiency and economy of inspection. Moreover, the existence of firms manufacturing measuring instruments in the United Kingdom greatly facilitated further developments in inspection and production technique and in measuring equipment.[1]

[1] F. H. Rolt, *The Development of Engineering Metrology*, March 1952. The Sir Alfred Herbert Paper. Institution of Production Engineers.

CHAPTER XIV

CAPITAL COST AND INDUSTRIAL STRUCTURE

(i)

Capital Cost

THE very large additions to manufacturing capacity for war production could only be obtained by the supply of large quantities of machine tools and plant. For more than half this new plant, new factory buildings had to be constructed. In the Ministry of Supply the construction and equipment of the Royal Ordnance Factories and agency factories accounted for the major part of the capital expenditure for war production.

War Office and Ministry of Supply
Capital Provision for Buildings and Plant [1]

(April 1936 to September 1945)

	£m.	No. of factories
I. NEW GOVERNMENT FACTORIES		
(a) *Royal Ordnance Factories*		
Explosives and chemicals	50·6	9
Filling factories	75·5	10
Armament factories	49·0	25
(b) *Ministry of Supply Agency Factories*		
Armament factories	31·8	35
Explosives and chemicals / Filling factories	57·8	44
Raw materials	18·1	67
Others	3·7	16
Total new factories and agency schemes	286·5	206
II. ASSISTANCE TO CONTRACTORS		
Armaments and munitions	137·0	3,532
Raw materials	36·9	560

[1] Including the pre-war expansion under the War Office and the cost of expansion and re-equipment of the R.O.Fs already available in 1936. The amounts given in this table are the approved value of expansion schemes in the United Kingdom. The total actual expenditure on fixed capital was substantially larger but this included additions for increased costs and other contingencies.

In the Ministry of Supply factory programme the largest expenditure was for the Royal Ordnance Factories. Factory construction and equipment had by far the largest share of the capital expenditure but this tabulation seriously understates the importance of new equipment for existing works as can be seen from a subdivision of the expenditure between building work and the supply of manufacturing plant. For whilst for R.O.Fs and agency factories building work accounted for £130 million and plant for £156 million, the building work in the assistance to contractors was less than £20 million but the supply of plant accounted for at least £120 million. This shows that the supply of plant to existing factories was only somewhat less than the supply to the new government factories. Over £100 million of the plant supplied to contractors was for armament manufacture,—guns, ammunition, tanks—but not explosives, filling and chemicals. The comparable figure for plant for this manufacture supplied to the new factories was about £80 million. The supply of plant to existing factories was clearly of great importance; it was only possible to make use of a wide range of engineering factories for armament production by the provision of a considerable amount of plant.

For aircraft production the position was not quite the same. It is not possible to identify any large block of expenditure on equipment which was for the existing factories of non-specialist firms. There was in general a greater matching of building and plant, nevertheless in each section of production there was a large number of schemes in which plant was provided without building work. In total, this supply of separate plant and machine tools may have been as large as that supplied to contractors by the Ministry of Supply for armament production, but it was not concentrated in a few sectors. Far more prominent and characteristic was the large number of extensions to existing factories, particularly of aircraft and engine factories. This was mainly due to the existence of a professional industry with over thirty firms all ready to operate on a larger scale and yet dependent on government assistance for the bulk of the additional capacity. For as we have seen, most of the extensions after 1937 were undertaken at public expense and rented by the aircraft firms.

As in the Ministry of Supply programme much the larger part of the plant was installed in contractors' works and extensions to these works; but for M.A.P., extensions to contractors works was a very large part of the building programme. In the end building of agency factories at about £55 million accounted for rather less than half the total amount spent on building work and a substantial part of the new plant and machine tools provided for contractors at a cost of about £130 million was installed in new factories or extensions rented to the firms.

Buildings and plant for Aircraft Production from April 1936 (£m) *

	To June 1943	To September 1945
I. NEW GOVERNMENT FACTORIES		
Government agency factories		
Aircraft	23·8	
Engines	61·3	
Other components	14·5	
Light metal fabrication . .	5·1	
Raw materials	7·2	
Other agency schemes . .	17·5	
Total for new government factories . .	128·4	145·8
II. EXTENSION TO CONTRACTORS' FACTORIES AND OTHER SCHEMES		
Aircraft and other equipment. . .	131·0	
Raw materials	25·3	
Other schemes †	54·0	
Total extensions and other schemes. .	210·3	279·8

* The amounts given are the total approved value of capital expansion schemes. With the exception of some overseas schemes for raw materials production all the schemes were in the United Kingdom. The analysis between different types of factories is only available up to June 1943.

† Includes government establishments and buildings mainly for research, storage, housing and airfields.

At the peak of aircraft production there were more than 14,000 factories employed on M.A.P. orders but the total number of factories that received some capital provision, building and plant, was less than 2,800. Judged by labour employed, three quarters of the capacity under M.A.P. was located in no more than a thousand factories, including the new factories. It was for these factories that the greater part of the capital expenditure of over £420 million was provided. The remainder went to less than 1,500 firms many of whom employed less than a hundred on M.A.P. work but who nevertheless required additional capital equipment or building work. Thus, whilst it was possible to employ many thousands of firms without any government capital expenditure, this was by no means the position of the 1,000 factories which contributed at least 75 per cent. of the capacity nor of at least a further 1,000 factories.

We have seen that, in order to introduce outside firms into specialised armament or aircraft production it was as a rule necessary to provide manufacturing equipment. For some production, e.g., ammunition and small arms production the equipment provided constituted a complete specialised manufacturing unit. In others, e.g., gun production, the equipment was often a specialised element added to otherwise suitable general plant. In general, the manufacture of products not within the commercial range, required the provision of additional, often complete and self-contained units of manufacturing equipment. The only way of avoiding this was to reduce the work to a process or to processes within the scope of the firm's existing plant. This method was of course extensively adopted and explains to some extent how thousands of firms were able to employ their own plant on armament production. It was in fact possible to subdivide the manufacture of even highly specialised stores to provide work for these firms. In addition, there was the very important sector of commercial counterparts i.e. of stores very similar to the normal products of the firms. Under the Ministry of Supply there were important commercial counterpart sectors in which the provision of capital equipment was negligible. These sectors include motor transport vehicles, electrical, radio and telephone and general engineering and clothing and equipment requirements. On the other hand many of the M.A.P. requirements in this range were needed in quantities so greatly in excess of the normal output that it eventually proved necessary to expand the manufacturing capacity and provide a good deal of capital equipment.

The expenditure of the Admiralty for the expansion of manufacturing capacity was much less than in the other two production departments. In contrast to aircraft production the main capacity for shipbuilding was already available. For explosives and for the filling of ammunition and for the production of small arms ammunition the Admiralty could rely on the Royal Ordnance Factories and agency factories under the Ministry of Supply. A very large part of the Admiralty expenditure on capital equipment was for the Royal Dockyards and the manufacturing depots and factories under direct Admiralty management including the two Royal Naval Propellant Factories. The few Admiralty agency factories were mostly on a small scale and accounted for only £4.5 million. The greater part of expenditure outside the Admiralty establishments was in assistance to contractors; from April 1936 to December 1944 this accounted for over £38 million. As with the Ministry of Supply schemes the greater part of the Admiralty assistance to contractors was for the supply of manufacturing plant. The expenditure on the building of factories was comparatively small.

(ii)
The Industrial Structure

The provision of new capital equipment for war production, financed from public funds, large and extensive as it was, did not result in any radical change in the structure of industry. Indeed, the industrial structure of war production retained most of the pre-war features of British industry. The specialised government factories were probably the only major addition to the normal pattern. The extensive use of existing industrial resources without any general disturbance of the pre-war industrial structure arose not merely as the result of what are usually described as conditions of total warfare but because mechanised warfare required very large supplies of military equipment that could be produced on the existing production lines or by the direct use of existing resources.

The most important change in the industrial structure was the altered balance of individual industries resulting from the very great increase in the number employed in the engineering, shipbuilding and chemical industries. By June 1943 the number employed in these industries had increased by over 70 per cent. compared with June 1939.

Number employed, including at government factories (thousands)

Industries	June 1939 Total	June 1943 Total	Civilian Requirements	Increase from June 1939
Engineering and allied	2,312·9	4,010·2	556·9	1,697·3
Shipbuilding and repairs	144·7	272·3	*	127·6
Explosives and chemicals†	284·4	565·3	166·5	280·9
Total	2,742·0	4,847·8	..	1,905·8

*The only 'civil' requirements were for the merchant fleet. For this the Admiralty had production responsibility and employment is not shown separately.

†including ammunition filling.

This employment was very largely on manufacturing work, i.e. on the manufacture of finished articles and components; but some raw material production, mainly non-ferrous metal and chemicals, is included; but iron and steel production, which employed over 300,000 in 1939 and just over 350,000 in 1943 is excluded. With minor exceptions these industries contained the main capacity employed on production for Service requirements. Some items of equipment, particularly clothing and other textile stores are outside these industries.

In addition some account must be taken of firms not belonging to these industries who undertook munitions work outside their normal field of manufacture. There were many notable examples; food and tobacco firms employed on ammunition filling; maintenance workshops and tool rooms of a wide range of textile factories and many other factories employed on munitions production. But in the aggregate they do not affect the general picture.

This expansion of employment was not all achieved within the existing industrial structure; the total in June 1943 includes about 900,000 employed in government factories most of which had been brought into operation from 1939 onwards. These government factories were of two kinds: the factories and dockyards owned and operated by the government, mainly the Royal Ordnance Factories and the Royal Dockyards; and the agency factories owned by the government but operated at government expense by selected firms.

Employment at Government Factories

	June 1943 (*thousands*)
Royal Ordnance Factories .	268
Royal Dockyards . . .	37
Agency Factories	
Ministry of Supply and Admiralty . . .	210*
Aircraft Production .	300

*excluding employment at raw materials agency factories.

With the exception of the Royal Dockyards, which in June 1939 employed at least 25,000, all but a very small proportion of the total employment at these factories was recruited after June 1939 and most of the factories came into operation after June 1939.

When these factories are excluded the expansion within the existing structure is disclosed.[1] Thus whilst the government factories, including the agency factories, accounted for only a sixth of the total employment they accounted for about 40 per cent. of the *increase* in employment between June 1939 and June 1943. For two major sectors of production—explosives and ammunition filling and assembly—the government factories accounted for almost all the war-time and indeed most of the pre-war expansion of capacity. In the engineering and metal using sectors the position was very different; here the government-owned factories accounted for less than a third of the war-time

[1] Of the employment at the government factories at least 500,000 were classified in the engineering and allied industries group and over 250,000 in the explosives, chemicals and ammunition filling group.

expansion. Moreover the larger proportion of the factories were agency factories and as these were operated by firms this meant an expansion in the activity of private industry. The agency factory system should indeed also be considered as one of the methods by which the industrial structure was enabled to bear so large an expansion. For explosives, chemicals and ammunition filling, the use of agency factories was the main method employed; in most of the other production the agency factories were important, for aircraft very important, but not preponderant.

For shipbuilding and repairs, the expansion of capacity for construction and repair of hulls was almost entirely by re-opening and renovating the existing yards and by increasing the labour force employed. Some engineering firms were employed on construction of landing craft, but in general new factory buildings were devoted almost entirely to the manufacture of ships' equipment, engines and armament; this expansion is included under engineering and allied industries. Shipbuilding was thus a prominent example of war-time expansion mainly achieved by an increase in labour force and by the rehabilitation of existing capacity.

The classification of engineering and allied industries covers a very wide group of metal working industries. The normal products cover a wide range—locomotives, motor vehicles, aircraft, electrical engineering, radio and instruments as well as armament and munitions. In the aggregate the labour force in this group was increased by about 1,700,000, an increase of over 70 per cent. on June 1939. Of the increase about one-third were employed in new factories or in some instances in newly occupied factories. Indeed, if dispersal and other factors which led firms to operate outside their own factories were taken into account, it might well be found that almost half the increase was employed outside the pre-war factories. These new factories were of very great importance in munitions production but they by no means accounted for all the increase nor did they exceed the capacity employed on Service requirements in the firms' factories. Thus the capacity employed in existing firms and factories greatly exceeded the capacity employed in the new factories. It should be noted however that total capacity here includes all processes of manufacture except the preparation of raw materials. The new factories were far more important in the final manufacture of munitions than in the processing of materials and in the manufacture of components.

In the three main sectors of war production—shipbuilding, aircraft and armament—it was only shipbuilding that remained substantially within its own industrial sector—shipbuilding and marine engineering. For aircraft production a very large part of the capacity was outside the industrial sector of aircraft and motor vehicles. Indeed in 1943, only 50 per cent. of the total employment on aircraft production was

Employment (in thousands)

	June 1939	*June 1943*	*Increase*
1. Shipbuilding and repair	145	272	127
2. Marine engineering*	59	99	40
3. Aircraft, motor vehicles and cycles	473	1,122	648
4. Mechanical and general engineering	742	1,503	761
5. Electrical engineering*	139	189	50
6. Electrical cables, apparatus, etc.	196	291	95
7. Scientific instruments, watches, clocks, etc.	87	99	12
8. Non-ferrous metal manufacture	56	114	68
9. Bolts, nuts, screws, hand tools, cutlery, brass and metal ware	378	448	70
10. Railway and other carriage construction and repair	66	59	—7
11. General iron founding and heating apparatus	117	86	—31

*Items 2 and 5 are insured workers as in Annual Abstract of Statistics 1935–45, Table 131: other totals are from Statistical Digest of the War. Item 4 is arrived at by subtraction of 3 and 5 from total for Engineering in Table 23 (Statistical Digest of the War).

in the aircraft and vehicle sector. About 25 per cent. of the total was in mechanical and electrical engineering and the rest was spread fairly widely over other sectors. Armament manufacture, apart from the production of explosives and the filling of ammunition, which were specialised factory sectors, had a share in most of the engineering and metal using industries with the general exception of aircraft, shipbuilding and marine engineering. There was some significant armament production in most of the other engineering sectors and even in some shipbuilding and marine engineering firms. It was particularly significant in electrical engineering, and in mechanical engineering. Of the more than 1,500,000 employed in these two sectors (excluding about 200,000 employed in government factories) about 400,000 were employed in aircraft work but about one million were employed on armament production including guns, ammunition and tanks.

The electrical engineering firms including electrical locomotive manufacture, made very important contributions to tank and gun manufacture but it was in the wide range of mechanical and general engineering firms that the great bulk of armament manufacture was located. This industrial sector in 1939 employed a much larger number than the aircraft and the motor vehicle industry. In 1935 it contained over 3,000 factories (excluding factories with less than 10 employed) employing about 400,000, but only one main section employed over 40,000 and very few sections employed even 15,000. In 1935, apart from constructional engineering (36,000), the three largest sections were locomotives and prime movers (52,000), textile machinery (40,000) and machine tools (21,000). It was at these more than 3,000 firms, that in 1939 employed over 700,000 and in 1943 employed over one million, that the main capacity for armament manufacture was found. As we have seen locomotive firms were prominent in tank production as well as in the manufacture of guns and mountings; and for the manufacture of guns and shell the manufacturers of all kinds of machinery and mechanical equipment were very important.

As it is clear that the bulk of firms in the engineering and metal industries were employed in war production, it follows that firms of all sizes were employed. Some small workshops ceased operation but in the main even the smallest workshops including those employing less than ten workers took some part in war production. It is probable that the wide range of size to be found in British industry was maintained in very similar proportions in war production. Nevertheless, in many of the industrial sectors employed on the final manufacture of war stores, the range was not so extreme, even before the war, as in industry generally. As was to be expected, employment did not expand equally in all firms; there was an exceptional increase in the operational size of the larger firms. The industrial sectors[1] in which small firms were especially predominant were the metal manufacturing trades in both ferrous and non-ferrous metals, and these firms normally manufactured a great variety of small metal ware, from nails and screws to domestic hollowware and plate and jewellery. In some of the trades within this sector the largest firms did not much exceed 300 employees and there was a general predominance of the smaller firms. Part of the output of these trades was for the private domestic consumers market but a large part were essential components for engineering production sold mainly to engineering firms. In war, the domestic consumption was severely restricted and most of the firms were employed in supplying engineering firms with essential components. Very largely then these small firms continued as primary subcontractors.

Even in 1935, in the engineering industries, with the exception of mechanical engineering and shipbuilding there was a general preponderance of capacity in large firms. But for the chronic underemployment in the shipbuilding industry the only major exception in 1935 would have been mechanical engineering.

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[1] For the pre-war range of size the following designation is adopted. Large (over 1,000): fairly large (500-1,000): medium (300 to 500): small (under 300): very small (less than 100).

	Percentage of labour employed in 1935 in firms of size stated Under 500	500–999	1,000 and over
Motor vehicles and cycles	28	14	58
Aircraft	..	..	76
Shipbuilding	41	15	44
Marine engineering	22	20	58
Electrical machinery	16	12	72
Radio	..	..	66
Electrical wires and cables	28	13	59
Mechanical engineering	52	18	30

It was in these industries that the final production of war equipment was undertaken. With the exception of mechanical engineering the firms with over 1,000 employed accounted for over half the total capacity, and all firms with over 500 employed accounted for at least 70 per cent. of the industrial capacity. Thus, in the sectors of industry that were employed on the final manufacture of war equipment, the greater part of capacity even before the war was in large firms with over 1,000 employed. Even so there were very few really large firms and even fewer very large factories. Thus even in 1939 no firm in the aircraft industry employed over 5,000. In the motor vehicle and the electrical industry only a few firms employed more than 5,000 and by no means all these firms had a factory with an employment of that size.

The effect of war production was not merely to increase the size of most firms and factories but also to bring about a significant increase in the number of firms employing over 5,000 and the number of factories with over 5,000 employed. This was especially true of the aircraft firms, and of the closely related motor vehicle industry. In the aircraft industry the expansion of firms to meet the increased demand for their product and the construction of large agency factories had a very noticeable effect. Aircraft firms sustained very great expansion in their operational size, indeed the largest increase of any type of firm. The operation of some of the motor vehicle firms employed on aircraft production, already very large firms, became even larger. Motor vehicle firms generally had no increase in size due to motor vehicle production; some existing capacity particularly for motor car manufacturing had to be put to other use. Even so, some firms had important additions to building and equipment due to special provision of capacity for aircraft and for tank production. Most motor vehicle firms did in fact increase the labour force under their management but with some exceptions the increase was not more than 100 per cent.

An analysis of the size of production units employed on aircraft production in 1943 reveals a remarkable proportion of large scale units. Out of just over one million operatives employed in firms with at least 100 operatives on aircraft production, over 800,000, or almost 80 per cent. were employed in units with a labour force of over 1,000. All these units had at least 1,000 employed on M.A.P. orders so that at many establishments the total labour force would be even larger. There were 240 units with over 1,000 employed on M.A.P. work and a large number of these units had more than 2,000 employed on M.A.P. work. Some of the units were very much larger.

Establishments with at least 1,000 employed on M.A.P. work

1,000— 1,500	—	82
1,501— 2,500	—	60
2,501— 4,000	—	40
4,001— 6,000	—	32
6,001— 8,000	—	13
8,001—10,000	—	9
10,001—15,000	—	8
15,001—25,000	—	4

Final manufacture of aircraft and engines accounted for most of the very large factories with over 5,000 employed on M.A.P. work. Of the 44 factories of this size twenty-five were aircraft factories, fourteen engine factories and five for radio and radar. Of the twelve factories with over 10,000 employed, three were engine factories and nine were airframe factories. Of these twelve factories, several were only slightly over the 10,000 mark but there were two that exceeded 20,000.

With the large factories—over 1,000 employed, accounting for at least 80 per cent. of this sector—there can be no doubt as to the importance of large factories in the total capacity. Yet even in aircraft production a very important part was played by smaller units of capacity, though some of them formed part of a large establishment.

*Employment and Size of Unit for Aircraft Production**

	Total Employed	Number
(a) In factories with over 1,000 .	950,000	248 factories
(b) In firms with under 1,000 but over 100	310,000	532 firms
(c) In firms usually with less than 100	440,000	12,000 firms
	1,700,000	

* Employment includes all employed, i.e. administrative, design and technical staff.

This approximate division of M.A.P. capacity, in terms of labour employed at the peak of war production, shows the preponderance of large manufacturing units but it also shows the considerable place of the smaller units. The bulk of the firms in (c) were employed as subcontractors. In addition there were at least 200,000 on subcontracts in (a) and (b).

In the Ministry of Supply programme the large expansion of existing factories and firms was not so prominent; most of the very large units were new government factories. Thus all but two of the 44 new R.O.Fs had an employment of over 1,000. More than half of the 23 new engineering R.O.Fs employed over 2,500 and at eight the employment exceeded 5,000. The nine main ammunition filling factories were all on a very large scale, most of them employed over 10,000 and no less than five had an employment of at least 20,000. By no means all the Ministry of Supply agency factories were large, there were many with less than 1,000 employed but at least twenty agency factories were large factories. In the Ministry of Supply programme it was only for explosives and the filling of ammunition that there was a preponderance of very large factories. In these sectors virtually all production was from large or very large factories.

The new engineering factories—both R.O.F. and agency—accounted for less than a fifth of the total employed on engineering armament production.[1] For weapon and ammunition production it was only for small arms ammunition and most small arms weapons that production was entirely from large factories. Other weapon and ammunition production was placed with a very large range of firms and undertaken to a very large extent in medium or small scale factories. By far the greater number of factories were found in the mechanical engineering industry a very large part of which consisted of small and medium sized factories. In 1935, out of over 3,000 factories with a total employment of 400,000, over 2,000 factories employed less than 100. Excluding marine engineering, less than 100 factories employed more than 750. No doubt by 1939 the employment at most of the factories had increased but even then there were few very large factories. By June 1939 the total employed in this sector had increased by 40 per cent. and there can be no doubt that a large part of the increase was due to an increase in the number employed at the existing firms and that by June 1943 employment at some firms had at least doubled since 1935. The average increase was a good deal less than this and for most firms the increase could be readily achieved within their existing factory accommodation.

[1] i.e. excluding explosives and ammunition filling.

The effect of war-time expansion on the capacity and structure of British industry was too varied to be expressed in a single formula. The productive capacity and the employment in the industries mainly engaged in the manufacture of munitions—the engineering, electrical and chemical industries—were increased far above the pre-war level. In addition, there were many new state factories constructed and equipped for specialised munitions production. The usefulness of some of this great expansion of capacity was not destined to survive the peak of war production. Even in the closing years of the war, filling factories and some ammunition and explosives factories could not be fully employed; after the war much of the specialised equipment was dismantled, and at least half the Royal Ordnance Factories were almost immediately declared redundant. From the point of view of peace-time production much of this war-time manufacturing equipment was so to speak ephemeral. Some of the great explosives and filling factories left behind them developed industrial sites which were employed as industrial estates; some of the explosives factories were absorbed into the peace-time capacity of the great chemical firms. But generally speaking, much, perhaps the bulk, of the capacity provided by the state for highly specialised munitions production, could not be regarded as a long-term investment in British industry or as a permanent addition to industrial capacity. In the final accounting of economic losses and gains these additions must be reckoned as part of war's 'unremunerative' expenditure and added to the unrequited cost of the war. This indeed was the way in which they were reckoned in the computations of national income.

On the other hand most of the other war-time provision of buildings, plant and machinery were to remain as valuable additions to the country's productive resources. Very nearly all the additional floor space provided in the engineering and electrical industries during the war was quickly occupied for post-war production. And, whereas some of the machines and machine tools engaged in the manufacture of weapons were quite unsuitable for employment in peace, while others were by 1945 too worn out to be capable of much peace-time service, some of the machining capacity, a great deal of the plant and the production services (water, steam, gas, electricity, internal transport) were available to serve the new production lines in the post-war years of industrial rehabilitation. In one or two industries, war-time developments had very direct effects which were felt over the whole post-war structure of the industry. The great war-time expansion of the aircraft industry, though too large for immediate post-war needs, brought a comparatively new industry to maturity and in a variety of ways made possible the new scale of post-war operation. Here, to a greater extent than in any other major industry, war-time factories could be directly absorbed into post-war production. In the shipbuilding industry, the equipment provided under the shipyard development schemes, barely in full operation before the end of the war, brought a measure of modernisation which strengthened the immediate post-war capacity of the industry. Thus to some extent at least, this story of capital equipment for war production transcends the more limited scope of war industry.

Appendix

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APPENDIX

Aircraft Factories and Scale of Production

FIGHTERS AND LIGHT BOMBERS

Three types of fighters dominated war production—the Hurricane, Spitfire and Beaufighter. Production for all three was planned in the pre-war programme. The Hurricane and Spitfire came into production in 1938 and the Beaufighter in 1940; the Hurricane continued in production until late in 1944 and the other two until the end of the war. Up to the end of 1943 output was at an ever increasing rate.

Peak monthly average for each year

Year	*Hurricane*	*Spitfire*	*Beaufighter*
1939	64	46	—
1940	258	160	22
1941	292	232	95
1942	277	359	130
1943	239	351	139
1944	147	404	124

Thus these aircraft had the advantage of more than four years continuous production. This was especially true of the Hurricane and Spitfire and it is not surprising that the peak output of these two types was greater than for any other type of aircraft. Even so, for each of these three types, two factories accounted for the greater part of the output and a very large part of the output came from the factories of the parent design firms.

Production of the Spitfire up to June 1940 came entirely from the parent factory Vickers Supermarine. In that month supplies also began from the shadow factory at Castle Bromwich planned by Lord Nuffield but already under the management of Vickers. More than 95 per cent. of the output of Spitfires came from these two factories. In addition some 600 Spitfires were produced by the Westland Aircraft Company in the years 1942–43. Output from the two main factories was thus on a very large scale—the parent factory reached a monthly average of 137 aircraft and the Castle Bromwich factory with a peak output of 320 aircraft a month attained a record output for any type of aircraft in the United Kingdom.

The output of the Hurricane was in many ways very similar, although the level of production was only about two-thirds that of the Spitfire. Here again, the output came almost entirely from two main factories; for with the exception of 300 Hurricanes assembled by Austin Motor Company in 1941 and 1942, the output came from the parent firm Hawker and their associate company the Gloster Aircraft Company. The parent company started production in December 1937, continued in production until 1944 and produced over 70 per cent. of the total output. The Gloster Company commenced production in October 1939 and supplied more than

20 per cent. of the total. Both firms reached their highest monthly output of over 150 Hurricanes in 1941.

Despite the continuous production of these fighters new types had to be introduced. In 1941, the Typhoon was brought into production and this was achieved without any substantial reduction of the other types. This was true even though with the introduction of the Typhoon the production of the Hurricane at the Gloster factory came to an end. This factory was for some time the sole source of the output of Typhoons. In 1942, Typhoons were also produced at Hawkers but without any significant drop in the output of Hurricanes until the autumn of 1943. This eventual reduction also enabled Hawkers to bring into production a further type—the Tempest—at the very end of 1943. The Typhoon and the Tempest required more machine and man-hours than the other types and additions to plant and labour force were necessary. To complete this story of fighter production it should be added that the Gloster factory started deliveries of the first jet-engined fighter—the Meteor—early in 1944.

The total production and the peak monthly output of the Beaufighter was only slightly more than half that of the Hurricane. Here again more than 80 per cent. of the total output came from two factories. Both these factories were under the management of the parent and design firm—Bristol. In addition the Fairey factory at Stockport was in production of the Beaufighter in 1941 and 1942 and the Rootes shadow factory also produced Beaufighters in 1943 and 1944. The largest monthly output of 90 Beaufighters came from the Bristol shadow factory at Weston-super-Mare, which had been specially constructed in 1940 for this production. At their Filton works Beaufighter production had for most of the time to share the factory accommodation with the manufacture of other types of aircraft.

Only two types of light bombers were in production during the war: the Blenheim which was in production at the outbreak of war and continued until the middle of 1943; and the Mosquito which was in continuous production from 1941. It was for Blenheim production that the Rootes shadow factory at Speke was approved in 1936. This factory came into production in 1938; the parent firm—Bristol—started production of the Blenheim in March 1937 and A. V. Roe in September 1938; but the combined production of these two aircraft firms was only about half the shadow factory output. By 1942, Rootes production of the Blenheim had been transferred to the shadow factory at Stoke and to a dispersal factory at Speke, but their peak output came in 1941 with a monthly output of 148 aircraft from Speke.

The introduction of the Mosquito light bomber in 1941 to replace the Blenheim was brought about in a very different fashion; no use was made of the capacity for Blenheim production. The Mosquito production was obtained elsewhere, in fact mainly under the firm that was responsible for the design—the de Havilland Aircraft Company. Some of the features of this production story have often been retold and emphasis given to the wooden construction that made it possible to spread subcontracting work throughout a large part of the woodworking industry. In August 1940, it was decided that the Mosquito should go into production at the new agency factory at Watford previously scheduled to bring de Havilland into the production of Halifax bombers; this factory and the greater part of the other de Havilland factories were together responsible for at least 80 per cent. of the total output of Mosquitos. The Mosquito was very suitable for firms previously engaged on the manufacture of trainers. Up to 1941, the production efforts of the de Havilland factories had been devoted to the production of trainers and the three other firms introduced into Mosquito production—the shadow firm Standard Motors, the aircraft firms, Airspeed and Percivals—had also been employed on the production of trainers. Thus to a large extent the Mosquito was produced from trainer capacity with the addition of a factory initially allocated to bomber production. With these three additional firms it was possible to maintain the output of Mosquitos at an increasing rate in 1944 and 1945, even though the parent factory of de Havilland also brought the jet Hornet into production by the beginning of 1945.

Fighter and light bomber production was thus usually planned on the basis of two or at most three firms and the bulk of the output of any type often came from two factories. Usually, one of the two factories was an agency factory either under the parent firm or under a shadow firm. For some types additional firms were introduced later, either to expand output or to compensate for some disturbance of the existing capacity. The peak output for each factory employed in the main types of fighter and light bomber production indicates something of the organisation of the factory capacity and even more directly the scale of manufacture.

Factory Output

Fighters and Light Bombers (Peak monthly average for quarter)

Hurricane . .	178	156	29*		
Spitfire . .	320	137	48*		
Mosquito . .	150	79	80	25*	4*
Blenheim . .	148 (43† 42†)	61	51		
Beaufighter . .	90	49	42	33*	

*Indicates ancillary schemes mainly intended to supplement the main output; total production on these schemes was usually a very small part of the total.

†Two factories which replaced Speke production of the Blenheim in 1942.

MEDIUM BOMBERS

By the beginning of 1939, three important types of medium bombers were in production—the Whitley in the Armstrong-Whitworth factory, the Hampden at the Handley Page works and the Wellington in the Weybridge factory of the Vickers organisation. In 1940, the English Electric also started production of the Hampden. Both the Whitley and the Hampden were precursors of the heavy bombers and in 1942 the Whitley at Armstrong-Whitworth was replaced by the Lancaster and the Hampden at the English Electric was replaced by the Halifax. It was the Wellington medium bomber that was to continue in production for the total period of the war: after 1941 the medium bomber programme was almost synonymous with the Wellington programme. In 1939, all the production of the Wellington was concentrated at the Weybridge factory of Vickers Aviation; this factory was to continue exclusively on Wellingtons until the summer of 1942 when the Warwick, a heavy bomber, was introduced,[1] but even then Wellington production there did not cease until September 1943; production at Weybridge had then covered a period of five years.

It was for the Wellington production that the agency factory under Vickers at Chester was approved in January 1939 and a second agency factory at Blackpool in December 1939. The Chester factory was in production by January 1940 and within little more than six months the output exceeded that of Weybridge. In the critical autumn of 1940 monthly deliveries from the Chester factory exceeded 65 Wellingtons with the Weybridge deliveries at just over 50 Wellingtons a month. Expansion of output at Blackpool was not so rapid but by the end of 1941 it had reached 36 aircraft a month and by the end of 1942 it was over 60 aircraft a month.

Wellington Production (Monthly average for quarters)

	1941				1942				1943				1944	
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd
Weybridge	53	62	62	64	66	66	61	51	44	33	8	—	—	—
Chester	63	68	82	85	100	107	125	121	115	113	108	116	119	111
Blackpool	5	11	15	36	38	53	53	61	64	74	79	92	98	98
Total	121	141	159	185	204	226	239	233	223	220	196	208	217	210

The Chester factory was planned as an assembly factory dependent on subcontracting for almost all components and sub-assemblies. This made rapid expansion possible but it also proved to be a limiting factor in the final expansion of output planned for 1942 and 1943. The Blackpool factory was not so completely dependent on subcontracting and was able to attain the 100 per cent. increase in output planned for 1942–43. In this apparent rivalry it was significant that both factories were dependent on many of the same subcontractors. The ultimate disadvantage for Chester was the decision in the spring of 1943 that the factory should prepare to change over to the Lancaster—a decision which also affected the subcontractors.

Although the monthly and total output at the Chester and Blackpool factories ran well ahead the contribution of Weybridge must not be underrated. For over two years, Weybridge alone supplied Wellingtons to the Royal Air Force thus laying the basis of successful production and providing the experience which enabled the later factories to escape the problems of the initial construction of a new type. It had also to meet the main demand for spares. It was arranged that spares production for the Wellington should be centred at the Weybridge factory leaving Blackpool and Chester free to concentrate on the output of complete airframes. When in the summer of 1943 Wellington production at Weybridge came to an end, the factory continued in production of Wellington spares up to a planned output equivalent to seventy aircraft a month.

HEAVY BOMBERS

Only three types of heavy bombers were in production at the peak of war production. Of these three, the Stirling came into production in the

[1] The Warwick was mainly produced as a reconnaissance and as a transport aircraft.

spring of 1940, the Halifax in October 1940 and the Lancaster in October 1941. All three types continued in production until the end of the war although by that time the Stirling was only in production as a transport aircraft. In addition to these, the Warwick came into production in 1942 but after 1943 only continued in production as a transport. The Manchester which had come into production in 1940 had by 1942 been replaced by the Lancaster. Delivery of the Lincoln bomber did not begin until January 1945. Thus no heavy bombers were in production at the outbreak of war although the Hampden was at that time nominally classed as a heavy bomber. Even so, although the new aircraft were not available for production, preparations had to be made in 1938 for factory accommodation for the eventual production of the heavy bombers. At this stage the immediate use of the planned capacity was for the production of the Manchester and the Hampden as the precursors of the Lancaster and the Halifax. At the same time it was proposed that the capacity in use for the Whitley medium bomber should also be eventually transferred to heavy bomber production.

Pre-war planning of Halifax production was based on the parent firm, Handley Page, and on the shadow firm English Electric and over 70 per cent. of the total output came from these two firms, which up to 1940 and 1941 continued in production of the Hampden. It was not until 1940 when Halifax production at Handley Page was almost ready to start that further factory capacity was planned. This scheme led to the formation of the London Aircraft Production Group which eventually started delivery of the Halifax early in 1942. Also in 1942, Faireys (Errwood Park) and the Rootes shadow factory at Speke came into the Halifax production; this was in fact a transfer of capacity from light bomber production. Thus by 1942 five manufacturing units were in production.

For the Lancaster production pre-war planning was also based on the parent firm—A. V. Roe and a shadow firm, Metro-Vickers—and here again immediate planning had to be on the basis of an interim type—the Manchester. At least 65 per cent. of the output of Lancasters came from these two firms. By November 1939, it had been decided that Armstrong-Whitworth should also come into production of the Manchester but this was later changed to the Lancaster and Armstrong-Whitworth commenced deliveries in 1942. A. V. Roe and Metro-Vickers were already in production of Lancasters in 1941. The output from these three firms amounted to at least 85 per cent of the total war production of the Lancaster. With the expansion of output required under the heavy bomber programme of 1941 it proved necessary to seek further factory accommodation for Lancaster production. It was then decided to find accommodation for this at the Castle Bromwich Spitfire factory. Then in the spring of 1943, it was decided to use in addition the Wellington agency factory at Chester. This meant fitting Lancaster production into factories equipped for fighter and medium bomber production. The final scheme came in May 1943 when it was decided to switch the Austin shadow factory from Stirlings to Lancasters. These three factories supplied a total of over 900 Lancasters in 1944–45 but they came too late to alter the main balance of output at the peak of war production.

Production of the third main type of heavy bomber—Stirling—remained much more the concern of the parent design firm, Short Brothers of Rochester and the associated company, Short & Harland, Belfast. Requirements were considerably less than for the Halifax and Lancaster but even so it proved necessary in 1940 to arrange for the production of Stirlings at the Austin shadow factory. Production of the Stirling began at Shorts in May 1940 but was almost immediately affected by the necessity for dispersal. The Rochester factory was already being expanded by an additional factory in the same area but in the autumn of 1940 dispersal capacity had to be found much further afield—the major part at Swindon. Final assembly was at Swindon and this factory delivered more than twice as many Stirlings as the parent factory at Rochester which was only partially reinstated after 1940. Stirling production also began at Belfast in November 1940 and it was possible to expand factory capacity there and to arrange extensive subcontracting, with the result that Short & Harland had the highest monthly output of Stirlings and in total produced considerably more than the Short factories in the United Kingdom. It was however the Austin shadow factory which made it possible to augment the supply of Stirlings for the peak output of 1943.

Although heavy bomber production was a very much larger manufacturing task, the monthly output of the Halifax and the Lancaster was required to reach a quantity very similar to that achieved for the Hurricane and not so far short of the Spitfire. Moreover, the expansion to these quantities was required in a very short time.

*Monthly Total Output of Heavy Bombers**

	Halifax	*Lancaster*	*Stirling*
1940	2	—	2
1941	23	6	20
1942	103	91	38
1943	159	190	79
1944	208	260	47

*Monthly average for fourth quarter of each year except 1944 which is monthly output at the peak.

With a greater production task and the larger floor space required heavy bombers could not be expected to reach the factory output of fighter production.

*Maximum Monthly Factory Output of Heavy Bombers**

Halifax	80	55	50	31	30	
Lancaster	155†	75†	47	31	27	25
Stirling			40	32		22†

* Each figure is the peak monthly output for a separate factory except where marked †. There the figure is the output of at least two factory units.

In an account of factories and output most types of general reconnaissance aircraft and transports are mainly of significance as causing a diversion or general division of factory capacity mainly in use for other aircraft requirements. Thus the Warwick, Stirling and Halifax transport aircraft were taken from production of the same type of heavy bomber and this usually affected production at more than one factory. The Beaufort reconnaissance aircraft which was in production from the end of 1939 to almost the end of 1944, came entirely from Bristol Aeroplane Company and mainly from the parent factory at Filton, where several other types of aircraft were also in production. The Sunderland flying boat made very heavy demands, on Shorts, Short & Harlands, and Blackburn but a good deal of quite separate factory accommodation was provided, especially for assembly of the aircraft. Thus several transports were a direct subtraction from heavy bomber output and the Sunderland made quite heavy demands on firms employed on production of the Stirling.

TRAINER AIRCRAFT

The production of trainer aircraft as early as September 1939 had attained an output of 400 aircraft a month. This output increased to over 600 a month in 1941 and despite reduction in requirements did not fall permanently below 400 a month until February 1944. The only other group with a higher total for war production was fighters and light bombers. Most trainers were of wood and canvas construction and in this and in other ways made a much smaller demand on productive resources than operational aircraft. Even so at least twelve firms were employed on trainer production and up to 1941 only three of these firms—A. V. Roe, Blackburn and Westland—were engaged on final assembly outside the trainer types. Even after 1941 it was only for the Mosquito that another three of the firms entered the manufacture of operational types. Only three shadow firms were employed on trainer production—Standard Motors, Morris Motors, and Brush Coach Work—but one or two of the aircraft industry firms were fringe firms who had not undertaken aircraft construction before. Large factory outputs were achieved on trainer production at a few factories. Three firms had maximum output of well over 100 a month though two of these firms had two factories employed on trainer production. Output from the other firms ranged from seven a month for an airfield service firm to over sixty a month. Extensive subcontracting had a large part in some trainer production but an increase in the size of the parent factory and the construction of agency factory proved necessary for at least two firms. In total, the provision of new factory capacity was considerable and one of the agency factories was on a large scale.

NAVAL AIRCRAFT

The output of naval aircraft was the last major group to reach peak production. It was not until January 1944 that the monthly output exceeded 200 aircraft and not until May 1944 that peak production was reached at an output of 279. The increase in output in 1943 was very much the same as for heavy bombers but whilst the output of bombers had increased steadily throughout the war the output of naval aircraft in the first quarter of 1943 was lower than it had been in July 1941. For eighteen months in the middle of the war the output of naval aircraft was for the most part on the decline. The peak output was hardly half that of heavy bombers and yet as a production task the naval aircraft were mostly comparable with light bombers and fighters.

In general explanation it may be said that naval aircraft production was beset with most of the disadvantages which prevent a good run of expanding output. Although not required in very large numbers, there were never less than four different types in production; at the end of 1942 there were eight different types in production. Most factories had two changes in types between the outbreak of war and 1943. This frequent change-over meant a serious loss of output and loss of efficiency. It gave very little time for the development of full efficiency which was rarely reached on any aircraft in less that two years.

Judged by the extent of factory specialisation the capacity for naval aircraft appeared to enjoy considerable advantage. Two of the Fairey factories were used exclusively for naval aircraft. Their factory at Hayes was at the outbreak of war employed on the Swordfish, changed over to the Albacore and then to the Firefly. The new factory at Heaton Chapel started on the Fulmar in 1940 and then went on to the Barracuda in 1942. Saunders Roe factory which began production of the Walrus in 1940 changed over to the Sea Otter in 1943. Blackburns had one factory continuously in production of the Swordfish from 1941 to 1944. Another of their factories began production of the Barracuda in 1942 and changed over to the Firebrand in 1944. Fairey, Blackburn and Saunders Roe were the firms employed on naval aircraft throughout the war. Of the firms that came in to increase the output in the second half of the war, Boulton Paul came in on the Barracuda in 1943 and General Aircraft on the Firefly in 1944; but the largest addition was for the Seafire—the variant of the Spitfire. For this three Spitfire factories were brought in—Supermarine, Westland and Castle Bromwich—and in addition Cunliffe Owen a firm not previously employed on the manufacture of complete aircraft for war production.

Apart from the Seafire there was a large measure of specialisation in naval aircraft production. Some types were only produced by one firm and several factories were only employed on naval aircraft. All the Albacores, the Fulmars and most of the Fireflies were manufactured by Fairey, most of the war-time Swordfish and all the Firebrands by Blackburns. Both of these firms had two factories almost continuously in production on one type of naval aircraft. But, except for the continuous production of the Swordfish at Blackburn's the advantage of this arrangement was reduced by changes of type. Moreover, both these firms had three separate major factories in operation on different types of aircraft with consequent strain on their management. Except for the Swordfish and the Seafire none of the naval aircraft had the advantages of prolonged production; large scale manufacture was usually impossible. At some factories this was available for the Seafire as it made use of well developed capacity for Spitfire production. Equally damaging was the division of orders for a type between several firms. This was usually done when the monthly requirement was above a very modest figure. Only in the production of the Swordfish and the Seafire was a monthly output of fifty aircraft achieved from single factories.

*Peak Factory Output of Naval Aircraft**

Aircraft	*Under 40 a month*			*Over 40 a month*
Swordfish		20		58
Walrus	7	21		
Barracuda		30	34	43
Seafire	6		37	62
Firefly	10		35	

* Each number for each type is the peak output of a separate factory.

For four types of naval aircraft there was no division of orders. Only one factory was employed on each type: even so peak factory output was not generally above the average: Albacore 34, Fulmar 28, Sea Otter 13, Firebrand 14.

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(The suffix letter 'n' denotes a footnote)

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