NASA TECHNICAL
MEMORANDUM

NASA TM X-53723

April 16, 1968

NASA TM X-53723

A STUDY OF SATURN V AND INTERMEDIATE VEHICLE IMPROVEMENT PROGRAMS EXECUTIVE SUMMARY REPORT

by Robert Davies
Advanced Systems Office

NASA

George C. Marshall
Space Flight Center
Huntsville, Alabama

TECHNICAL MEMORANDUM X-53723

A STUDY OF SATURN V AND INTERMEDIATE VEHICLE IMPROVEMENT PROGRAMS EXECUTIVE SUMMARY REPORT

By

Robert Davies

ABSTRACT

The purpose of this report is to summarize the results of three companion studies designed to investigate both the performance growth potential of the Saturn V and the utilization of Saturn V equipment to fill the performance gap in the intermediate payload range between the Saturn IB and the Saturn V. This report includes significant data which is intended to aid the planning of future missions. This data reflects some of the various vehicle configurations which can be used by mission planners to satisfy payload desires in excess of the Saturn IB and Saturn V.

NASA — GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA — GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM X-53723

A STUDY OF SATURN V AND INTERMEDIATE VEHICLE IMPROVEMENT PROGRAMS EXECUTIVE SUMMARY REPORT

By

Robert Davies

ADVANCED SYSTEMS OFFICE
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
OBJECTIVES OF THE STUDY	2
METHOD OF APPROACH AND ASSUMPTIONS	3
Approach	3
1. Intermediate Payload Vehicles	3
a. S-II Ground-Launch Vehicle	3
b. S-IC Ground-Launch Vehicle	4
2. Uprated Saturn V Vehicle	4
a. Advanced Engine Application	4
b. Solid Motor Applications	4
c. Liquid Pod Applications	4
Assumptions	7
1. General	7
2. Fluid and Flight Mechanics	7
3. Resource	8
BASIC DATA GENERATED AND SIGNIFICANT CONCLUSIONS	8
Intermediate Payload Saturn Vehicles	10
1. S-II Ground Launch Vehicles	10
a. MLV SAT-INT-17	10
b. MLV SAT-INT-18.5	12
c. MLV SAT-INT-18.7	14
2. S-IC Ground Launch Vehicles	14
a. MLV SAT-INT-20	14
b. MLV SAT-INT-21	16

TABLE OF CONTENTS (Concluded)

Page

Uprated Saturn V Vehicles 16

1. Advanced Engines Application 16

   MLV SAT V-3B 16

2. Solid Motor Application 20

   a. MLV SAT V-4(S) B 20
   b. MLV SAT V-25(S) 23

3. Liquid Pod Application 25

   MLV SAT V-23 (L) 25

Facilities 27

1. Manufacturing 27

   a. MS-IC, MS-II, and MS-IVB 27
   b. Solid Rocket Motors 27

2. Test 27
3. Transportation 27
4. Launch 27

Performance 28

Resources 32

CONCLUSIONS AND RECOMMENDATIONS 34

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Saturn Improvement Program (FY-65 Funded Studies) MLV SAT V Intermediate Payload Configurations	5
2.	Saturn Improvement Program (FY-65 Funded Studies) MLV SAT V	6
3.	Standard SAT V	9
4.	MLV SAT-INT-17	11
5.	MLV SAT-INT-18.5	13
6.	MLV SAT-INT-18.7	15
7.	Intermediate Payload Vehicles S-IC/S-IVB and S-IC/S-II .	17
8.	MLV SAT-INT-20	18
9.	MLV SAT-INT-21	19
10.	MLV SAT V-3B	21
11.	MLV SAT V-4(S)B	22
12.	MLV SAT V-25(S)	24
13.	MLV SAT V-23(L)	26
14.	Intermediate Vehicles Circular Orbit Performance with Altitude Variation	29
15.	Circular Orbit Performance with Launch Azimuth Variation	30
16.	High Energy Performance	31

LIST OF TABLES

Table	Title	Page
I.	Reference Performance	28
II.	MLV Saturn V Summary Cost at Six Per Year, Dollars in Millions	32
III.	MLV Saturn-INT Summary Cost at Six Per Year, Dollars in Millions	33
IV.	MLV Saturn V Summary Cost at Two Per Year for Ten Years, Dollars in Millions	33
V.	MLV Saturn-INT Summary Cost at Two Per Year, Dollars in Millions	34

TECHNICAL MEMORANDUM X-53723

A STUDY OF SATURN V AND INTERMEDIATE VEHICLE IMPROVEMENT PROGRAMS EXECUTIVE SUMMARY REPORT

SUMMARY

The purpose of this report is to summarize the results of three companion studies designed to investigate the performance growth potential of the Saturn V and to investigate the potential of using Saturn V equipment to fill the payload gap between the Saturn IB and Saturn V launch vehicle.

This report includes significant data which is intended to aid the planning of future missions. The data reflect the various configurations of solid rocket motor (SRM) strap-ons, advanced engine adaptations, and rearrangement of standard stage.

This report lists five specific areas which are recommended for additional study effort.

INTRODUCTION

NASA is continuously investigating potential space mission applications subsequent to the Apollo manned lunar landing program. Certain proposed missions indicate a need or a desire for a vehicle with a payload capability greater than the present Saturn IB and less than that of the Saturn V (referred to in this report as an intermediate payload vehicle). Other proposed missions have payload requirements beyond that of the Saturn V launch vehicle. A series of study programs initiated and directed by NASA/MSFC during fiscal year 1964 and 1965 have been addressed to possible ways to modifying the present Saturn hardware in such a way as to satisfy the need for a wide payload range. This report summarizes the study contracts which were funded in FY-65.

Study contracts were established with each of the present Saturn stage contractors — The Boeing Company, NAS8-20266 ($ 400 000); North American Aviation, Inc., NAS8-20265 ($ 329 000); and Douglas Aircraft Company, NAS8-20264 ($ 96 730) — for investigation of the respective stage modifications. The first-stage contractor had the additional responsibility of being the "systems analysis" or "integration" contractor. The 10-month study program began December 6, 1965. At that time each of the three stage contractors began working on a coordinated schedule. These launch vehicle studies were coordinated with programs investigating advanced engine systems (Advanced Engine Aerospike by Rocketdyne and Advanced Engine Bell by Pratt and Whitney), solid rocket motors (NAS8-20398, United Technology Center), and required launch facility support (KSC contract NAS10-3547 with the Martin Company) for the modified launch vehicle programs. At the completion of these studies, a contract was implemented with International Business Machines, NAS8-21076, for a study of the astrionics impact of uprating the Saturn launch vehicle. The documents referenced are listed below:

The Boeing Company, NAS8-20266, D5-13183

North American Aviation, Inc., NAS8-20265, SID 66-1326

Douglas Aircraft Company, NAS8-20264 (Report Integrated into The Boeing and NAA Documents)

The Martin Company, NAS10-3547, CR-66-41

United Technology Center, NAS8-20398, UTC 5100-FR

International Business Machines, NAS8-21076-67-K44-0005.

The documents referenced in this report may be obtained from:

Scientific and Technical Information Facility
Attn: NASA Representative (S-AK/RKT)
P. O. Box 33
College Park, Maryland 20740

OBJECTIVES OF THE STUDY

The objectives of the study, using Saturn V equipment, were as follows:

1. To investigate the application of several selected methods by which an increase performance capability can be achieved;

2. To investigate methods of achieving payload capability between that of the Saturn IB and that of the Saturn V;

3. To determine necessary design changes and the resulting impact on the facility ground support equipment (GSE), cost and schedule estimates.

METHOD OF APPROACH AND ASSUMPTIONS

Approach

Studies of the vehicle configurations and associated modifications were conducted concurrently through contracts with the Saturn V stage contractors and launch facility-study contractors. Specified configurations were assigned to the stage manufacturers to establish and describe the complete vehicle system. The configuration description included performance capability, the complete vehicle and stage modification, vehicle/facility/GSE adaptation, and cost/schedule estimates for its introduction into flight test and operational use. The designated systems analysis contractor for a configuration was responsible for that configuration, e.g., stage interface, vehicle/facility interfaces, aerodynamics and flight performance analysis and vehicle trade studies. Each stage contractor performed supporting studies for the system analysis contractor.

The studies were divided into two phases: Phase I (the trade phase) was a 12-week investigation of candidate vehicle performance and preliminary cost trade studies to select a feasible and cost effective baseline vehicle in each category. Trade considerations were as follows:

1. Intermediate Payload Vehicles

a. S-II Ground-Launch Vehicle

(1) MLV SAT-INT-17: S-II plus S-IVB with advanced engines either bell or aerospike.

(2) MLV SAT-INT-18(S): S-II plus S-IVB with 120-inch diameter utilizing both 5- and 7-segment solid motors.

(3) MLV SAT-INT-19(MM): S-II plus S-IVB with varying number of Minute Man solid motors for boost assist. This configuration was dropped at the end of the trade phase.

b. S-IC Ground-Launch Vehicle

(1) MLV SAT-INT-20: S-IC plus S-IVB.

(2) MLV SAT-INT-21: S-IC plus S-II (standard 2-stage Saturn V).

2. Uprated Saturn V Vehicle

a. Advanced Engine Application

MLV Sat V-3B: Uprated F-1 engines plus advanced engines in the upper stages. The upper stages would be the INT-17 vehicle.

b. Solid Motor Applications

(1) MLV SAT V-4(S)B: 120-inch diameter 7-segment solid motors for boost assist.

(2) MLV SAT V-22(S): 120-inch diameter solid motors for boost assist with advanced engines in the upper stages. The upper stages would be the same as those on the MLV SAT V-3B or the INT-17. This configuration was dropped at the end of the trade phase.

(3) MLV SAT V-25(S): 156-inch diameter solid motors for boost assist.

c. Liquid Pod Applications

(1) MLV SAT V-23(L): liquid pods with standard engines for boost assist.

(2) MLV SAT V-24(L): liquid pods with uprated F-1 boost assist and advanced engines in the upper stages. The upper stages would be the same as those on the MLV SAT V-3B. This configuration was dropped at the end of the trade phase.

At the completion of the trade phase, five intermediate vehicles and four uprated Saturn V vehicles were selected for in-depth study during Phase II. Those configurations are shown on Figures 1 and 2.

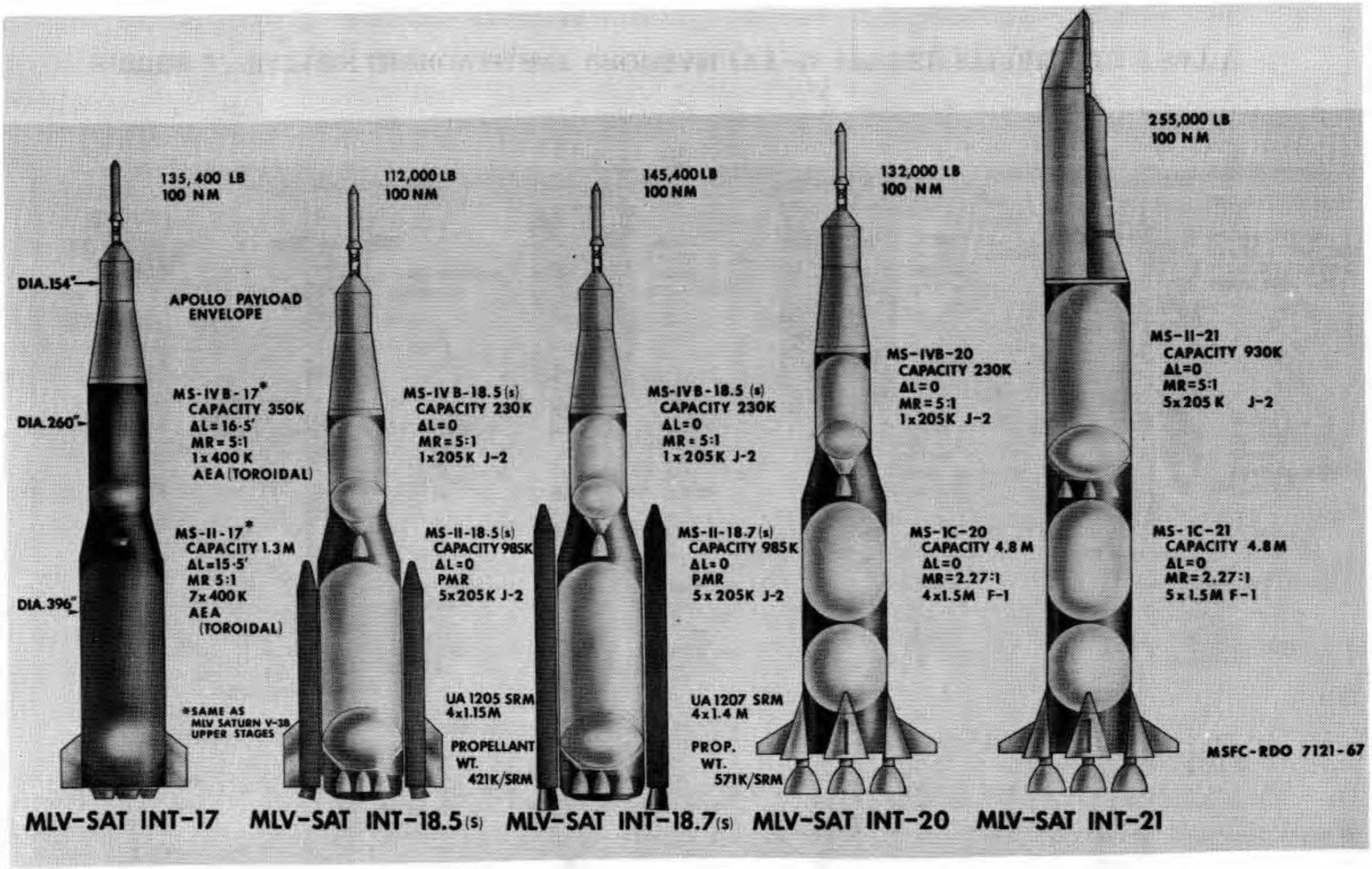


FIGURE 1. SATURN IMPROVEMENT PROGRAM (FY-65 FUNDED STUDIES)
MLV SAT V INTERMEDIATE PAYLOAD CONFIGURATIONS

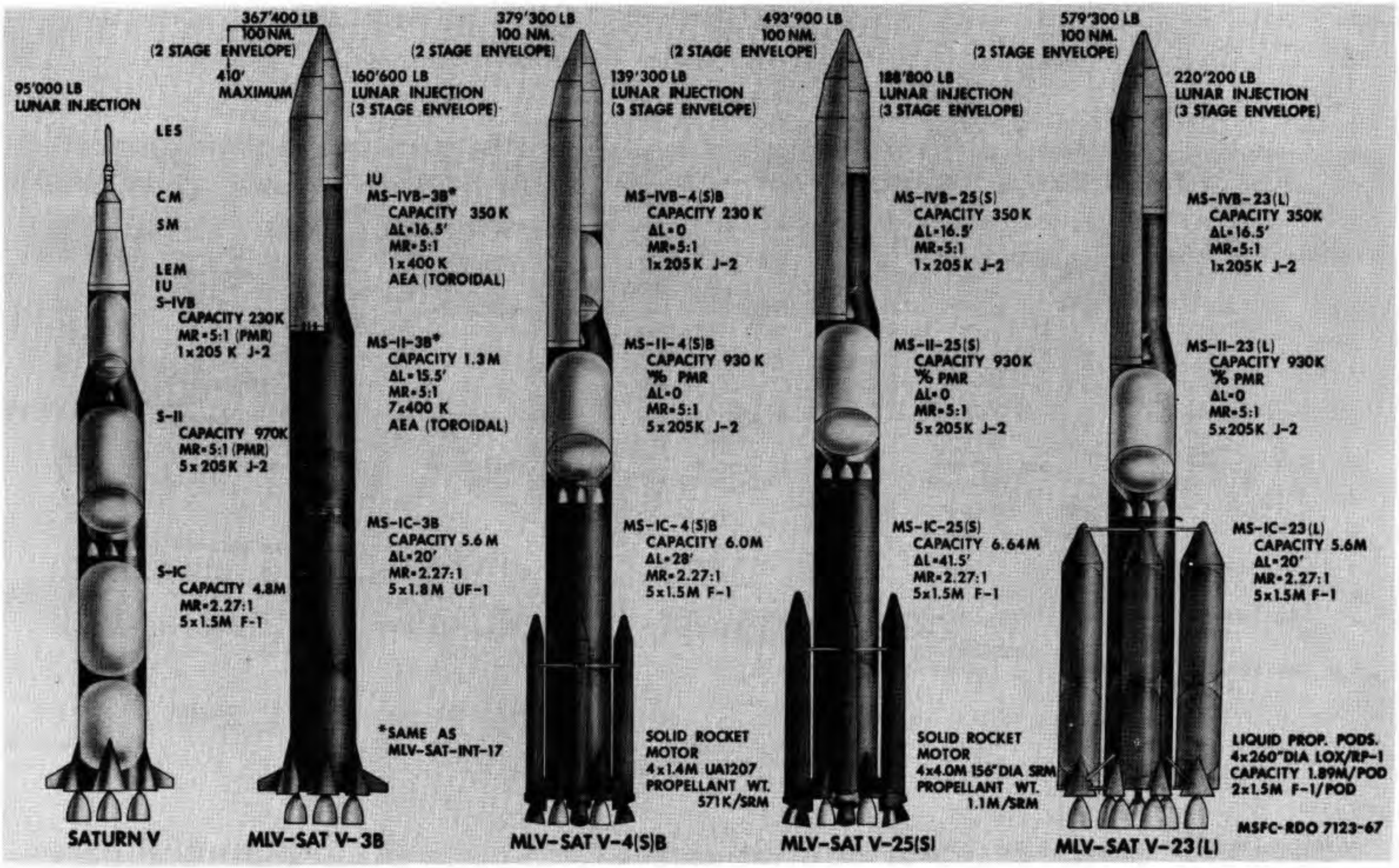


FIGURE 2. SATURN IMPROVEMENT PROGRAM (FY-65 FUNDED STUDIES) MLV SAT V

Assumptions

1. General

a. Baseline vehicle defined as AS-516;

b. Apollo design criteria used for all configuration;

c. S-II stage length not to exceed 15.5-foot extension, facility limitation;

d. S-IVB stage length not to exceed 16.5-foot extension, facility limitations;

e. Apollo-shaped payload assumed on intermediate vehicles;

f. Uprated Saturn V investigations used a constant diameter payload shape above the S-II stage for the two-stage application and above the S-IVB stage for the three-stage configuration.

2. Fluid and Flight Mechanics

a. Nominal mission profiles were:

(1) A circular orbit mission via direct ascent to 100 n. mi. altitude for all vehicles.

(2) For MLV SAT V vehicles, injection into a 72-hour lunar transfer trajectory after passing through a 100 n. mi. parking orbit.

b. Stage sizing, etc., for MLV SAT V vehicles, were selected as a compromise between the two nominal missions.

c. Flight performance reserve is 0.75 percent of total vehicle characteristic velocity in the last stage.

d. Nominal wind assumptions are consistant with Apollo wind restrictions.

3. Resource

a. Cost estimates are in 1966 dollars without inflationary factors;

b. There is no interference with Apollo Saturn program.

c. Earliest go-ahead for hardware will be January 1968, preceded by a 6-month program definition phase.

d. Funds are available as required.

e. Development program includes two flight test vehicles.

f. Operational program based on six vehicles per year for 5 years with a concurrent Saturn IB program.

BASIC DATA GENERATED AND SIGNIFICANT CONCLUSIONS

For a baseline, the contractors were instructed to use a document which identified an SA-516 configuration. Figure 3 gives some of the important features of this vehicle. This will provide a reference for the other configurations discussed in this document.

Additional data were given to and generated by the contractors pertaining to solid motors. A summary of the significant data pertaining to three types of solid motors used in this study are as follows:

1. A UA 1205, 120-inch SRM with 5 segments, has been developed for the Air Force's Titan III-C program. It has a length of 85 feet, a thrust of 1.15×10^6 pounds, propellant weight of 435 450 pounds, and an inert weight of 91 500 pounds. Thrust vector control (TVC) is obtained through the use of nitrogen tetraoxide (N_2O_4) secondary fluid injection.

2. A UA 1207, 120-inch SRM with 7 segments, is planned for development by the Air Force for the Titan III Manned Orbital Laboratory (MOL) program. It has a length of 108 feet and a thrust of 1.4×10^6 pounds with a propellant weight of 589 400 pounds and an inert weight of 98 100 pounds. TVC is obtained by using N_2O_4 for secondary fluid injection.

Vehicle Characteristics	
Lunar Transfer Payload 72 hr (lb)	95 000
Weight at Lift-Off (lb)	6 085 000
Launch Escape System	8200
Thrust/Weight	1.25
Max. Q (PSF)	766
Max. Axial Acceleration (g)	4.6
Instrument Unit	
Gross Weight (lb)	3847
3rd Stage	
Gross Weight (lb)	32 541
Propellant Weight (lb)	230 000
Thrust with one J-2 using LOX and LH_2 (lb)	205 000
2nd Stage	
Gross Weight (lb)	89 939
Propellant Weight (lb)	970 000
Thrust with five J-2 engines using LOX and LH_2 (lb)	1 025 000
1st Stage	
Gross Weight (lb)	286 324
Propellant Weight	4 560 000
Thrust with five F-1 engines using LOX and RP-1 (lb)	7 610 000

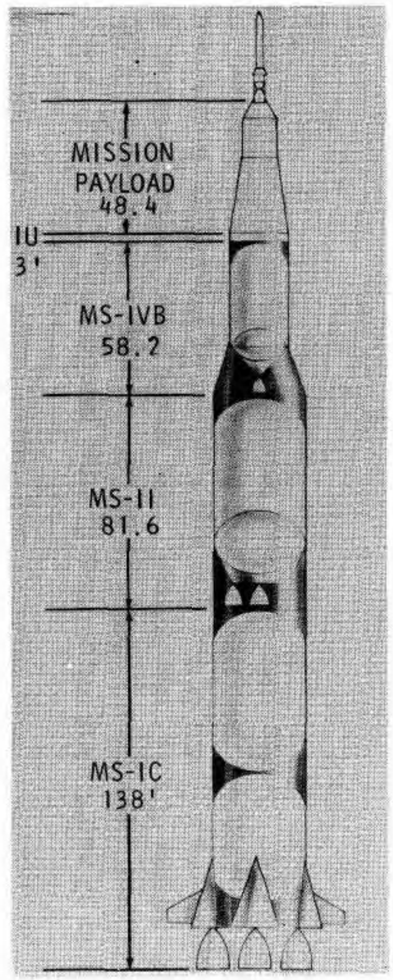


FIGURE 3. STANDARD SAT V

3. A 156-inch SRM was planned for development as a contender for the UA 1207 for the Titan III MOL program. The motor selected for use in this study had a length of 123 feet and a thrust of 4.0 million pounds with a propellant weight of 1 112 000 pounds. The motor burns regressively so that at burnout thrust has been reduced to 65 percent of the liftoff value. TVC is obtained by using N_2O_4 for secondary fluid injection.

Each type of uprating or derating in the case of the intermediate configurations imposed a unique set of characteristics and restrictions. Therefore, the data generated applies to the specified problems of each configuration. Comparisons of various modified vehicles with the baseline vehicle were made to measure and evaluate the increase in performance and the resulting required modification.

This section is divided into two parts: the intermediate payload class, and the uprated Saturn V vehicles.

Intermediate Payload Saturn Vehicles

The vehicles discussed in this section can feasibly fill the payload gap between the Saturn IB and the standard Saturn V vehicle. The vehicles are separated into two major classes: the S-II and the S-IC ground launched vehicles.

1. S-II Ground Launch Vehicles. These configurations utilize the S-II stage as the first stage of a two stage vehicle. Since the standard S-II stage of the S-II/S-IVB combination does not have sufficient thrust for a first stage application, additional thrust must be gained from some source other than the five J-2 engines. Two different techniques will be discussed herein: (1) replacement of the J-2 engine with an advanced engine and (2) using a solid motor for thrust augmentation.

a. MLV SAT-INT-17. The MLV SAT-INT-17 (Fig. 4) is a vehicle investigating the application of the advanced engines which were being studied under joint NASA/USAF funding and direction. Trade studies were performed to determine the desirability of either toroidal aerospike or high chamber pressure bell engines. Since the INT-17 is the S-II/S-IVB from the MLV SAT V-3B, trades had to be performed on both configurations and a compromise made between the desires of the S-II stage thrust level for a ground launch stage and the second stage application. The comparison and compromise will be discussed under the section pertaining to the MLV SAT V-3B.

Vehicle Characteristics	
Earth Orbit Payload to 100 n. mi. on 72° A_z (lb)	136 000
Weight at Lift-Off (lb)	1 967 000
Launch Escape System	8200
Thrust/Weight	1.19
Max. Q (PSF)	504
Max. Axial Acceleration (g)	4.2
Instrument Unit	
Gross Weight (lb)	3847
2nd Stage	
Gross Weight (lb)	40 907
Propellant Weight (lb)	350 000
Thrust (VAC) from one 400 000 lb thrust toroidal engine using LOX and LH_2 (lb)	400 000
1st Stage	
Gross Weight (lb)	122 370
Propellant Weight	1 200 000
Thrust (VAC) from seven 400 000 lb thrust toroidal engines using LOX and LH_2 (lb)	2 800 000

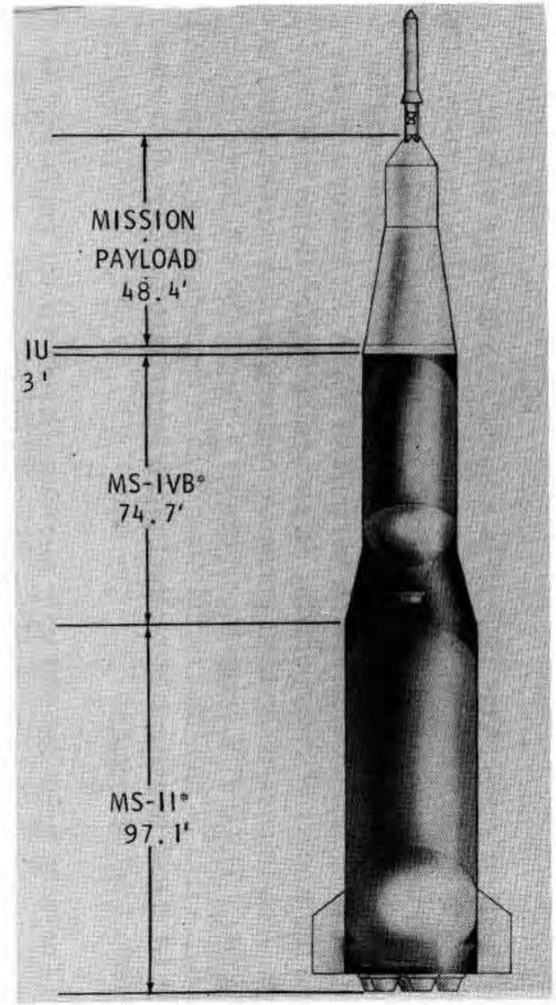


FIGURE 4. MLV SAT-INT-17

The first stage of the INT-17 is a modified S-II stage with an increase in length of 15.5 feet for a 24 percent gain in propellant capacity. The engines selected were seven toroidal aerospike engines which develop a total of 2.8 million pounds of thrust. The selection of the toroidal aerospike engine does not necessarily reflect a choice on the part of NASA but rather a desire to determine the impact of incorporating an aerospike engine in the S-II and S-IVB stage. The impact of the high pressure bell engine was investigated in the 1964 studies. The S-IVB stage incorporates a single 400 000 pound thrust aerospike engine that is identical to the ones used in the S-II stage. The S-IVB is elongated 16.5 feet to accept 52 percent more propellant to fully utilize the inertial thrust of the new engine.

Analysis indicates that only minimum thrust vector angle will be required when the control mode is using altitude, altitude rate, and normal velocity feed-back. However, in order to limit the engine gimbal to 6 degrees, stabilizing fins extending 7.5 feet from the mold line are required.

b. MLV-SAT-INT-18.5. The MLV-SAT-INT-18.5 (Fig. 5) is another in the ground launch S-II/S-IVB family. Four Titan III-C, UA-1205, 120-inch diameter 5-segment solid motor are utilized in a "zero stage" launch mode.

Revisions to the S-II stage for this configuration entail modifications to the forward skirt, redesign of the aft skirt, and a new base heat shield design. Structural modifications to the forward skirt encompass an increase in frame and skin gages to accept the additional loads imposed by the SRM forward attach struts. The new aft skirt design incorporates four stage hold-down pads and is designed to accept the maximum weight of the vehicle. The new base close-out heat shield is required to protect the core engine compartment for the first 70 seconds of flight. The new heat shield consists of fiberglass honeycomb and ablative cork which extends 59 inches aft of the J-2 nozzle exit plane and is separated prior to J-2 engine ignition.

The SRM s are separated after burnout by explosive separation nuts at each attachment and eight separation motors, four forward and four aft.

The control analysis indicated that the control mode using attitude, attitude rate, and normal acceleration feedback information requires the minimum thrust vector angle. However, to limit the thrust vector angle to the present capability of the solid motor, stabilizing fins extending 7 feet from the solid motor mold line are required.

Vehicle Characteristics

Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	114 000
Weight at Lift-Off (lb)	3 489 680
Launch Escape System	8 200
Thrust/Weight	1.31
Max. Q (PSF)	520
Max. Axial Acceleration (g)	5.0

Instrument Unit

Gross Weight (lb)	3847

2nd Stage

Gross Weight (lb)	33 064
Propellant Weight (lb)	230 000
Thrust with five J-2 engines using LOX and LH_2 (lb)	205K

1st Stage

Gross Weight (lb)	97 030
Propellant Weight (lb)	985 000
Thrust with five J-2 engines	1025K

Strap-On Motors

Gross Weight (lb)	2 066 060
Propellant Weight (lb)	1 742 600
Total Thrust (lb)	4 600 000

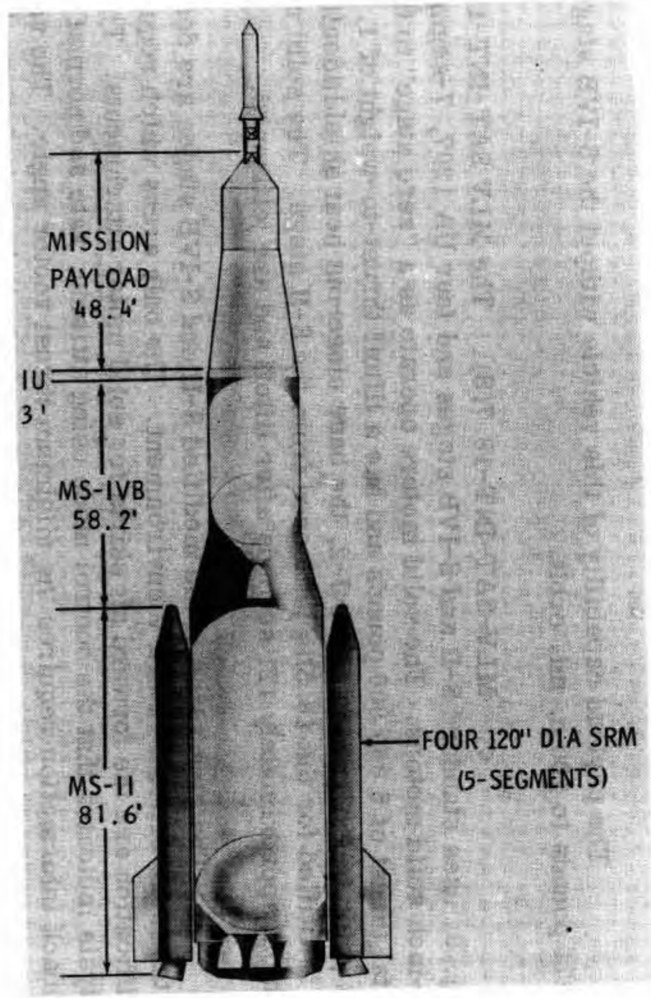


FIGURE 5. MLV SAT-INT-18.5

The payload capability of this vehicle without the S-IVB stage is 82 871 pounds to 100 n. mi. orbit.

c. MLV-SAT-INT-18.7(S). The MLV SAT-INT-18.7(S) (Fig. 6) uses standard S-II and S-IVB stages and four UA 1207, 7-segmented 120-inch solid motors. The solid motors operate as a "zero stage" to deliver a total thrust of 5 600 000 pounds and has a liftoff thrust-to-weight of 1.34. Just prior to the ignition of the J-2, the base close-out heat shield(identical to the one identified for the 18.5)is jettisoned from the S-II stage. The solid motors burn out approximately 121 seconds after liftoff and are jettisoned.

The structures of the modified S-II and S-IVB stages are designed for the more critical Saturn V environment. The only areas which required modification are the forward aft skirts for solid motor attachments. The analysis indicates that the control mode using attitude, rate and normal velocity feedback information requires the minimum thrust vector angle. The vehicle (without stabilizing surfaces)has satisfactory control characteristics. The required nominal thrust vector angle in a peak wind condition is 3.72 degrees, and the root sum square (RSS) value for dispersions from nominal is 4.31 degrees. The payload capability of this vehicle is 145 400 pounds. For the same mission, the payload capability without the second stage MS-IVB-18.7(S) is 118 000 pounds.

2. <u>S-IC Ground Launched Vehicles</u>. These configurations are two-stage vehicles using the S-IC stage as the first stage and either the S-II (INT-21) or the S-IVB (INT-20) as the second stage. In order to minimize the modifications to the vehicle the axial acceleration was limited to 4.68g's which is the present design limit for the Saturn V.

Control requirements are below those of the existing Saturn V; aerodynamic heating has increased slightly for both the INT-20 and INT-21 but is still within existing design criteria requiring no additional protection.

a. MLV SAT-INT-20 (S-IC/S-IVB). Three variations of the INT-20 were considered for the trade study each having a standard S-IVB stage but modified for either three, four or five F-1 engines in the first stage. The standard five-engine S-IC version, even though launched at a thrust to weight ratio of 1.25, depletes first stage propellant rapidly; therefore, it reached structural load limit at about 88 seconds and three engines had to be shutdown. The resulting payload is not significantly better than the four-engine configuration.

Vehicle Characteristics

Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	145 000
Weight at Lift-Off (lb)	4 181 500
Launch Escape System	8200
Thrust/Weight	1.34
Max. Q (PSF)	616
Max. Axial Acceleration (g)	5.0

Instrument Unit

Gross Weight (lb)	3847

2nd Stage

Gross Weight (lb)	33 064
Propellant Weight (lb)	230 000
Thrust with one J-2 engine using LOX and LH_2 (lb)	205K

1st Stage

Gross Weight (lb)	96 070
Propellant Weight	985 000
Thrust with five J-2 engines	1025K

Strap-On Motors

Gross Weight (lb)	2 729 320
Propellant Weight (lb)	2 357 500
Total Thrust (lb)	5 600 000

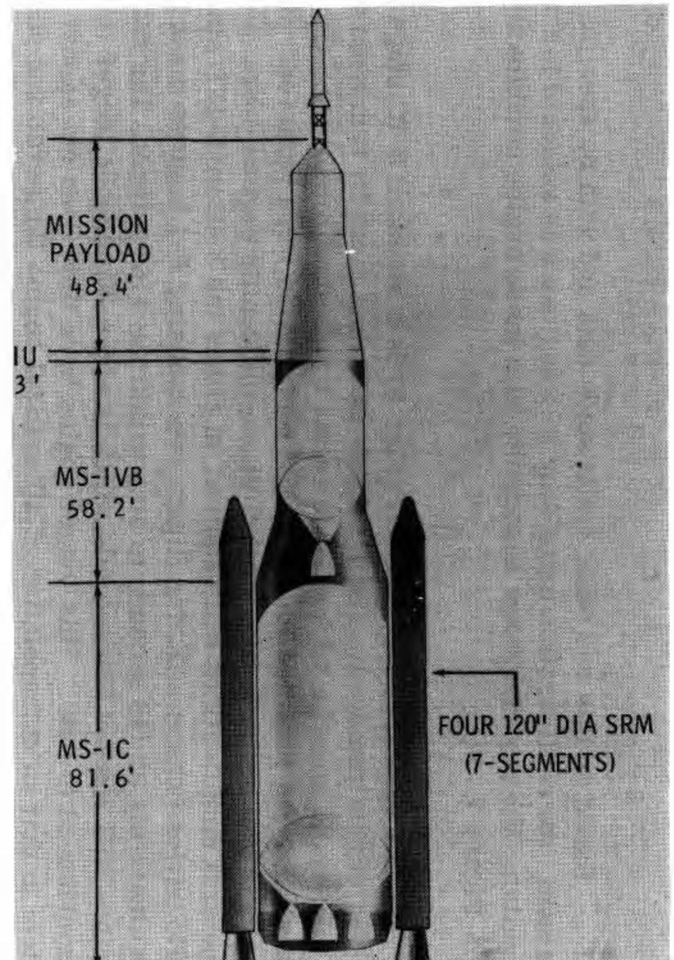


FIGURE 6. MLV SAT-INT-18.7

Based on this and other trade study data and with no specific payload requirement, the configuration using four F-1 engines was selected for detailed investigation. The payload range associated with these engine combinations is shown in Figure 7.

The baseline configuration (Fig. 8) is a standard S-IC stage with the center F-1 engine removed. The insolated LOX duct must be removed; then the center duct spool must be supported to retain cross-feed capability. Cover plates and seals close the LOX and fuel bulkhead where lines were removed. Heat shield panels and supports are located where the center engines were mounted. No structural modifications are required on either the S-IC or S-IVB stage with an Apollo payload shape. During flight, two opposing F-1 engines must be shut down prematurely at 146 seconds to stay within the 4.68 g limit. The remaining two engines will run for 210 seconds which is some 20 seconds longer than has been experienced to date. This longer engine burn time does not appear to be a problem in that an extrapolation of all critical engine temperatures shows the engine to be within design limits. The removal of the F-1 engine and the S-II stage has only minor impact on the IU.

b. ·MLV SAT-INT-21 (two-stage Saturn V). The trade study for INT-21 was accomplished without exceeding the structural limits of the stages. The number of engines was varied from three to five in both stages and the payloads associated with these engine combinations are shown in Figure 7. The selected vehicle (Fig. 9) consisted of a standard S-IC first stage and a standard S-II second stage.

Uprated Saturn V Vehicles

No specific mission requirements were established for this study; therefore, the payload capabilities of the uprated vehicles represent a reasonable growth and not necessarily the maximum payload attainable. The advanced engine, solid motor, and liquid pod applications were the three approaches for uprating the Saturn V which were investigated.

1. Advanced Engines Application

MLV SAT V-3B. The two advanced technology liquid-oxygen/liquid hydrogen engine concepts, considered for the intermediate payload INT-17 and the uprated Saturn V vehicles, were the high chamber pressure bell and toroidal chamber/aerodynamic spike designs. The engines operate over a mixture ratio range of from 5:1 to 7:1. The engine designs also provide throttling to 3 percent of maximum thrust for alternate vehicle applications.

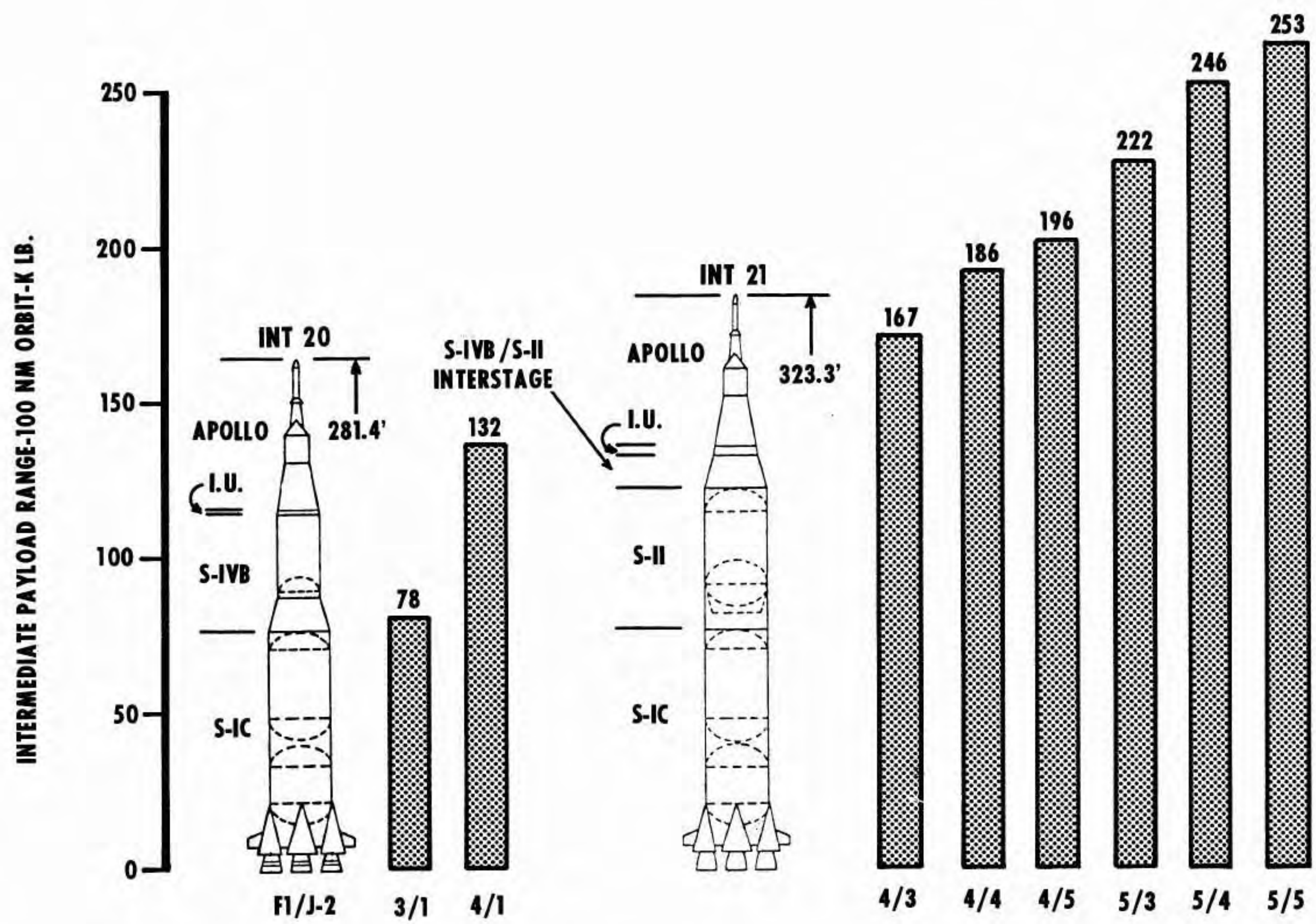


FIGURE 7. INTERMEDIATE PAYLOAD VEHICLES S-IC/S-IVB AND S-IC/S-II

Vehicle Characteristics

Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	131 300
Weight at Lift-Off (lb)	4 870 400
Launch Escape System	8200
Thrust/Weight	1.23
Max. Q (PSF)	764
Max. Axial Acceleration (g)	4.68

Instrument Unit

Gross Weight (lb)	3847

2nd Stage

Gross Weight (lb)	31 328
Propellant Weight (lb)	230 000
Thrust with one J-2 engine using LOX and LH_2 (lb)	205K

1st Stage

Gross Weight (lb)	266 450
Propellant Weight	4 129 241
Thrust with five F-1 engines	6000K

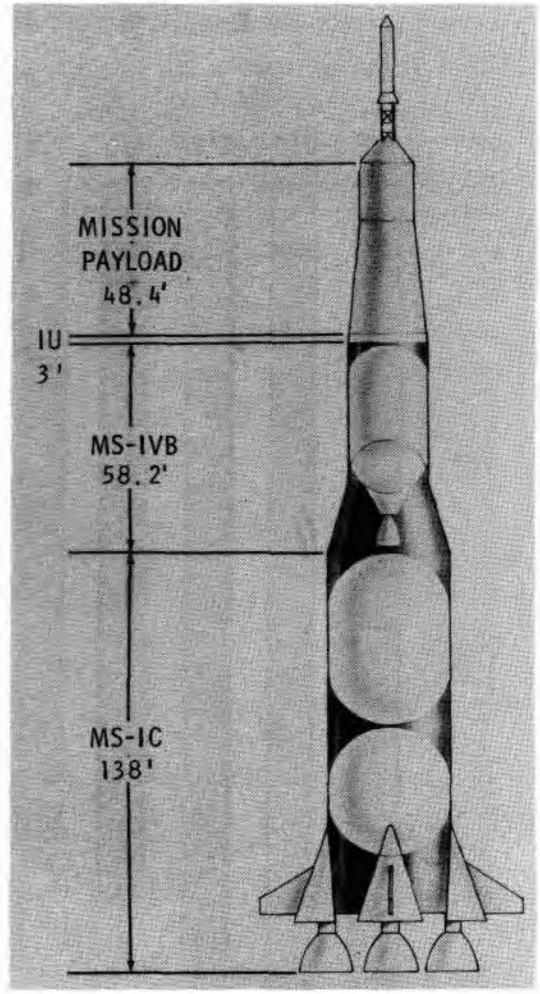


FIGURE 8. MLV SAT-INT-20

Vehicle Characteristics

Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	255 142
Weight at Lift-Off (lb)	6 088 000
Launch Escape System	8200
Thrust/Weight	1.24
Max. Q (PSF)	760
Max. Axial Acceleration (g)	4.68

Instrument Unit

Gross Weight (lb)	3847

2nd Stage

Gross Weight (lb)	92 759
Propellant Weight (lb)	929 730
Thrust with five J-2 engines using LOX and LH_2 (lb)	1025K

1st Stage

Gross Weight (lb)	289 139
Propellant Weight	4 419 469
Thrust with five J-2 engines	7500K

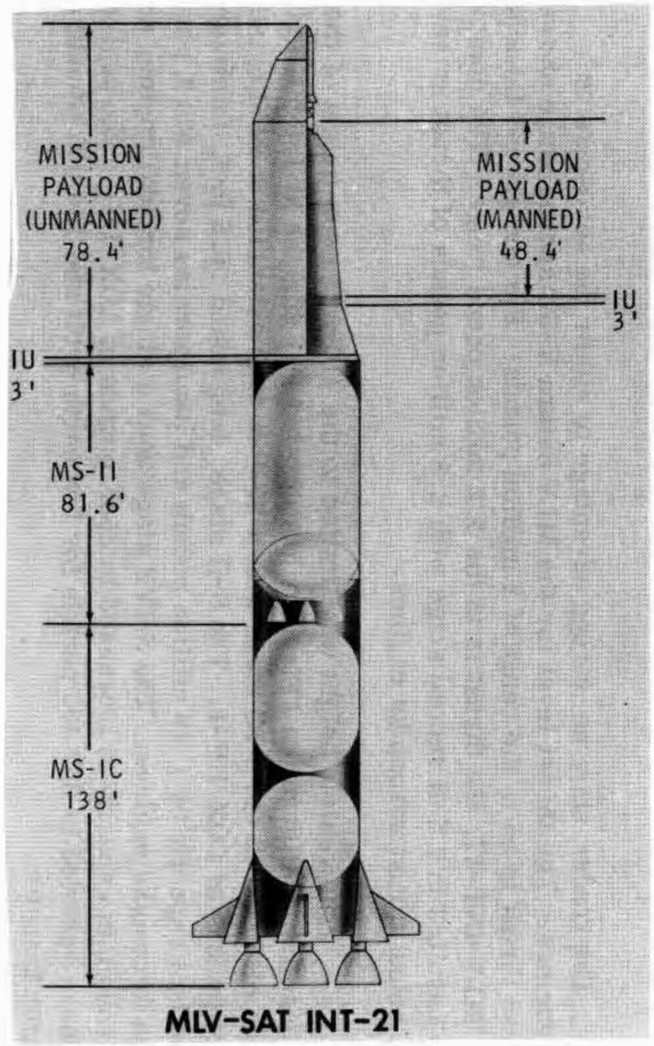


FIGURE 9. MLV SAT-INT-21

The trades show no strong advantage to either the aerospike or bell engines. The thrust level for the MLV Saturn V-3B second stage shows the desired thrust to be in the range of 2 million pounds. For the ground launched S-II, MLV-INT-17, the thrust is in the 3.2 million pound range. The compromise resulted in a S-II second stage with 2.8 million pounds of thrust or seven 400K pound thrust aerospike engines.

The vehicle height was limited to the 410-foot hook-height of the VAB. The baseline configuration (Fig. 10) has uprated F-1 engines at 1.8 million pounds of thrust in the S-IC stage with a 20-foot tank extension to accommodate 5.6 M pounds of LOX/RP-1. The S-II stage, lengthened 15.5 feet, increases the propellant capacity by 1.29 million pounds and incorporates seven 400 K pound thrust aerospike engines. The S-IVB stage uses a single toroidal engine, and its propellant capacity is increased to 350K pounds of LOX/LH_2. The payload for these vehicles is 367 400 pounds for low earth orbit and 160 000 pounds for 72-hour transfer.

The maximum dynamic pressure and acceleration are slightly less for the SAT V-3B vehicle than the Standard Saturn V. The increased height of the payload and increased engine thrust have significantly increased the structural loading, and major structural strengthening is required.

2. Solid Motor Application

a. MLV SAT V-4(S) B. This vehicle incorporates four of the 120-inch-diameter solid motors which are planned for use in the Titan III program. During the trade phase the vehicle was optimized for best performance by investigating 5-, 6-, and 7-segment motors while varying the propellant capacity in all stages. The thrust to weight was held at a constant 1.25. The selected vehicle (Fig. 11) incorporates standard length S-II and S-IVB stages with a 28-foot longer S-IV stage. The 120-inch rocket motors contain seven segments which conform to the preliminary design developed by United Technology Center for the Titan III-M application. Each motor has an initial sea level thrust of 1.4 million pounds and a propellant weight of 579 000 pounds. Each motor has a liquid injection N_2O_4 thrust vector control system to supplement the control capabilities of the gimballed F-1 engine during flight through the maximum dynamic pressure (q) regime. The liquid core stages are equipped with standard F-1 and J-2 engines. The first stage of the vehicle is rotated 45 degrees from its position in the standard Saturn V configuration to minimize the impact on launch facilities and operations.

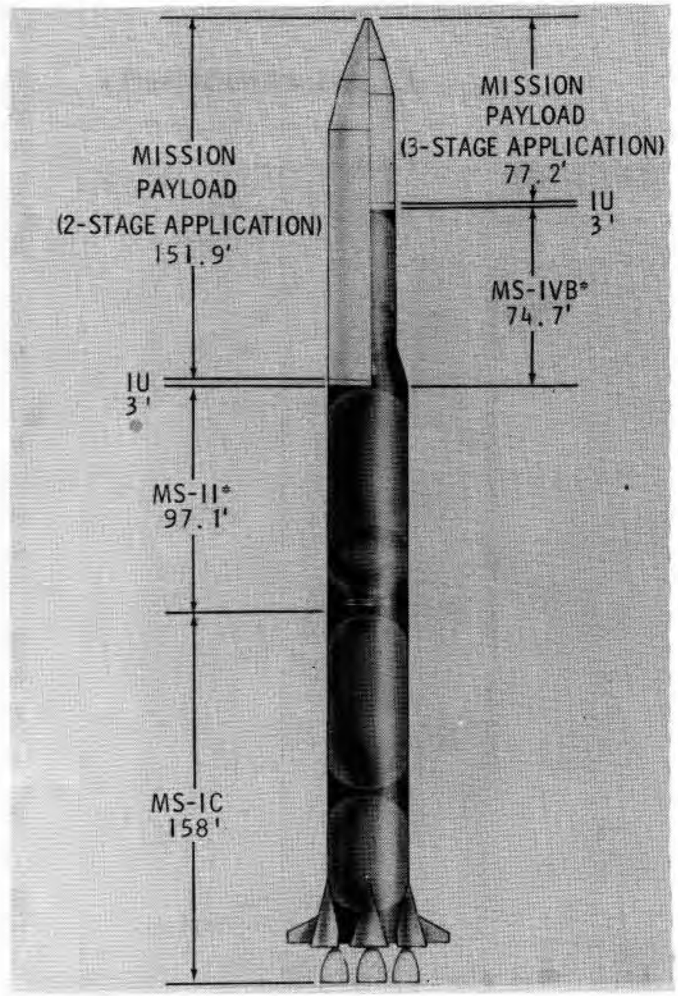
Vehicle Characteristics	
Lunar Transfer Payload 72 hr (lb)	160 300
Two Stage Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	368 600
Weight at Lift-Off (lb)	7 200 000
Launch Escape System	8200
Thrust/Weight	1.25
Max. Q (PSF)	735
Max. Axial Acceleration (g)	4.3

Instrument Unit	
Gross Weight (lb)	3780

3rd Stage	
Gross Weight (lb)	40 907
Propellant Weight (lb)	350 000
Thrust with one Aerospike engine using LOX and LH_2 (lb)	400K

2nd Stage	
Gross Weight (lb)	110 970
Propellant Weight (lb)	1 292 270
Thrust with seven Aerospike engines using LOX and LH_2 (lb)	2800K

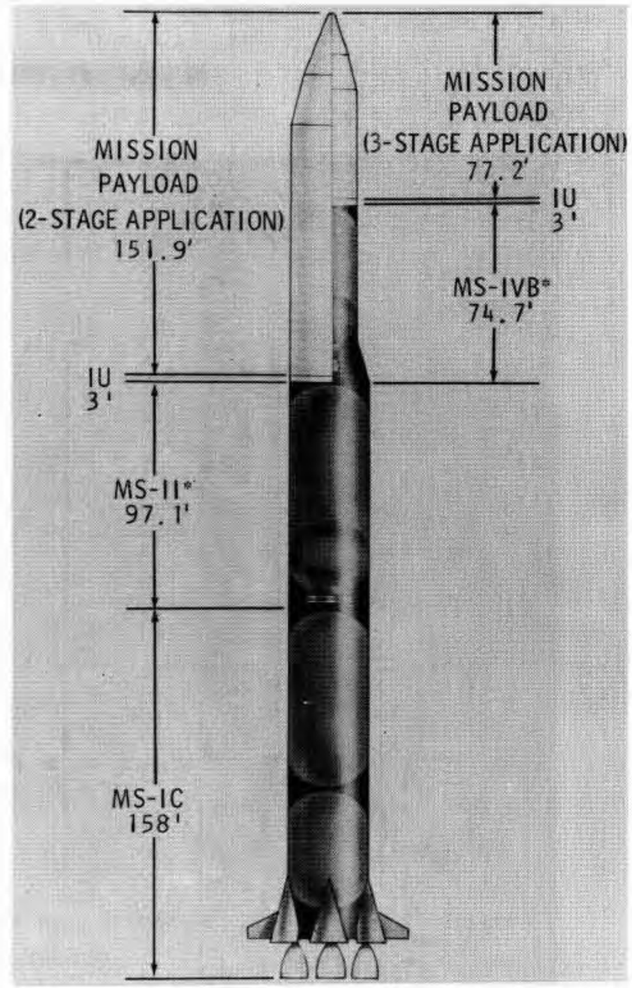
1st Stage	
Gross Weight (lb)	328 945
Propellant Weight	4 793 427
Thrust with five F-1 engines using LOX and RP-1 (lb)	9 000 000



* SAME AS ON SAT - INT - 17

FIGURE 10. MLV SAT V-3B

Vehicle Characteristics	
Lunar Transfer Payload 72 hr (lb)	138 500
Two Stage Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	373 900
Weight at Lift-Off (lb)	10 535 517
Launch Escape System	8200
Thrust/Weight	1.26
Max. Q (PSF)	610
Max. Axial Acceleration (g) .	4.6
Instrument Unit	
Gross Weight (lb)	3847
3rd Stage	
Gross Weight (lb)	37 446
Propellant Weight (lb)	230 000
Thrust with one J-2 using LOX and LH_2 (lb)	205K
2nd Stage	
Gross Weight (lb)	94 245
Propellant Weight (lb)	930 000
Thrust with five J-2 engines using LOX and LH_2 (lb)	1 025 000
1st Stage	
Gross Weight (lb)	318 000
Propellant Weight	6 000 000
Thrust with five F-1 engines using LOX and RP-1 (lb)	7 610 000
Strap-On Motors	
Gross Weight (lb)	2 750 000
Propellant Weight (lb)	2 357 500
Total Thrust (lb)	5.6M



* SAME AS ON SAT - INT - 17

FIGURE 11. MLV SAT V-4(S) B

The aerodynamic heating indicator (AHI) at 653 000 foot-pounds is 18 percent below the maximum AHI for the Saturn V. The shock wave from the solid motor nose cap may inpinge on the first stage near the intertank and local insulation may be required.

The base heating environment is more severe than for the Saturn V because of the solid motor exhaust. Selected heat shield materials can withstand the 2200°F temperatures. A base heat shield will be required for each of the solid motors. The aft solid motor attachment skirt will reach 2480°F and will require additional protection.

The combined loads are approximately 60 percent higher than those for the standard Saturn V and the acoustic specification limits are exceeded at several locations. Although maximum q and acceleration are reduced, compared to the Saturn V, the 410-foot vehicle height and the 33-foot diameter two-stage payload has considerable impact on structural design requirements. These structural modifications cause a dry weight increase: the MS-IC stage 13.9 percent, the MS-II stage 8.6 percent, and the MS-IVB stage 11.8 percent.

b. MLV SAT V-25(S). The MLV SAT V-25(S) is a Saturn V vehicle which has been modified to accept four 156-inch diameter SRM's. The number of segments in the solid motors was varied between two and four.

The selected configuration (Fig. 12) maintained standard Saturn V engine systems in all stages; however, the S-IC and S-IVB stages were modified for a larger propellant capacity. The S-IC stage length was increased 41.5 feet with a resulting propellant loading capability of 6.64 million pounds. The S-IC stage for the SAT V-25(S) stage was also rotated 45 degrees to minimize the launch impact upon the vehicle. The length of S-IVB was increased by 16.5 feet to accommodate 350 000 pounds of LOX/LH_2. Each of the four solid motors contain three segments (4.45 million pounds of propellant) with a burn time of 100.6 seconds. Each of the solid motors has a liquid injection (N_2O_4) thrust vector control system to augment the capability of the gimballed F-1 engines for 26 seconds near the maximum time of flight. The vehicle height was limited to the 410-foot hook-height in the VAB, and the payload is 493 900 pounds and 188 800 pounds for the two and three stage capability, respectively.

Aerodynamic heating is significantly lower than that of the Saturn V. However, the shock wave from the solid motor nose cap may impinge on the first stage LOX tank requiring local insulation.

Vehicle Characteristics	
Lunar Transfer Payload 72 hr (lb)	188 800
Two Stage Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	493 900
Weight at Lift-Off (lb)	13 614 645
Launch Escape System	8200
Thrust/Weight	1.72
Max. Q (PSF)	8.33
Max. Axial Acceleration (g)	4.3
Instrument Unit	
Gross Weight (lb)	4193
3rd Stage	
Gross Weight (lb)	42 575
Propellant Weight (lb)	350 000
Thrust with one J-2 using LOX and LH_2 (lb)	205K
2nd Stage	
Gross Weight (lb)	94 245
Propellant Weight (lb)	930 000
Thrust with five J-2 engines using LOX and LH_2 (lb)	1025K
1st Stage	
Gross Weight (lb)	379 504
Propellant Weight	6 634 810
Thrust with five F-1 engines using LOX and RP-1 (lb)	7 510 000
Strap-On Motors	
Gross Weight (lb)	4 967 596
Propellant Weight (lb)	4 448 000
Total Thrust (lb)	16 000 000

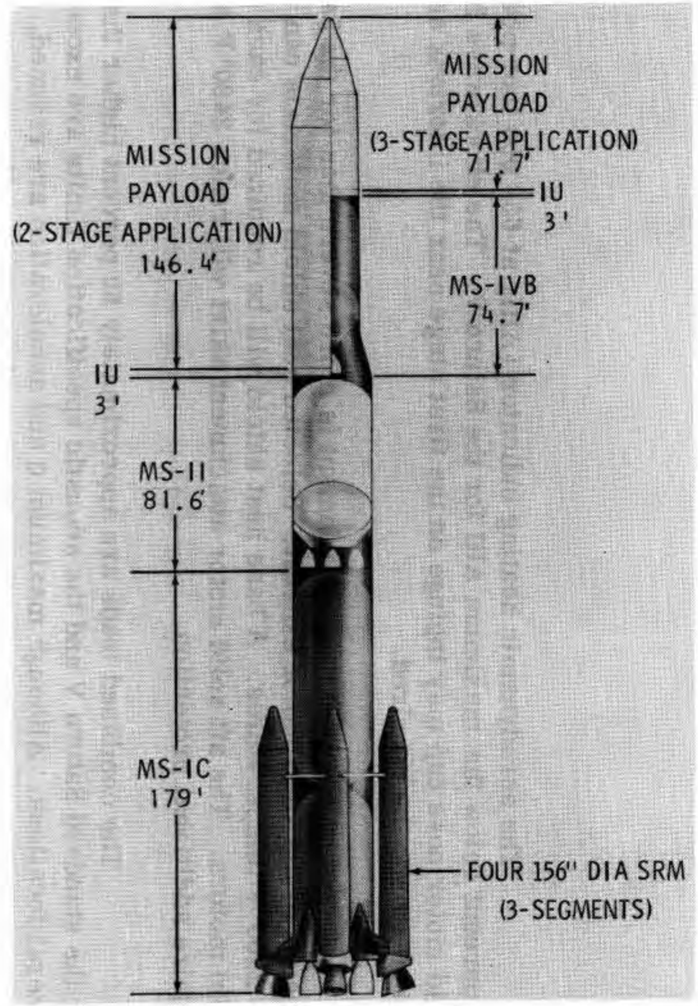


FIGURE 12. MLV SAT V-25(S)

The base heating environment is more severe for the SAT V-25(S) than for the standard Saturn V because of the solid motor exhaust plumes and will require additional heat shield material. The aft solid motor attachment skirt will reach 1950°F and will require additional insulation.

Structural loads and acoustic environment are greater than the design loads for the standard Saturn V requiring an increase in structural strength/weight.

3. Liquid Pod Application

MLV Saturn V-23(L). The MLV Saturn V-23 (L) vehicle is a modified Saturn V vehicle with four liquid propellant pods, LOX and RP-1, for boost assist; each of the pods uses two standard F-1 engines. During the trade phase, the propellant capacity of the S-IC stage varied as did the propellant capacity, diameter and length of the pod. The vehicle selected (Fig. 13) during the trade phase incorporated a third stage (which was lengthened by 16.5 feet), a standard length second stage, and a first stage which was lengthened by 20 feet. The 131-foot long pod is attached to the MS-IC-23(L) into position with the outboard engines using S-IC technology, and systems structural concepts. Each pod is an independent stage which can be checked out and test fired as a single unit.

Control for the MLV-SAT V-23(L) requires a gimbaling of the four outboard engines on the core vehicle and all eight of the engines in pods. The maximum gimbal requirement during maximum q flight is 4.1 of the available 5.15 degrees.

Combined structural loads have increased substantially and result in dry weights which are approximately 23 percent higher than those for AS-516.

The Aerodynamic heating of the S-IC forward skirt has increased from 167°F, for the standard vehicle to 215°F because of the shock wave from the pod nose cones. This increased temperature is not a major problem.

Base heating of S-IC increased from 1700°F to 2200°F. Heat shield material which can withstand this temperature is obtainable through current technology.

Vehicle Characteristics	
Lunar Transfer Payload 72 hr (lb)	220 200
Two Stage Earth Orbit Payload (lb) to 100 n. mi. on A_z of 72°	579 300
Weight at Lift-Off (lb)	15 828 800
Launch Escape System	8200
Thrust/Weight	1.25
Max. Q (PSF)	792
Max. Axial Acceleration (g)	6.4
Instrument Unit	
Gross Weight (lb)	4111
3rd Stage	
Gross Weight (lb)	41 539
Propellant Weight (lb)	350 000
Thrust with one J-2 using LOX and LH_2 (lb)	205K
2nd Stage	
Gross Weight (lb)	96 715
Propellant Weight (lb)	930 000
Thrust with five J-2 engines using LOX and LH_2 (lb)	1025K
1st Stage	
Gross Weight (lb)	373 141
Propellant Weight	5 594 810
Thrust with five F-1 engines using LOX and RP-1 (lb)	7 600 000
Strap-On Motors	
Gross Weight (lb) (4)	487 816
Propellant Weight (lb)	7 538 621
Total Thrust (lb)	12 160 000

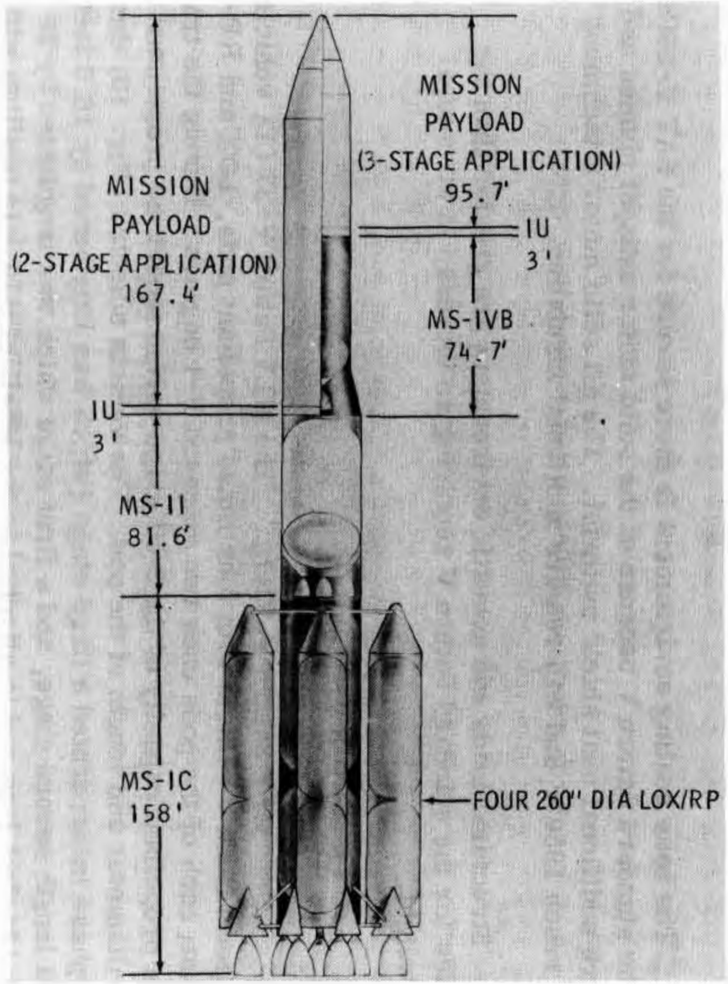


FIGURE 13. MLV SAT V-23(L)

Facilities

1. Manufacturing

a. MS-IC, MS-II, and MS-IVB. The vehicle improvement changes will not adversely affect the basic manufacturing and quality control procedures which were established for manufacturing the standard stages. Major facility changes are necessary for the longer stages and for special equipment to manufacture thicker tanks, interstages and thrust structures.

b. Solid Rocket Motors

(1) 120-inch: Existing facilities for both 1205 and 1207 SRM's will satisfy the programs assumed for this study.

(2) 156-inch: Since this stage will constitute a new start, manufacturing and assembly facilities have not been solicited for the stage-associated equipment. The nature of the required components and assembly procedures are within the capability of current technology.

2. Test. Static test facilities for the stages with increased length and/or thrust require modification to accommodate the increased length and/or thrust of the stage. Dynamic test facilities will require modification to enable testing of stages with strap-ons and varied length.

3. Transportation. Existing modes of transportation will be used for the uprated configuration. The equipment must be modified to accept both the heavier weight and extended length. The only exception is those configurations with a longer S-IVB stage. The super Guppy cannot be modified to accept these longer stages; they must be shipped by seagoing barge in the same manner as the S-II stage.

4. Launch. Modifications will be required at Kennedy Space Center's (KSC) Complex 39 for all configurations presented in this report. There is a direct relationship between the size of the vehicle and the extent of the necessary modifications. The impact upon the launch facility is reflected in the cost summary (Resources). Investigation of the launch impact was conducted by the Martin Company under NASA Contract NAS10-3547 (with KSC); results of the study can be found in the following report.

Study of Improved Saturn Launch Facilities
Report No. Martin CR-66-41
The Martin Company/Denver Division, December 1966

Performance

Results of the trajectory analysis are given in Table I. Reference trajectories for the candidate vehicles were determined using the following mission profile:

1. AMR launch azimuth of 72 degrees;

2. Direct injection into 100 n. mi. circular orbit for all two-stage vehicles;

3. Lunar transfer is accomplished through 100 n. mi. parking orbit.

TABLE I. REFERENCE PERFORMANCE

CONFIGURATION	PAYLOAD		$(T/W)_{LO}$	MAX Q (PSF)	a_x MAX (g)
	100 n. mi.	Lunar Transfer			
AS5 16	—	95 000	1.25	766	4.68
MLV SAT-INT-17	136 000	—	1.19	504	4.20
MLV SAT-INT-18.5	114 000	—	1.31	520	5.00
MLV SAT-INT-18.7	145 000	—	1.34	616	5.00
MLV SAT-INT-20	131 300	—	1.23	764	4.68
MLV SAT-INT-21	255 000	—	1.24	760	4.68
MLV SAT-V-3B	367 400	160 300	1.25	735	4.30
MLV SAT-V-4(S) B	379 300	139 300	1.26	610	4.60
MLV SAT-V-25(S)	493 000	188 800	1.72	833	4.30
MLV SAT-V-23(L)	579 300	220 200	1.25	792	6.40

Payloads at various circular orbits altitudes and launch azimuth variations are given in Figures 14 and 15, respectively. Performance curves for the configurations for high energy missions are presented in Figure 16.

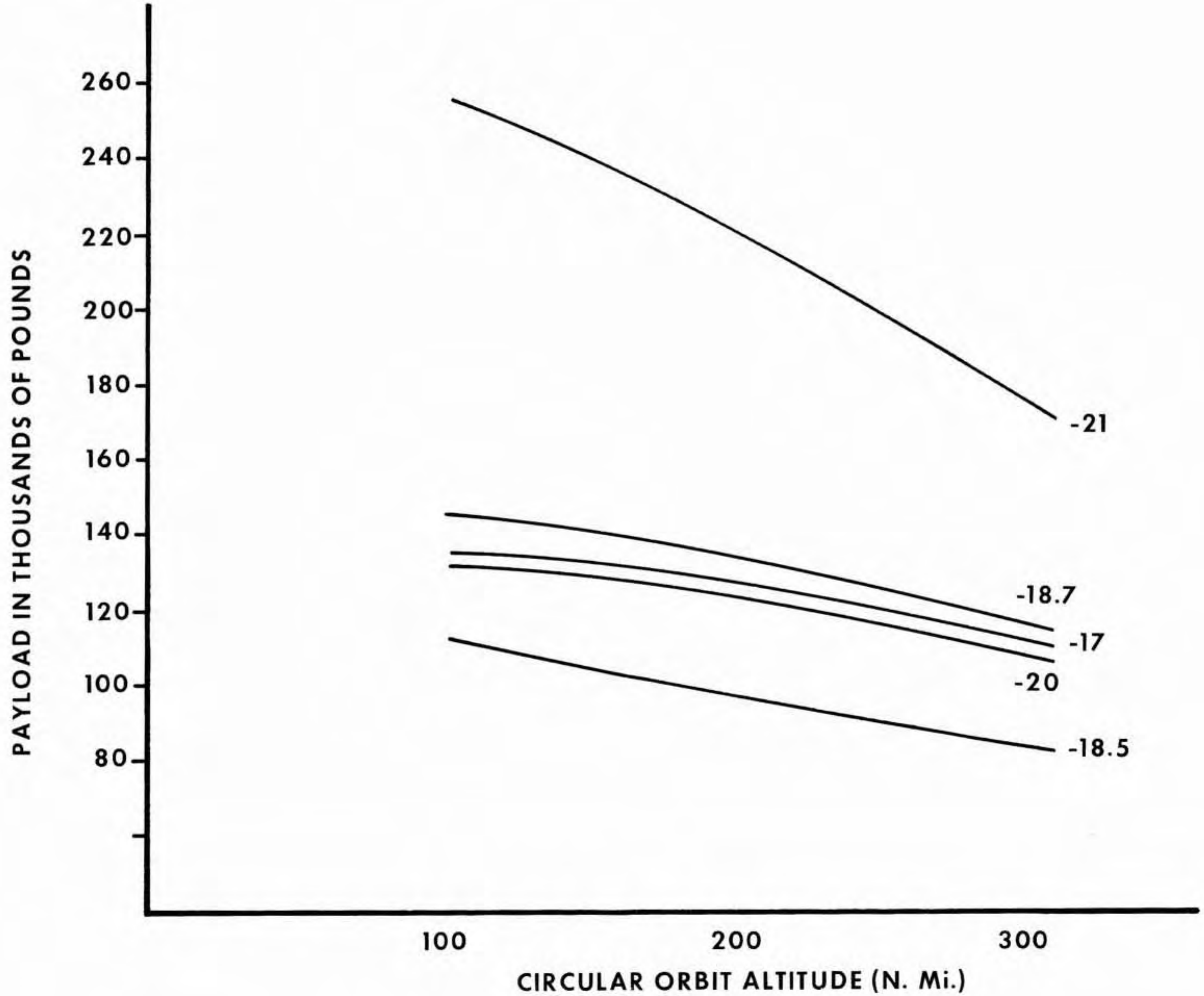


FIGURE 14. INTERMEDIATE VEHICLES CIRCULAR ORBIT PERFORMANCE

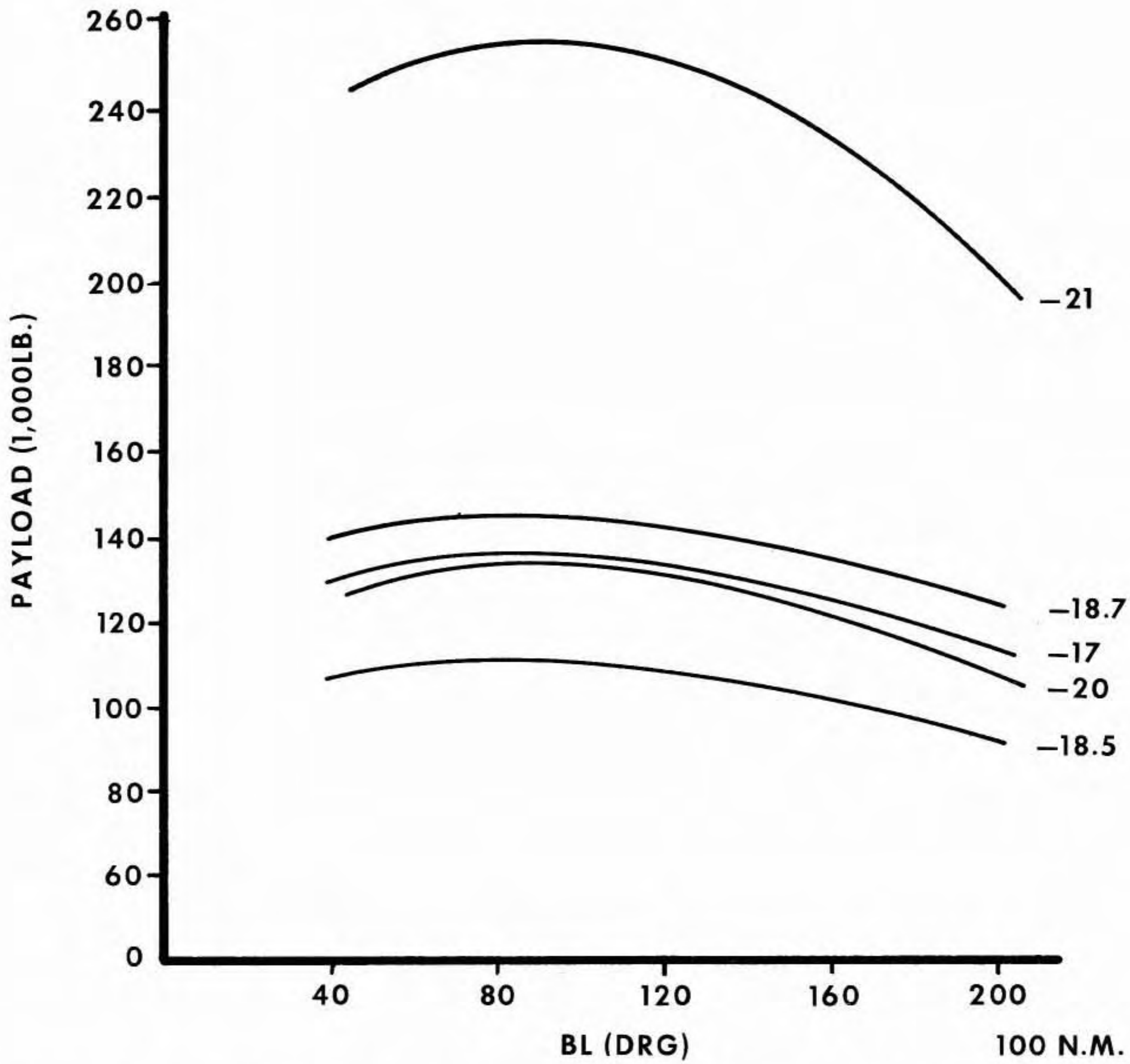


FIGURE 15. CIRCULAR ORBIT PERFORMANCE WITH LAUNCH AZIMUTH VARIATION

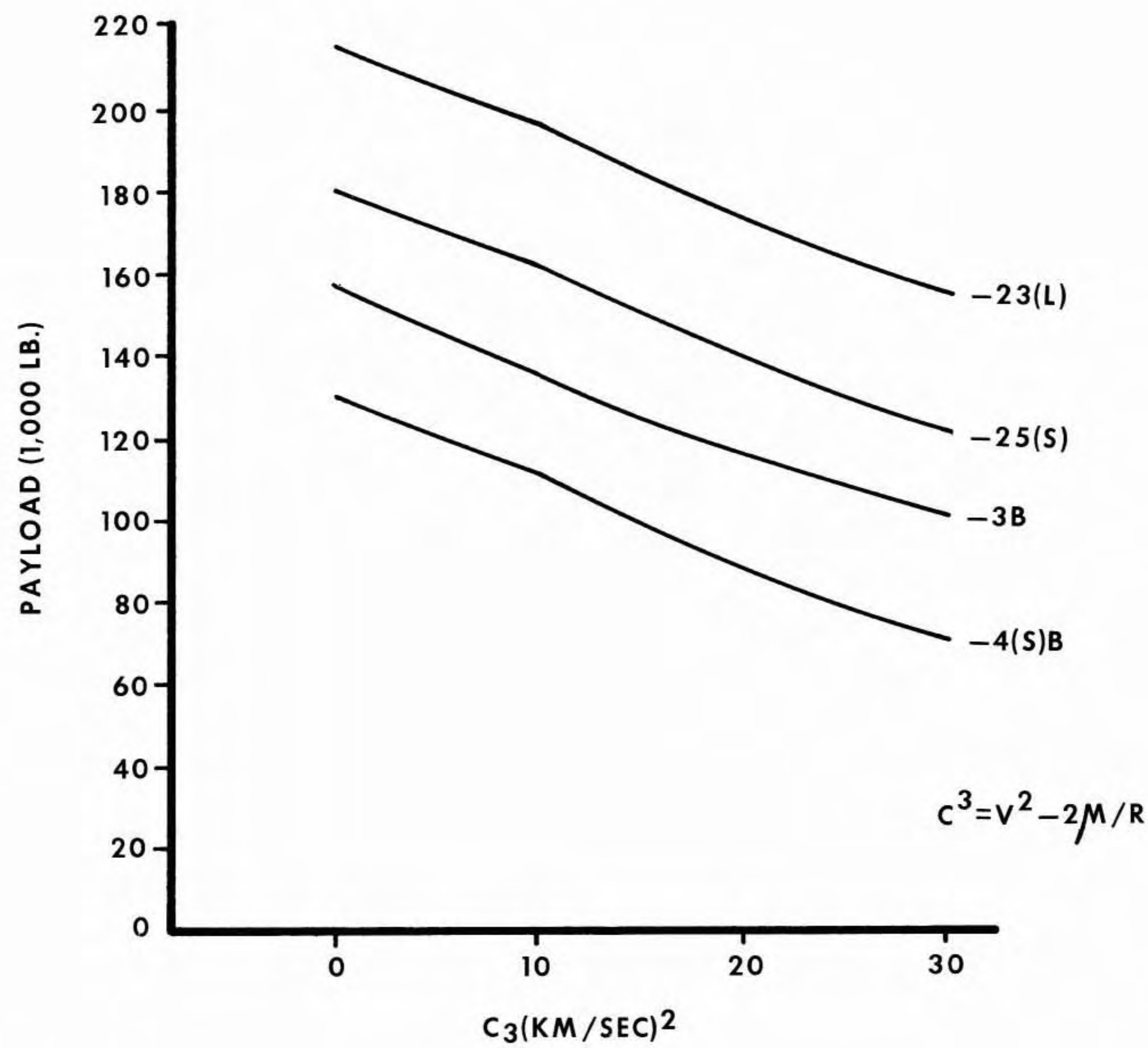


FIGURE 16. HIGH ENERGY PERFORMANCE

Resources

Table II and III list the Design, Development, Test and Engineering (DDT& E) Facilities and Operational cost for the uprated Saturn V and Intermediate programs which were developed to support a launch rate of six vehicles per year for 10 years. It is recognized that the proposed launch rate is optimistic; therefore, Tables IV and V were developed to give an indication of how a more realistic launch rate of two vehicles per year for 10 years would compare.

TABLE II. MLV SATURN V SUMMARY COST AT SIX PER YEAR, DOLLARS IN MILLIONS

MLV	-3B	-4(S)B	-25(S)	-23(L)
DDT& E	1 015.9	254.3	410.6	731.7
Launch Facilities	81.7	177.3	192.5	213.2
Total Investment	1 097.6	431.6	603.1	944.9
Two R& D Vehicles, Launched	299.0	312.0	322.0	390.0
Total Development	1 396.6	743.6	925.1	1 334.9
Total Operational	8 980.0	9 374.0	9 681.0	11 719.0
Total Program	10 376.6	10 117.6	10 606.0	13 053.9
Average Operational Cost Launched	150	156	161	195
Payload Lunar Injection	160 300	139 300	188 800	220 000
Pacing Element	Advanced Engines	MS-IC	MS-IC	MFR Facilities
Availability (Months from ATP)	70	42	43	64
Note: Production Rate Based on Six Per Year for 10 Years.				

TABLE III. MLV SATURN-INT SUMMARY COST AT SIX PER YEAR, DOLLARS IN MILLIONS

MLV	-17	18.5	-18.7	-20	-21
DDT&E	77.8	100.5	105.4	35.8	40.4
Launch Facilities	73.7	145.4	144.6	121.7	123.5
Total Investment	151.5	245.9	250.0	157.5	163.9
Two R&D Vehicles, Launched	226.0	219.0	221.0	178.0	235.0
Total Development	377.5	464.9	471.0	335.5	398.9
Total Operational	6765.0	6545.0	6610.0	5321.0	7042.0
Total Program	7142.5	7009.9	7081.0	5656.5	7440.9
Average Operational Cost Launched	108	109	110	89	117
Payload 100 n. mi.	136 000	114 000	145 000	131 300	255 000
Pacing Element	Advanced Engine	MS-II	MS-II	MS-IC	516
Availability (Months from ATP)	70	24	24	24	24
Note: Production Rate Based on Six Per Year for 10 Years					

TABLE IV. MLV SATURN V SUMMARY COST AT TWO PER YEAR FOR TEN YEARS, DOLLARS IN MILLIONS

MLV	-3B	-4(S) B	-25(S)	-23(L)
DDT&E	1 015.9	254.3	410.6	731.7
Launch Facilities	81.7	177.3	192.5	213.2
Total Investment	1 097.6	431.6	603.1	944.9
Two R&D Vehicles, Launched	545.0	582.0	611.0	652.0
Total Development	1 642.6	1 013.6	803.1	1 596.9
Total Operational	5 456.0	5 822.0	6 109.0	6 521.0
Total Program	7 098.6	6 835.6	6 912.1	8 117.9
Average Operational Cost Launched	273	291	306	326
Payload (LOR) 100 n. mi.	160 300	139 300	188 800	220 200
Pacing Element	Advanced Engines	MS-II	MS-II	MFR. Facilities
Availability (Months from ATP)	70	42	43	64

TABLE V. MLV SATURN-INT SUMMARY COST AT TWO PER YEAR, DOLLARS IN MILLIONS

MLV	-17	-18.5	-18.7	-20	-21
DDT&E	77.8	100.5	105.4	35.8	40.4
Launch Facilities	73.7	145.4	144.6	121.7	123.5
Total Investment	151.5	245.9	250.0	157.5	163.9
Two R&D Vehicles, Launched	337.0	403.0	405.0	351.0	415.0
Total Development	488.5	648.9	655.0	508.5	578.9
Total Operational	3 367.0	4 030.0	4 052.0	3 509.0	4 154.0
Total Program	3 855.5	4 433.0	4 457.0	3 860.0	4 569.0
Average Operational Cost Launched	168	202	204	175	208
Payload 100 n. mi.	136 000	114 000	145 000	131 300	255 000
Pacing Element	Advanced Engines	MS-II	MS-II	MS-16	516
Availability (Months from ATP)	70	24	24	24	24
Note: Production rate based on two per year for 10 years					

It should be noted that the Int-17 has assumed the development of the advanced toroidal aerospike engine and all associated upper stage modifications necessary to accommodate these engines for the MLV SAT V-3B.

CONCLUSIONS AND RECOMMENDATIONS

Study results confirm that it is feasible to increase the payload of the Saturn V vehicle by the use of uprated and advanced engines, and by strapping on both SRM and liquid pods to provide boost assist. The investigation of standard Saturn V stages to fill the payload gap between the Saturn IB and Saturn V also verified the configuration studies to be feasible. Each uprated configuration offers mission flexibility in that the modifications give the capability of constant diameter payload above either the second or third stage. Maximum use of the Saturn hardware has been achieved. The studies have provided essential material in the area of vehicle configuration, performance, facilities, and cost. This report is intended to aid the planning of future missions.

It is recommended that the following areas be investigated:

1. Mission applications to establish a meaningful evolutionary approach for Saturn improvement;

2. Instrument unit impact and modification;

3. Aerodynamic data analysis and evaluation;

4. Launch facility impact for a vehicle with strap-on SRM's; and

5. Onboard checkout system as a method of product improvement, time savings device, and method of reducing cost.

APPROVAL

TM X- 53723

A STUDY OF SATURN V AND INTERMEDIATE VEHICLE IMPROVEMENT PROGRAMS EXECUTIVE SUMMARY REPORT

By Robert Davies

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

W. G. Huber
Chief, Vehicle and Systems Analysis Office

F. L. Williams
Director, Advanced Systems Office

DISTRIBUTION

INTERNAL

DIR

F&D-CH
Mr. Schulze

F&D-PT
Mr. Hirshburg

R-AERO-X
Mr. Scott

R-AERO-AD
Mr. Andrews

R-ASTR-A
Mr. Digesu
Mr. Wiesenmaier

R-QUAL-T
Mr. McFolin

R-P&VE-P
Mr. Paul
Mr. Miller
Mr. McCarty

R-P&VE-A
Mr. Goerner
Mr. Barker
Mr. Corcoran
Mr. Heyer
Mr. Orillion

R-P&VE-S
Mr. Zimmerman

PAT

MS-T (6)

MS-IP

MS-IL (8)

MS-H

I-RM-M

R-TEST-C
Mr. Verschoore

R-EO-DIR
Dr. Johnson

R-TO-DIR
Mr. Richard

R-AS-DIR
Mr. Williams
Mr. Becker

R-AS-M
Mr. Dannenberg
Mr. von Tiesenhausen
Mr. Harris
Mr. Hamby

R-AS-S
Mr. Huber
Mr. Spears
Mr. Crawford
Mr. Rutledge
Mr. Sharpe
Mr. Page (25)

R-AS-RD
Mr. Payne (3)

DISTRIBUTION (Concluded)

I-DIR
Dr. Mrazek

I-E-E
Mr. Thomas

I-E-T
Mr. Mitchell

I-S/AA
Mr. Belew

EXTERNAL

Manned Spacecraft Center
Library

Lewis Research Center
Library

Kennedy Space Center
Library

Langley Research Center
Library

Ames Research Center
Library

Goddard Space Flight Center
Library

Jet Propulsion Laboratory
Library

NASA Headquarters
National Aeronautics and Space Administration
Washington 25, D. C.
Attn:

Mr. Tischler (RP/A)
Mr. Cohen (RPM)
Mr. Gomersall (OART/MAD)
Mr. McGlorick (SV)
Mr. Schnyder (MTV)
Col. Burke (MTV) (15)
Mr. Fero (MLC)
Mr. Bumgardner (MLT)

USS-10
Library

Electronics Research Center
Library

Flight Research Center
Library

Bellcomm
Library

Scientific and Technical Inf. Facility (25)
Attn: NASA Rep. (S-AK/RKT)
P. O. Box 33
College Park, Maryland 20740