SAT V GROWTH AND FLEXIBILITY

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Summary

This paper summarizes work conducted under a recent NASA study contract and Boeing studies on improved Saturn V vehicles and intermediate payload Saturn vehicles. The contractual study was a part of a continuing effort by NASA to identify a spectrum of practical launch vehicles to meet potential future payload and mission requirements as they become defined.

Certainly, two of the problems which face space program planners are: (1) the large gap in launch vehicle capability between the uprated Saturn I (40,000 pounds in low-Earth orbit) and Saturn V (262,000 pounds in low-Earth orbit), and (2) the possible need for larger payload capability than Saturn V for more ambitious objectives than the lunar landing. Vehicles studied provide a range of payload capability which extends well into both problem areas. The vehicles are combinations of existing or modified Saturn V stages; some vehicles also included boost-assist components. Vehicle performance, availability, investment costs, and cost efficiency (dollars per pound of payload in orbit) were used as significant evaluation criteria.

To fill the intermediate payload gap, the study evolved a concept of using the Saturn V's S-IC/S-IVB and S-IC/S-II stage combinations, removing engines for several of the vehicles to maximize cost efficiency. Ten stage/engine combinations result which could be implemented through a single modest R&D expenditure approximately ten percent greater than required for just one of the vehicles. NASA would then have the flexibility of selecting the vehicle matching payloads which materialize in the "intermediate" range.

Uprated vehicles studied provided payloads up to 960,000 pounds to a 100 nautical mile low-Earth orbit. However, existing facility limitations which were study ground rules (maximum stage and vehicle height) restricted the maximum payload to 579,000 pounds. All of the configurations studied were feasible and logical configurations for their respective payload capabilities. Comparisons of uprating methods generally favored the solid motor strap-on method because of availability and cost efficiency considerations.*

Symbols

ATP	Authorization-to-Proceed
INT	Intermediate Payload Class Vehicle
K	Thousand
ΔL	Length Change
LOR	72-Hour Lunar Transfer Trajectory
LOX	Liquid Oxygen
M	Million
MILA	Merritt Island Launch Area
ML	Mobile Launcher
MR	Stage Propellant Mixture Ratio
MS-IC	Modified First Stage of the Saturn V
MS-II	Modified Second Stage of the Saturn V
MS-IVB	Modified Third Stage of the Saturn V
MTF	Mississippi Test Facility
NM	Nautical Miles
P/L or P_L	Payload
SEG	Segment
SRM	Solid Rocket Motor
STG	Stage
T_o	Liftoff Thrust
T/W_o	Liftoff Thrust-to-Weight
W_{P1}	Propellant Weight of First Stage
W_{P2}	Propellant Weight of Second Stage
W_{P3}	Propellant Weight of Third Stage
W_{ps}	Propellant Weight of Solid Rocket Motors
W_{pp}	Propellant Weight of Liquid Propellant Rockets
ρ	Density

*Costs quoted are primarily for comparative purposes and are not to be construed as actual costs.

Intermediate Launch Vehicles

Figure 1 illustrates the intermediate launch vehicles studied. The INT-20 is a combination of the Saturn V S-IC and S-IVB stages. The INT-21 combines the Saturn V S-IC and S-II stages. Each of the ten stage/engine configurations could be used to efficiently launch payloads in increments between 36,000 pounds and 255,000** pounds to a 100 nautical mile Earth orbit at a nominal T/W_o of 1.25.

The maximum acceleration limit of the Saturn V (4.68 g's) can be increased to 6 g's for the INT-20 configurations with minimal change to the S-IC and S-IVB stages. This results in a significant payload increase for several versions as illustrated in Table I and Figure 4.

To provide complete launch vehicle flexibility to match payload weights between those listed, each vehicle's payload capability may be increased further by loading additional propellant down to minimum T/W's. Conversely, propellant can be used to lower each vehicle's payload capability by employing early engine cut-off (unused fuel becomes ballast).

Data were generated for the candidate INT vehicles covering the following: (1) weight and mass characteristics, (2) trajectories and performance, (3) aerodynamics and heating, (4) vehicle control, (5) design loads, and (6) separation. A summary of INT-20 and INT-21 launch, propellant, and payload weights is shown in Table I.

All INT-20 and -21 vehicles are flown essentially within existing design limitations, therefore, modifications are minimal. For example, the manner in which a four-engine S-IC is achieved is illustrated on Figure 2. The center LOX duct is removed, but it is necessary to retain the center duct spool to retain cross-feed capability. Cover plates and seals close the LOX and fuel bulkheads where lines are removed. Heat shield panels and supports from other locations replace those used where the engine was mounted. Conversely, the stage could readily be returned to the Saturn V configuration. The S-IVB (INT-20) second stage requires adaptation of its aft interface to the S-IC. An S-IVB/S-II interstage is used to adapt to the instrument unit and payload for the INT-21.

Performance data were developed for the four F-1 -20 version and the largest -21 intermediate for numerous missions. The nominal mission was direct ascent to a 100 nautical mile circular Earth orbit with a liftoff thrust-to-weight of 1.25 and a launch azimuth of 70 degrees. Alternate missions considered a range of orbit altitudes and launch azimuths as illustrated by Figure 3.

Facilities to accommodate these vehicles are affected only at Cape Kennedy where service towers, mobile launcher, and vertical assembly buildings require relocation of servicing connection equipment or work platforms for the shortened (compared with Saturn V) intermediate vehicles.

Availability of the INT-20 and INT-21 vehicles is two years from authority to proceed which is only one month additional from that required to order the current Saturn V stages.

Total R&D dollars to introduce these variations of Saturn V are likewise minimal at $45M* for 8/year total production and launch of Saturn V plus INT vehicles or only $14.6M* for 6/year total production of Saturn V plus INT versions. The difference is due only to the additional production facilities required for the additional 2/year launches.

Figures 4 and 5 summarize the INT vehicle investigations. Figure 4 illustrates the incremental payload steps available by implementing the ten versions of the INT-20 and INT-21 vehicles. An unmanned payload first launch of the INT-20 is recommended prior to man-rating this composite of two previously man-rated stages. This flight is shown and costed in Figure 5 as an R&D flight. The operational unit costs* shown cover procurement of stages and engines, maintenance of Ground Support Equipment and facilities, transportation, launch operations, propellant, and launch system refurbishment. These costs lead to operational payload cost efficiency estimates of 458 dollars per pound of payload for the INT-20 (4 F-1, 4.68 g limit version) and 292 dollars per pound of payload for the INT-21 (5 F-1, 5 J-2 version). A sample calculation for INT-20 cost efficiency follows:

PAYLOAD - 10^3 lbs. 100 NM Orbit	132K
TOTAL OPERATIONAL COST (30 Vehicles + Launch Operations)	$1814.4M
UNIT OPERATIONAL COST = $\frac{1814.4}{30}$ =	$60.5M
OPERATIONAL COST EFFICIENCY = $\frac{\$60.5M}{132K\ LBS}$ =	458 $/LB P_L

Uprated Vehicles

To examine Saturn V growth for more ambitious missions beyond the lunar landing, three general methods were examined: 1) Solid Rocket Motor (SRM) Boost Assist, 2) Advanced Engines, and 3) Liquid Rocket Boost Assist. Each was studied in sufficient depth to allow detailed comparison of significant capabilities and characteristics. Figure 6 summarizes the categories and variations studied. In all cases, the maximum vehicle height was limited to 410 feet by existing facility restrictions (Vertical Assembly Building limit at Cape Kennedy). In determining vehicle height, a maximum payload density of 5 pounds per cubic foot and 11 pounds per cubic foot for the two- and three-stage configuration, respectively, was used.

Solid Rocket Motor (SRM) Boost Assist

Uprating the Saturn V with thrust augmentation from solid rocket motors (SRM) using basic and/or modified Saturn V components was studied. In the analysis of the 120-inch or 156-inch diameter motors both number of motors and their size were variables. In some cases, advanced upper stage engines were examined in the core vehicle.

**This value and henceforth in this paper all performance will be referenced to nominal T/W_o vehicles and without PMR (programmed mixture ratio) which is presently used in Saturn upper stages. Performance quoted will, therefore, be approximately 3% conservative from that which could actually be predicted.

Three basic configurations were studied (see Figure 6): 1) The V-4(S)B vehicle used modified Saturn V stages with standard engines and four 120-inch diameter strap-on SRM's, 2) the V-22(S) used a modified S-IC stage with standard F-1 engines, a modified S-II stage with advanced engines, a modified S-IVB stage (where applicable) with an advanced engine*** and four 120-inch diameter SRM's and, 3) the V-25(S) used modified Saturn V stages with standard engines and four 156-inch diameter SRM's.

All three configurations experience increased (from Saturn V) loads from the 410 foot vehicle height coupled with the 33-foot diameter two-stage payload shape and increased lift-off thrust. Major structural beefup is required on all stages to take the increased loads.

First stage control requirements of these vehicles necessitates additional control beyond the present gimbal capability of the F-1 engines. Use of liquid injection thrust vector control on the solid motor is required near maximum dynamic pressure time of flight.

Aerodynamic heating is significantly lower than the Saturn V, but the base heating environment is more severe due to the solid motor exhaust plumes. However, heat shield materials can withstand the anticipated temperatures successfully. The aft solid motor attachment skirt will require insulation protection.

Separation of the solid motors from the core vehicle can be accomplished satisfactorily using explosive separation devices and small rocket motors for lateral translation of the spent SRM cases.

By varying the propellant weight and thrust of the solid rocket motors and the propellant weight in the core stages, a variety of potential configurations was examined. The number of segments in the 120-inch solid motors (SRM propellant weight) was varied from five to seven and in the 156-inch solid motor from two to four.

Figure 7 is typical of the parametric performance data prepared to determine vehicle characteristics. This data, for the V-4(S)B, illustrates the net payload versus the number of segments in the 120-inch motors for the three-stage vehicles. The chart shows two conditions, optimized first-stage propellant weight with the upper stage propellant weights fixed, and propellant weights for all stages optimized. For the optimized vehicles, the S-IVB would have to be lengthened approximately 14 feet while the S-II stage remains at its standard length and the S-IC stage is increased in length by about 28 feet. A similar study of two-stage vehicles shows the optimum core vehicle to be basically a standard length S-II stage and a 28-foot longer S-IC stage.

Figure 8 compares the payload cost efficiency* for the V-4(S)B when varying the number of segments in the 120-inch motors for a three-stage vehicle with either fixed or optimized core stages.

This type of data was prepared for all SRM boost-assist vehicles. The general trend was that increasing SRM propellant weight significantly improved vehicle cost efficiency while optimization of the S-II stage did not. Comparisons of the relative values (see Figure 9 illustrating cost efficiency* for the V-4(S)B, V-22(S), and V-25(S)) also show that the most cost efficient method for further improvement of performance is through the use of larger solid motors (V-25(S)) rather than through the use of advanced upper stage engines (V-22(S)). The V-4(S)B and V-25(S) vehicles were studied in more detail to derive data for comparison with the other general growth methods. The V-22(S) vehicle was not subject to further detailed evaluations.

The V-4(S)B vehicle studied in depth is illustrated in Figure 10 and incorporates standard Saturn V engines, standard length upper stages, and a 28-foot longer first stage augmented by four seven-segment 120-inch SRM's.**** Each motor has an initial sea level thrust of 1.4 million pounds and a propellant weight of 570,000 pounds.

Structural loading increases (over Saturn V) significantly but structural modifications and resulting weight increases are modest as can be seen by comparing the increased loading and resultant weight increases for the core stages. See Figure 11.

The V-25(S) vehicle, also shown in Figure 10, uses standard Saturn V engines, and a standard length S-II stage. The S-IVB third stage is increased in length by 16.5 feet. The 41.5-foot longer first stage is augmented by four three-segment 156-inch strap-on SRM's - each with 1.1 million pounds of propellant and a sea level thrust of 4.0 million pounds.

The payload to LOR and 100 nautical mile low Earth orbit for the three and two stage vehicles respectively are shown in Figure 10. Additional studies for the V-4(S)B identified information useful for mission planning. These alternate mission capabilities are shown in Figure 12 and include the following: 1) Payloads available for various orbital altitudes between 80 and 300 nautical miles and launch azimuths between 45 degrees and 180 degrees, 2) Three-stage mission payload capability for a 24-hour synchronous orbit, and more generally, payload as a function of the specific energy parameter (C_3), and 3) Polar and near polar orbit payloads for both two and three-stage vehicles. Both the V-4(S)B and V-25(S) vehicles were considered for applications where the baseline core vehicle (liquid stages without solids) could be flown, or with only two strap-on solid motors. This gives flexibility in the selection of vehicles for specific missions where payload capability can be varied from approximately Saturn V to the maximum obtainable with the four SRM's strapped on. (See Table II).

***The section following on "Advanced Engines" describes the advanced upper stage engines used.

****The SRM's conform to preliminary designs developed by United Technology Center for Titan III-C applications.

The launch facility use and launch operations sequence for the V-4(S)B would follow the current procedure of assembly of the modified core vehicle in the VAB on the Mobile Launcher, which is then transported to the pad.[4] The solid motor segments would be assembled in a Mobile Assembly and Handling Structure (MAHS) (See Figure 13) and transported by this MAHS to the launch pad for subsequent assembly of the solids to the core vehicle. The MAHS would mate with the mobile launcher (ML) for this assembly operation and handling equipment within the MAHS would be utilized for placement of the solid motors against the core vehicle. After assembly of the solid motors, the MAHS would be removed and replaced by the service tower. Normal operations for the core vehicle would then be resumed and additional operations as required for solid motor final checkout and arming would be accomplished.

The existing VAB with work platform locations altered and the existing launch pad and its existing flame trench can be utilized. The crawler transporter roadways are sufficient for this vehicle with the exception of the requirement for some additional crawler transporter roadways required for access to a solid motor assembly site. Major impact areas include the development and construction of the MAHS and modifications to the mobile launcher (ML) to increase its deck load capacity, to relocate the swing arms, to relocate the tail service masts and holddown structure, and to enlarge the aspirator hole to allow additional space for the solid rocket motor nozzles. Insulation in selected areas would be required to protect the ML during launch.

The V-25(S) vehicle launch facility and launch operations sequence are similar to V-4(S)B except that the longer and heavier 156-inch SRM segments areassembled at the pad and require a new mobile erection and processing structure (MEPS) for SRM receiving inspection, component installation and individual checkout. At the launch pad, the MEPS will be used to transfer and assemble the 156-inch segments to the core vehicle.

A dynamic test vehicle, structural test components, and two R&D flights for man-rating were assumed. The existing dynamic test stand can be used for the V-4(S)B vehicle but a new dynamic test stand would be required for test of the V-25(S) vehicle since its launch weight exceeds present Saturn V stand capability.

A production rate of six vehicles per year for a period of five years was utilized to assess production and launch impact.

Detailed scheduling showed availability of the V-4(S)B in 41 months after ATP and the V-25(S) 42 months.

Advanced Engines

Saturn V growth by lengthening all stages to increase propellant capacity and increasing the thrust of each stage was studied to determine its relative merits compared to other uprating methods. The variations studied are summarized on Figure 6. This vehicle is designated V-3B. The first stage thrust is uprated from 7.61 to 9.0 million pounds at lift-off by uprating the F-1 engines to 1.8 million pounds thrust per engine. The second stage variations included four to seven advanced engines of toroidal aerospike or bell design with 300,000 to 700,000 pounds of thrust. The third stage used a single engine of the same type and thrust level as for the second stage. The advanced LOX/LH_2 aerospike engine has a toroidal combustor and truncated aerodynamic spike annular nozzle. (See Figure 14). This design results in a 64-inch reduction in engine length. The other engine considered was a high-pressure LOX/LH_2 concept with a bell nozzle. Bell nozzle engine length, from gimbal point to nozzle exit plane, was maintained at 116 inches because of upper stage interstage clearance requirements. Both concepts achieve an approximate 26 seconds specific impulse improvement over the current J-2 engine. Parametric data of second stage thrust and payload for optimized and fixed upper stage lengths at a 15.5 foot increase for the second stage and a 16.5 foot increase for the third stage were derived to allow MSFC to determine the best compromise second stage thrust level which satisfied requirements for both the V-3B vehicle and a two stage launch vehicle made up of the second and third stages of the V-3B (studied in depth by another contractor[3] and not reported here). The "fixed" length increases were set by upper stage facility limitations.

Figure 15 summarizes performance for the "fixed" upper stage configurations. It also shows available performance should the stage limits be exceeded up to VAB 410-foot limit. These data cover two- and three-stage vehicles with bell and toroidal upper stage engines. Performance results favor the use of toroidal engines as indicated due primarily to added propellant available as a result of a shortened interstage available with the toroidal configuration. This advantage could be at least partially offset by the recently unveiled two-position nozzle concept for the high pressure bell. Performance results for the V-3B favor a total S-II thrust of around two million pounds using 400,000 to 500,000 pounds of thrust per engine. Seven 300,000 pound thrust second stage engines showed a slight (2.6 percent) increase over five 400,000 pound thrust engines. Performance optimized at approximately 3.0 million pounds of thrust for the S-II/S-IVB (INT-17)[3] launch vehicle, whereas, the V-3B optimizes at approximately 2.0 million pounds thrust. Further, V-3B third stage requires not more than 180,000 pounds of thrust for most efficient operation. A compromise was made at a second stage thrust of 2.8 million pounds using seven 400,000 pound thrust engines. The toroidal aerospike engine rather than the bell nozzle engine was then selected for detailed studies primarily since the bell was examined in detail in a prior study.[2]

The V-3B vehicle which shows the best performance when using the compromised upper stage thrust is described in Figure 10. First stage length increase is 20 feet for a propellant capacity of

5.6 million pounds with a propellant loading ($T/W_o = 1.25$) of 4.99 million pounds and 4.8 million pounds for the two- and three-stage vehicles, respectively. The second stage uses the seven 400,000 pound thrust toroidal aerospike engines. It has a length increase of 15.5 feet for a propellant capacity of 1.29 million pounds in the second stage. The shorter toroidal engines allow a 62-inch reduction in interstage length thereby permitting the commensurate tankage capacity increase. The third stage (for three-stage application) uses a single 400,000 pound thrust toroidal aerospike engine, and a 16.5 foot length increase for a propellant capacity of 350,000 pounds of propellant.

Figure 16 summarizes the orbit/altitude capability for the two stage V-3B. Net payload for the nominal mission is 367,400 pounds. However, with the high thrust (2.8 million pounds) and short burn time of the second stage, a sizable performance loss occurs at the higher orbit altitudes. For example, more payload is obtained at a 300 nautical mile orbit with existing two stage Saturn V (INT-21) than is obtained with a V-3B. If engine throttling is used in the second stage, the payload losses to the higher orbits are reduced considerably as shown in the orbit altitude azimuth plot (Figure 16). High energy mission (C_3) performance of the three stage vehicle is also illustrated on Figure 16. Net payload for the nominal 72 hour lunar injection mission is 160,000 pounds. Payloads for polar and sun synchronous orbits are also shown. A boost turn is required to obtain these orbits from Cape Kennedy. This maneuver requires energy expenditure which is reflected in less payload capability. However, in this regard, the high thrust of the boost turning second stage is advantageous as can be seen by comparing the V-4(S)B characteristic for this type mission.

The 410-foot vehicle height, 33-foot diameter two-stage payload, and increased thrust have significantly increased structural loads over the existing Saturn V requiring major structural beefup.

The control and heating requirements are within Saturn V criteria and no stage changes are needed.

Changes in the launch facility and operational sequence at MILA for the V-3B vehicle are primarily due to increased vehicle length. Mobile launcher swing arms as well as VAB high and low bays access platforms would require relocation. Vehicle assembly in the VAB will be according to standard procedure.

Increases in the length and thrust of the V-3B stages impacts existing production, test, transportation, and launch facilities. Uprated F-1 engine and new toroidal upper stage engine developments are the most costly items required. Existing facilities would be employed to manufacture and test the V-3B.

A dynamic test vehicle, structural test components, and two man-rating R&D flights are included in the development program. Relocation of work platforms and increase in height is required at the MSFC Dynamic Test Stand to handle the new configuration.

A production rate of six vehicles per year for a period of five years was used to assess production and launch impact.

The V-3B vehicle could be available 69 months after ATP. V-3B availability is paced by the advanced engine development.

Liquid Rocket Boost-Assist

Two basic liquid rocket boost assist configurations were studied (see Figure 6): 1) V-23(L) used standard Saturn V engines and varied the weight of propellant in the core stages and pods and 2) V-24(L) used uprated 1.8M pounds thrust F-1 engines in the first stage and liquid rocket strap-ons, various numbers and thrust levels of the advanced engines in the upper stages, and varied the propellant weight in the core stages and strap-ons. Two F-1's were used in each Boost-Assist Rocket (RP-1/LOX propellants).

The propellant capacities of the core stages and boost assist rockets were determined by trading propellant between the core and strap-ons to maximize payload. Typical parametric data, for the V-23(L), is shown in Figure 17. The variation of performance as a function of boost assist to S-IC burn time and propellant loading is not extremely sensitive for either two- or three-stage vehicles. The strap-on and core were sized, therefore, to satisfy the 410 foot vehicle height limit.

The vehicle heights as shown on Figure 17 demonstrate the critical limitation imposed on this method of uprating by the facility height restriction of 410 feet. It was necessary to configure the vehicle off optimum to stay within the facility and payload density restrictions. For the V-24(L) vehicle, the height restriction was always exceeded and consequently, was not studied in depth for comparison with the other methods of Saturn V growth. It is worth noting that V-24(L) vehicles were identified which achieved 410,000 pounds of payload to LOR and 960,000 pounds to 100 nautical mile earth orbit. A vehicle height of 600 feet would be required for those payload weights to stay within the payload density restrictions of 11 lb/ft^3 (LOR) and 5 lb/ft^3 (earth orbit).

The V-23(L) vehicle selected for detailed studies incorporates a 16.5 foot longer third stage, standard length second stage, and 20 foot longer first stage-thrust augmented by four 260-inch diameter liquid rocket boost assist strap-ons (see Figure 10). The boost assist rockets use S-IC technology structural concepts and systems. Each unit gimbals its two standard F-1 engines to supplement the control capabilities of the core vehicle. Each rocket is an independent stage which can be checked out and test fired as a unit. Aerodynamic fins are not used on either core or boost assist rockets.

Aerodynamic and base heating environments are similar to the SRM strap-on configurations and the solutions are similar.

Digital simulation of separation dynamics for the expended strap-ons demonstrates that a positive core strap-on separation clearance is obtained and that axial clearance occurs at 1.83 seconds after separation. Separation is obtained by a thruster strut system which uses the required primary structural members as housings for the separation energy source.

The payload to LOR and 100 nautical mile low Earth orbit is shown on Figure 10. The V-23(L) vehicle was also considered for application where the core vehicle (without the liquid rockets) could fly alone or with two strap-on liquid rockets. The payloads calculated for these alternates are shown on Table III.

The V-23(L) core vehicle would be assembled according to standard procedures in the VAB on the Mobile Launcher.[4] The boost assist rockets would be shipped to MILA where they would be attached to the core vehicle in the VAB. After test and checkout the assembled vehicle would be moved to the launch pad.

The existing VAB with work platforms relocated and modified and doors modified can be used. The launch pad and flame trench need modification to adapt to the V-23(L) configuration. The existing crawler transporter would be replaced. The Saturn V mobile launcher requires substantial modification to handle this configuration.

A dynamic test vehicle, structural test components, and two R&D vehicles are required in the R&D program. A new dynamic test stand is required because the V-23(L) launch weight exceeds Saturn V dynamic test stand foundation capability by 30 percent.

Boost assist rocket requirements are similar to those of any new stage. The new structure would be tested and its ultimate load carrying capability determined. Post-manufacturing testing can be accomplished in the existing S-IC test cells at Michoud. A static firing test rocket (battleship weight) is also required to qualify the two engine cluster. A scaled-down S-IC dual position test stand and storage facilities must be provided at MTF for acceptance firing.

Approximately two million square feet of manufacturing area would be required to produce the 24 boost assist rockets per year (assumed rate). The facility could be located at Michoud.

Thirty V-23(L) operational vehicles at a rate of six per year for five years formed the basis for the production and launch cost estimating.

Vehicle availability was based on new manufacturing and test facilities for the boost assist rockets. Availability was estimated at 65 months from authority to proceed based on a two year delay to build new manufacturing and test facilities.

Uprating Conclusions

The V-4(S)B, V-25(S), V-3B and V-23(L) are all feasible and logical candidates for their respective payload ranges.

Payload capabilities, costs,* availability, and design impact for the four uprated vehicles are compared in Figure 18. Operational costs shown are the averages for thirty launch vehicles. The solid strap-on method requires the least lead time (3 1/2 years) which is comparable to the liquid rocket strap-on (V-23(L)) method except for the two-year delay included in the V-23(L) lead time to build facilities. The five-year nine-month lead time for the advanced engines growth method (V-3B) is due to the new toroidal aerospike engine development for upper stage applications.

Figure 19 compares investment costs* for developing the growth vehicles as a function of payload increase from Saturn V. The more favorable vehicles from an investment standpoint fall to the left, i.e., least cost for a given payload improvement.

Of the growth methods studied, the V-3B launch vehicle features the best payload to launch weight and the minimum launch facilities impact. On the other hand, this vehicle requires the most research and development cost per pound of payload, and requires the most lead time.

The V-4(S)B launch vehicle has the best payload per research and development dollar with a nominal launch impact. However, as shown on Figures 20 and 21, when operation costs* are included, the V-4(S)B does not become the most cost efficient launch vehicle. It requires the least lead time and development cost of all the growth launch vehicles.

Of all the growth vehicles studied, the V-25(S) launch vehicle is the most cost efficient (slightly ahead of V-23(L)). The V-25(S) vehicle, when compared to the V-4(S)B vehicle, costs more to develop and may have an increased impact at the launch facility.

The V-23(L) launch vehicle has the greatest payload capability of all the launch vehicles studied and is almost as cost efficient as the V-25(S). It also has the advantage of using existing standard Saturn V engines, propellants, and systems. It does, however, have the greatest impact on the launch facility.

A factor restraining the potential payload capability and, therefore, the cost efficiency of the V-23(L) vehicle is the 410-foot height restriction established as a ground rule for the study. Further work should be done to consider overcoming the 410-foot height limitation such as installing the payload outside VAB, modification to VAB, etc.

Concluding Remarks

All the launch vehicles studied were feasible and logical configurations for their respective payload capabilities. Each was configured within restrictive existing facility limitation ground rules, limiting the maximum payload achieved to 579,000 pounds to 100 nautical mile Earth orbit (V-23(L)). The liquid rocket strap-on concept, with uprated F-1's and advanced engines in the second stage (V-24(L)), achieved payloads to 960,000 pounds to 100 nautical mile Earth orbit when stage and total vehicle length restrictions were relaxed.

Boeing believes further studies should be directed toward future refinements of the vehicle designs and specifically toward possible future applications. We believe the increased payload capability and improved cost efficiency of both "intermediate" and uprated vehicles over that of the existing Saturn vehicles could be used to significantly reduce overall space program costs.

References

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2. MS-IC Stage for Modified Launch Vehicle (MLV) Saturn V, Boeing Document D5-11420-1 to -6.

3. Studies of Improved Saturn V Vehicles and Intermediate Saturn Vehicles, North American Aviation Document SID-66-1326-1 to -7.

4. Study of Launch Facilities for Improved Saturn Vehicles, Martin-Marietta Document CR-66-41

TABLE I INTERMEDIATE VEHICLE PERFORMANCE SUMMARY

VEHICLE	STAGE ARRANGEMENT	NUMBER OF ENGINES	LAUNCH WEIGHT 10^6 LBS	W_{p1} 10^6 LBS	W_{p2} 10^6 LBS	100 NM PAYLOAD 10^3 LBS 4.68 G LIMIT	6 G LIMIT
INT-20	S-IC/S-IVB	2/1	2.44	1.9	0.23	36	60
		3/1	3.65	3.0	0.23	78	103
		4/1	4.87	4.1	0.23	132	138
		5/1	5.07	4.3	0.23	133	158
INT-21	S-IC/S-II	4/3	4.87	3.56	0.71	167	
		4/4	4.87	3.40	0.85	186	
		4/5	4.87	3.30	0.93	196	
		5/3	6.09	4.56	0.84	222	
		5/4	6.09	4.47	0.91	246	
		5/5	6.09	4.42	0.93	255	

W_{p1} = First stage mainstage propellant

W_{p2} = Second stage mainstage propellant

Initial launch azimuth - 70 degrees

TABLE II

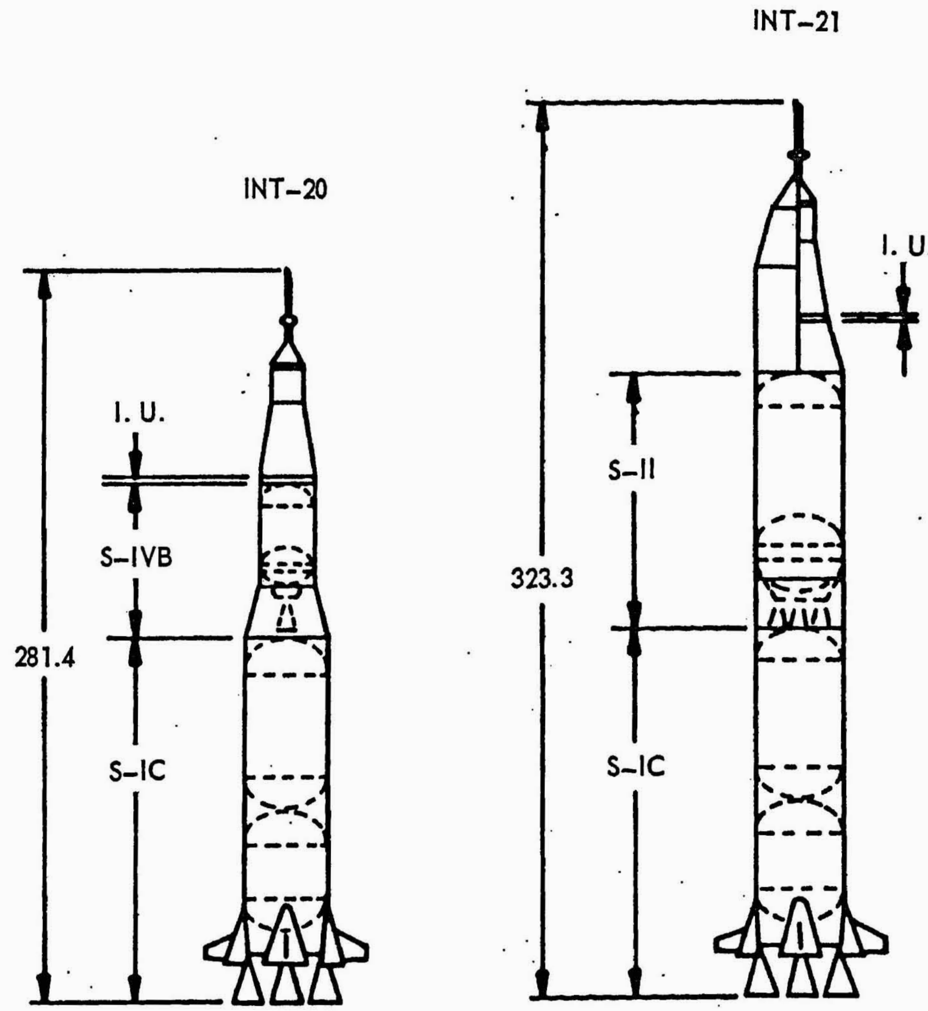
V-4(S)B AND V-25(S) PAYLOAD CAPABILITY

VEHICLE		NET PAYLOAD (LBS) TWO-STAGE 100 NM ORBIT	NET PAYLOAD (LBS) THREE-STAGE LOR
	Core Vehicle Without Solid Motors		
V-4(S)B	$T_o/W_o = 1.25$	243,512	89,444
V-25(S)	$T_o/W_o = 1.25$	231,466	88,475
	Core Vehicle With Two Solid Motors		
V-4(S)B	$T_o/W_o = 1.25$	320,725	117,805
V-25(S)	$T_o/W_o = 1.40$	387,073	147,954
	Core Vehicle With Four Solid Motors		
V-4(S)B	$T_o/W_o = 1.25$	379,300	139,300
V-25(S)	$T_o/W_o = 1.734$	493,900	188,800

TABLE III

V-23(L) THREE-STAGE LOR PAYLOAD CAPABILITY

NUMBER OF BOOST ASSIST ROCKETS	NET PAYLOAD (LBS)
0	80
2	155
4	220



F-1/J-2	100 N MI ORBIT P_L - 10^3 LBS 4.68g	6g
2/1	36	60
3/1	78	103
4/1	132	138
5/1	133	158

F-1/J-2	100 N MI ORBIT P_L - 10^3 LBS
4/3	167
4/4	186
4/5	196
5/3	222
5/4	246
5/5	255

Figure 1. Intermediate Vehicles.

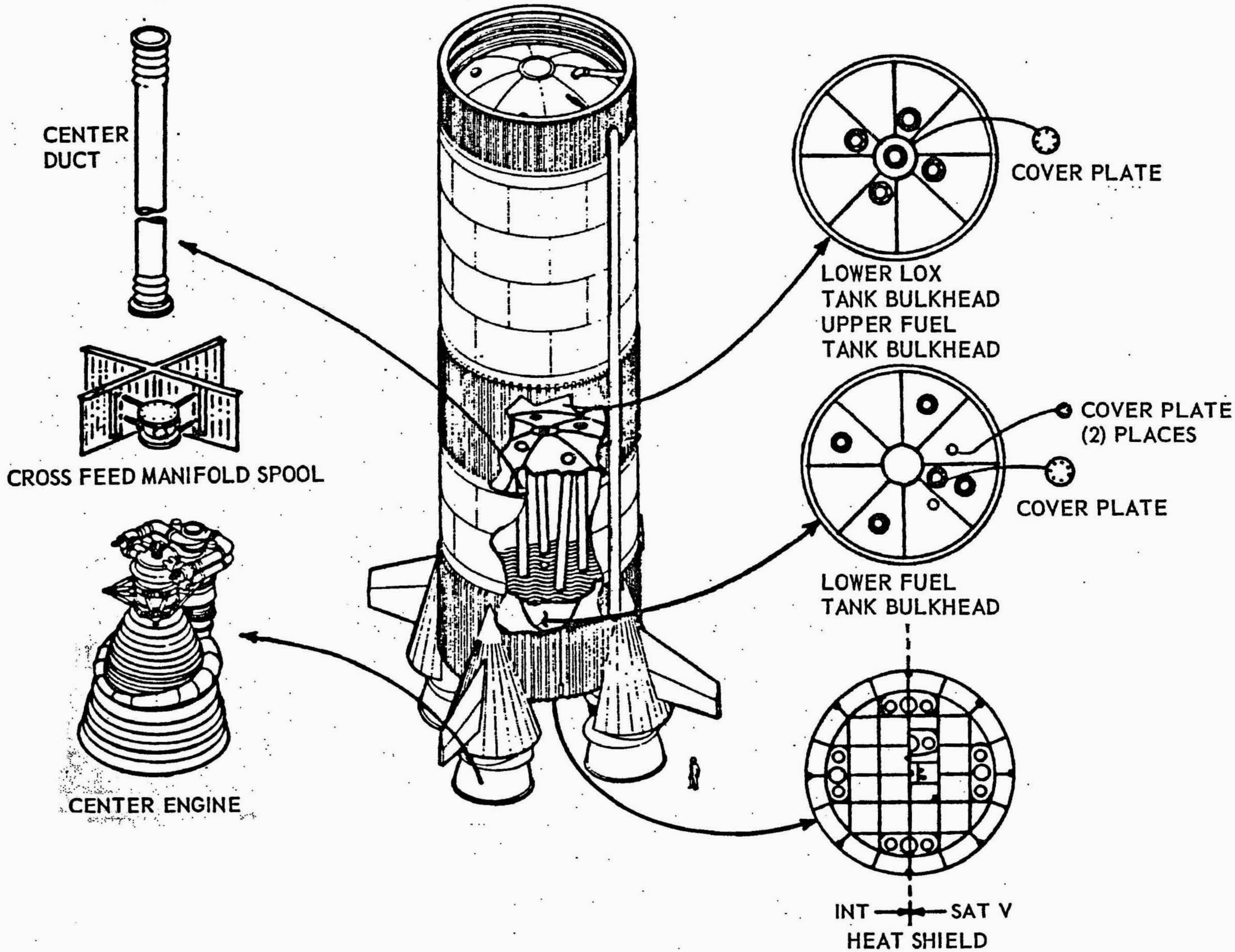
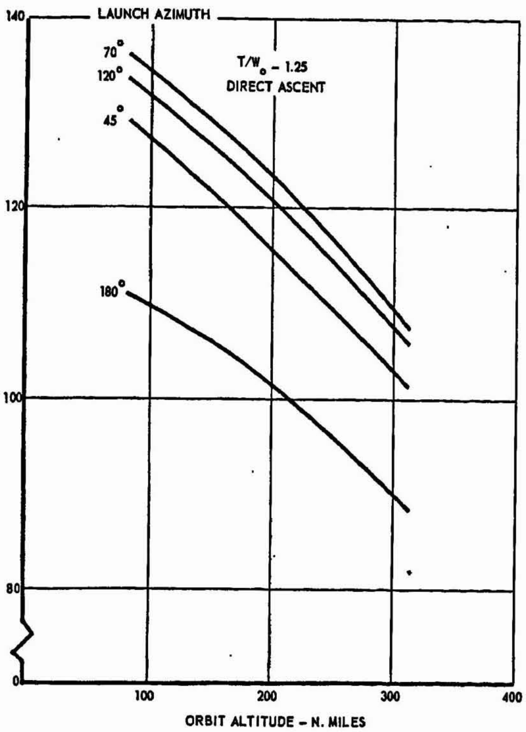
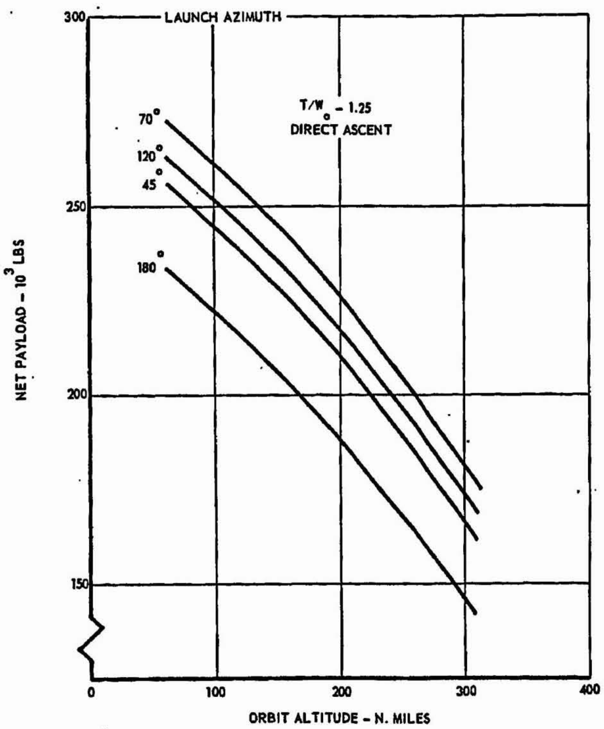


Figure 2. Four Engine INT-S-IC Stage.



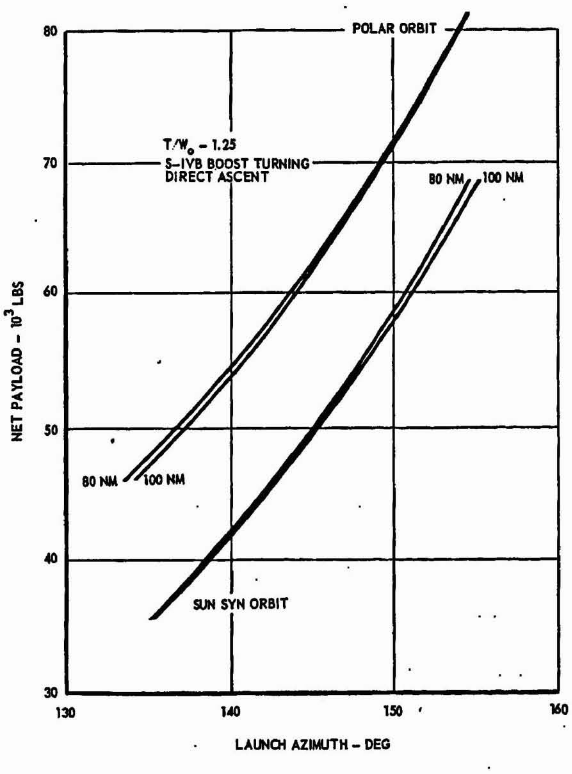


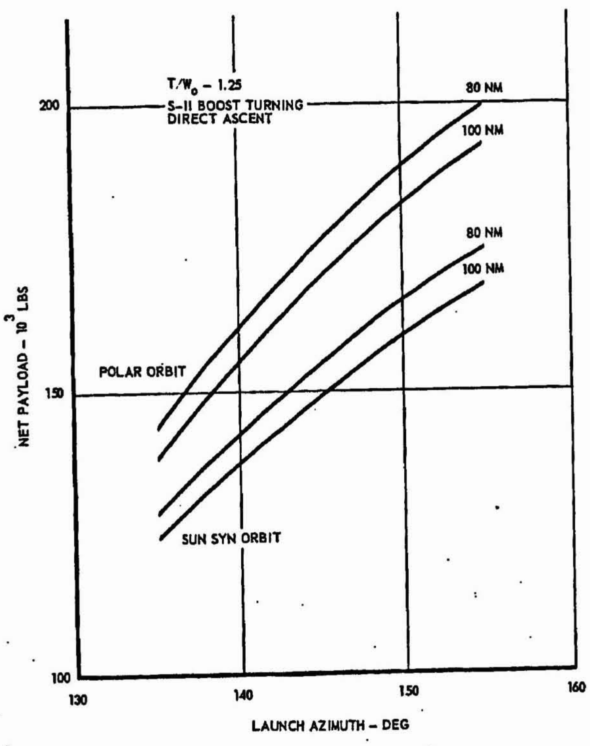
ORBIT ALTITUDE - AZIMUTH

PAYLOAD CAPABILITY

INT-20 (4-F-1/4.68g)

INT-21





POLAR AND SUN SYNCHRONOUS ORBIT PAYLOAD CAPABILITY

Figure 3. INT-20 and INT-21 Alternate Missions.

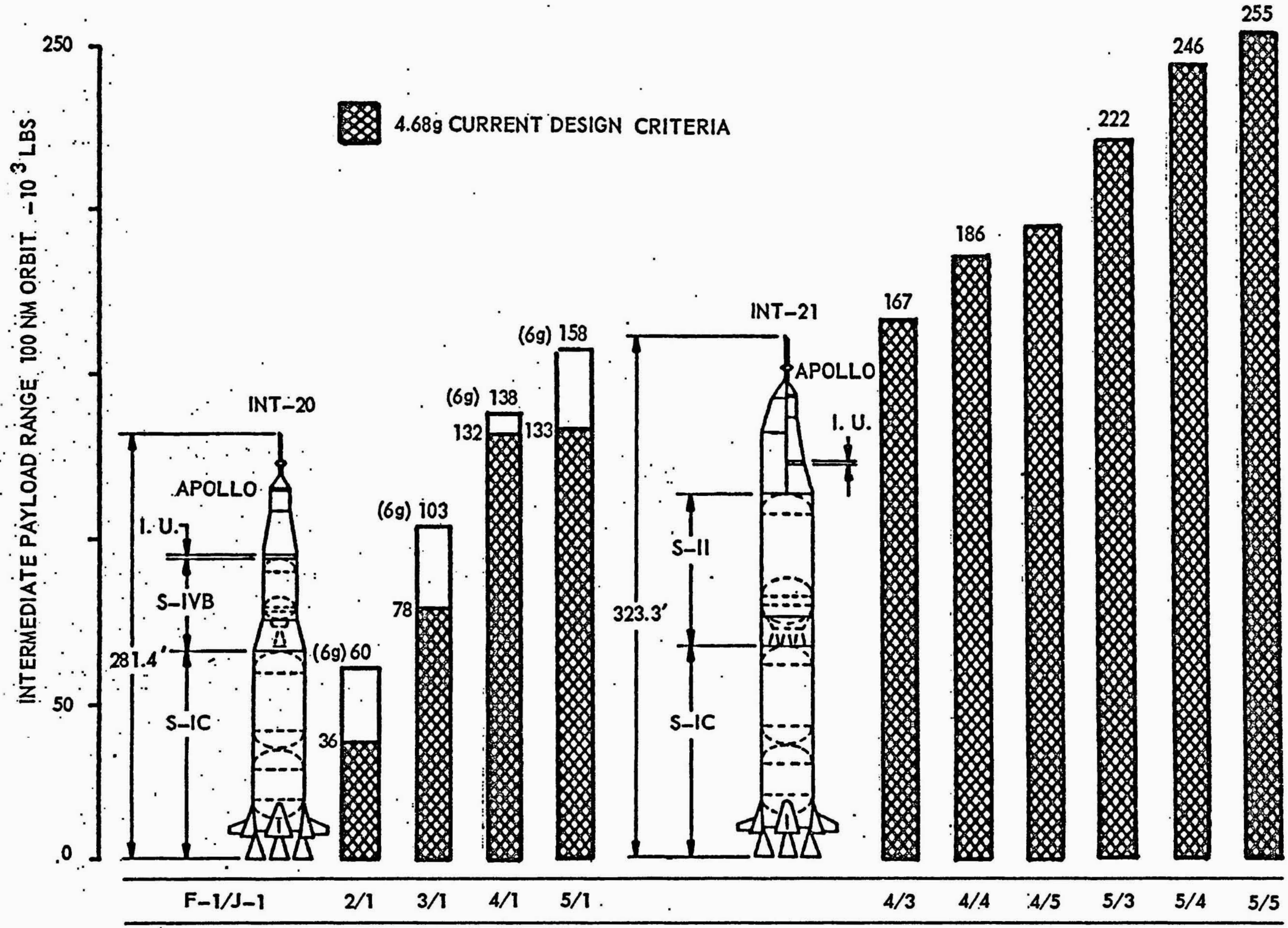
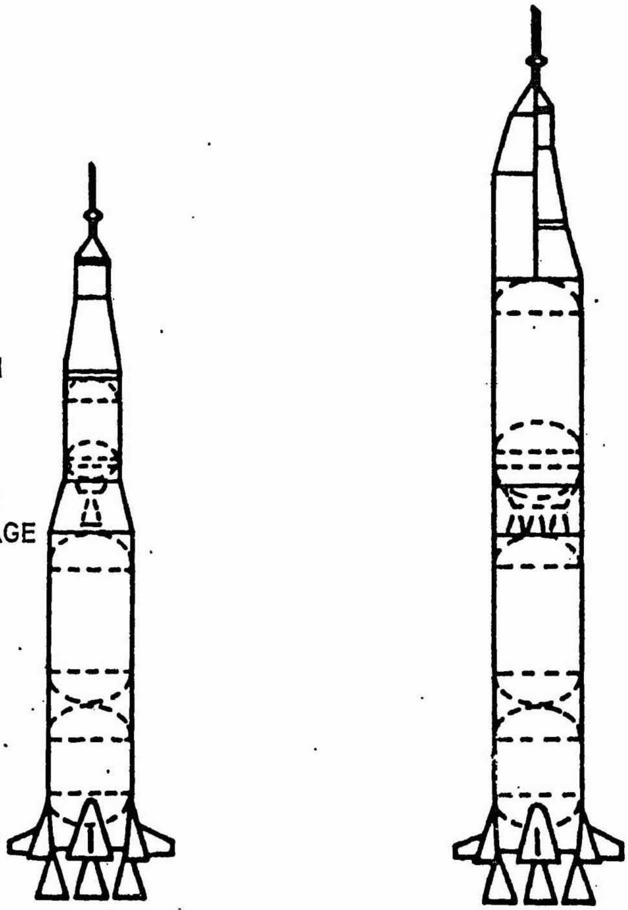


Figure 4. Saturn V Intermediate Payload Vehicles.

* $45M FOR 8/YR. PRODUCTION

$14.6M FOR 6/YR. PRODUCTION

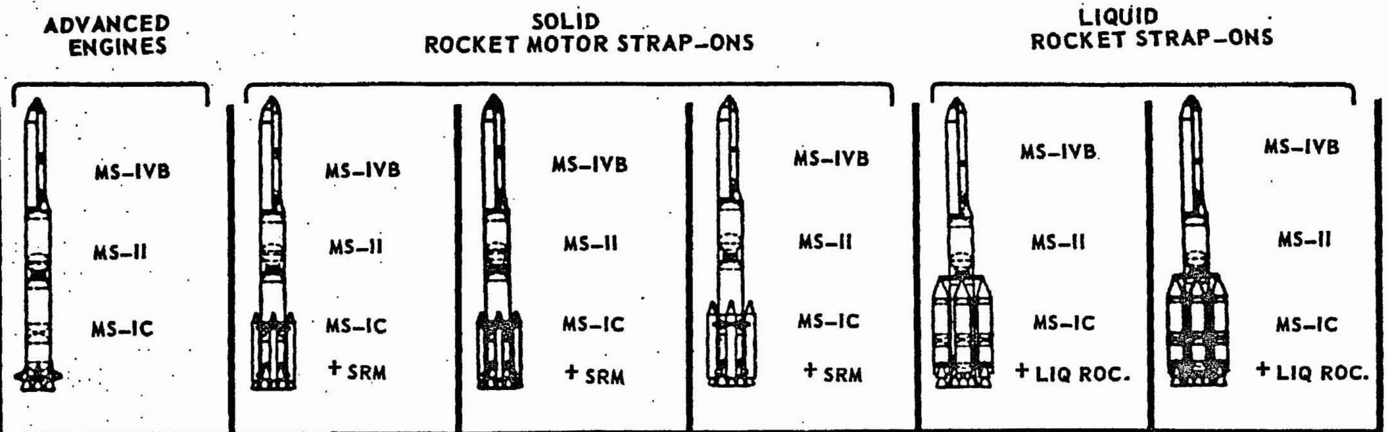
SINGLE COST FOR SIMULTANEOUS IMPLEMENTATION OF ALL 10 –20 & – 21 ENGINE/STAGE COMBINATIONS



	INT–20 (2 STG)				INT–21 (2 STG)					
NO ENG'S F–1/J–2	2/1	3/1	4/1		4/3	4/4	4/5	5/3	5/4	5/5
PAYLOAD 10^3 LBS	36–60	78–103	132–138	133–158	167	186	196	222	246	255
* R&D FLIGHT VEHICLES – $M	(1) 60.8									
* AVG. OPERATIONAL UNIT COST – $M	60.5				74.6					
* OPERATIONAL COST EFFICIENCY – $/LB P_L	458				292					
AVAILABILITY					2 YRS					

Figure 5. INT Vehicle Comparison.

GROUND RULES
MAX VEHICLE SIZE – 410 FT
MAX MS–II SIZE 1160 IN
MAX MS–IVB SIZE 350K PROPELLANT AT MR 5:1
MAX PAYLOAD ρ 5 LB/FT³ (2 STG)
11 LB/FT³ (3 STG).
STD = STANDARD
ΔL = CHANGE IN STAGE LENGTH



LAUNCH VEHICLE	V–3B	V–4(S) B	V–22 (S)	V–25 (S)	V–23(L)	V–24 (L)
THIRD STAGE	ADVANCED ENGINE Δ L VARIABLE	STD J–2 Δ L VARIABLE	ADVANCED ENGINE Δ L VARIABLE	STD J–2 Δ L VARIABLE	STD J–2 Δ L VARIABLE	ADVANCED ENGINE Δ L VARIABLE
SECOND STAGE	ADVANCED ENGINES Δ L VARIABLE	STD J–2'S Δ L VARIABLE	ADVANCED ENGINES Δ L VARIABLE	STD J–2'S Δ L VARIABLE	STD J–2'S Δ L VARIABLE	ADVANCED ENGINES Δ L VARIABLE
FIRST STAGE	5 X 1.8M F–1 ENGINES Δ L VARIABLE.	STD F–1'S Δ L VARIABLE	STD F–1'S Δ L VARIABLE	STD F–1'S Δ L VARIABLE	STD F–1'S Δ L VARIABLE	5 X 1.8M F–1 ENGINES Δ L VARIABLES
STRAP–ON COMPONENTS		4 X 120 IN DIA SOLID MOTORS	4 × 120 IN DIA SOLID MOTORS	4 X 156 IN DIA SOLID MOTORS	4 LIQUID ROCKETS 2 X STD F–1 ENGINES	4 LIQUID ROCKETS 2 X 1.8M F–1 ENGINES

Figure 6. Candidate Growth Methods.

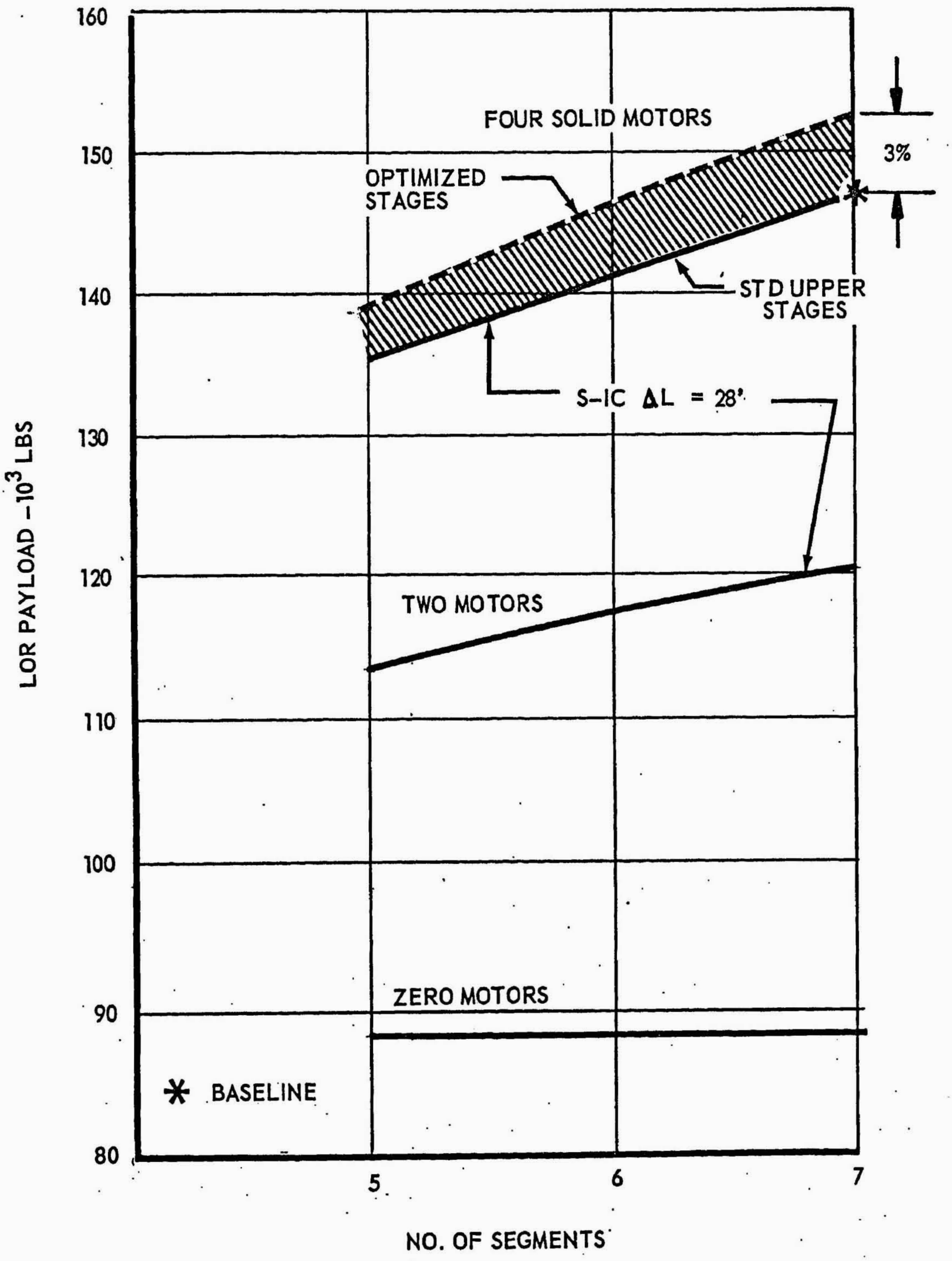


Figure 7. V-4(S)B Performance Trade Data.

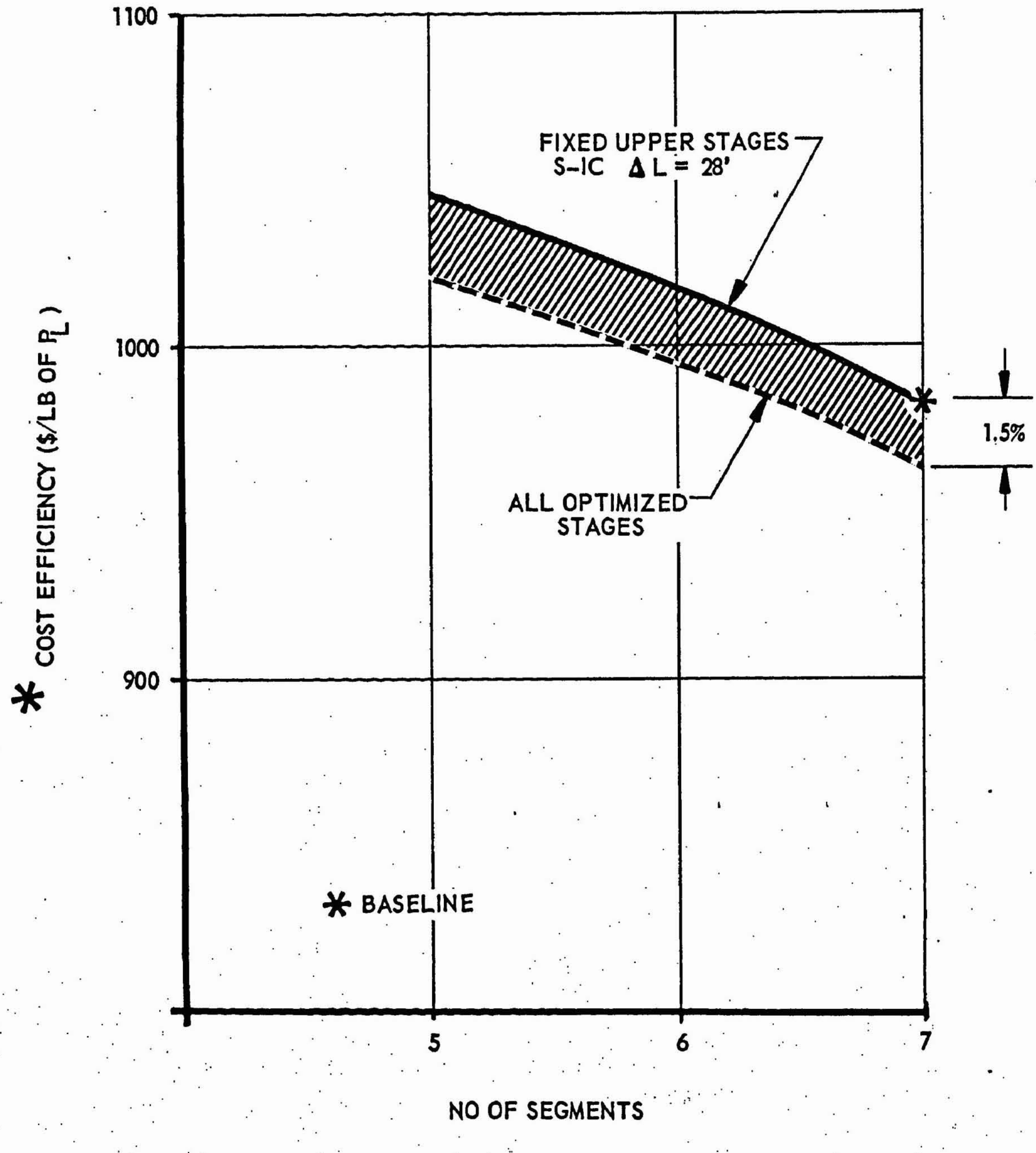


Figure 8. V-4(S)B Cost Trade Data.

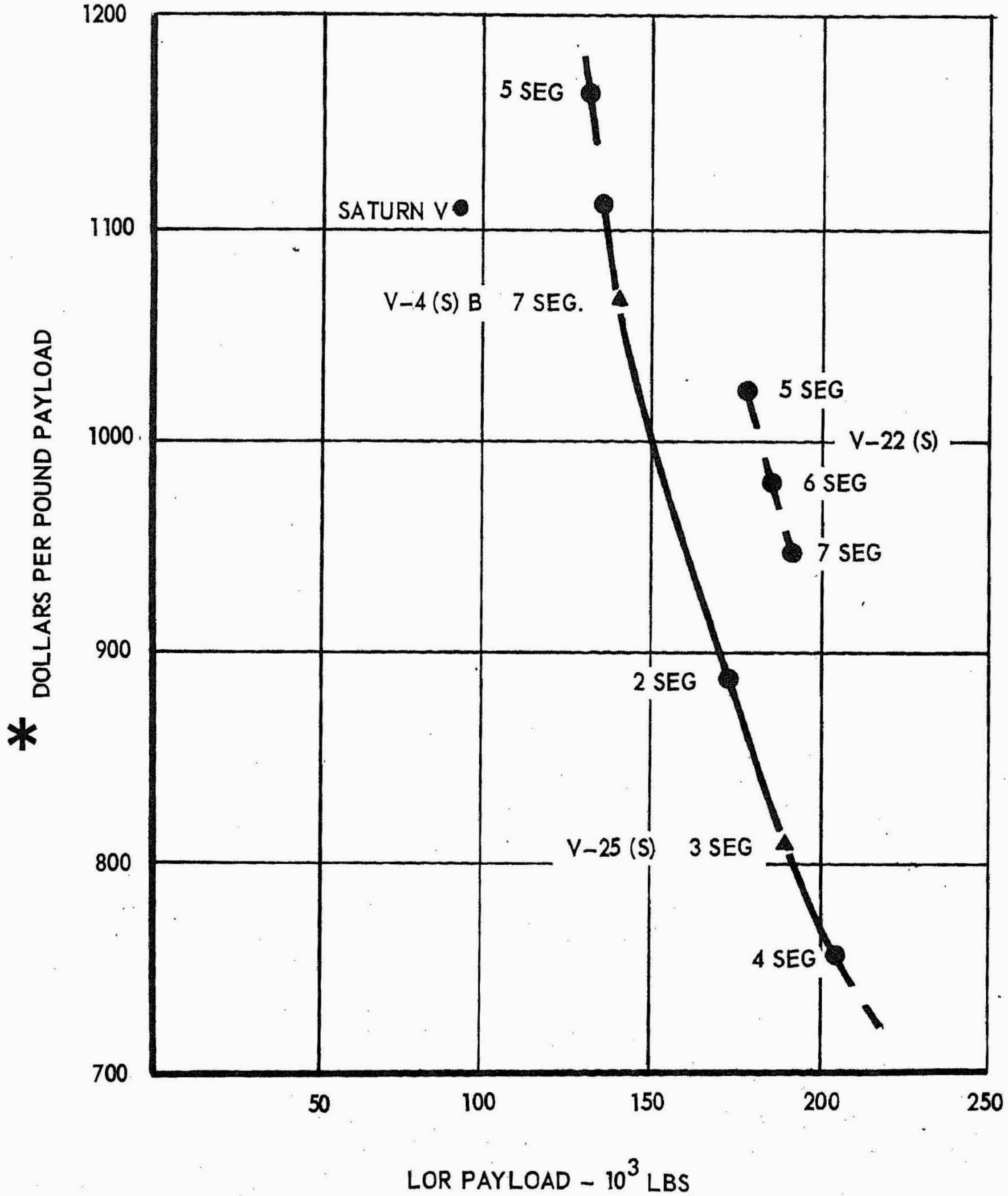


Figure 9. SRM Boost-Assist Cost Efficiency Comparison.

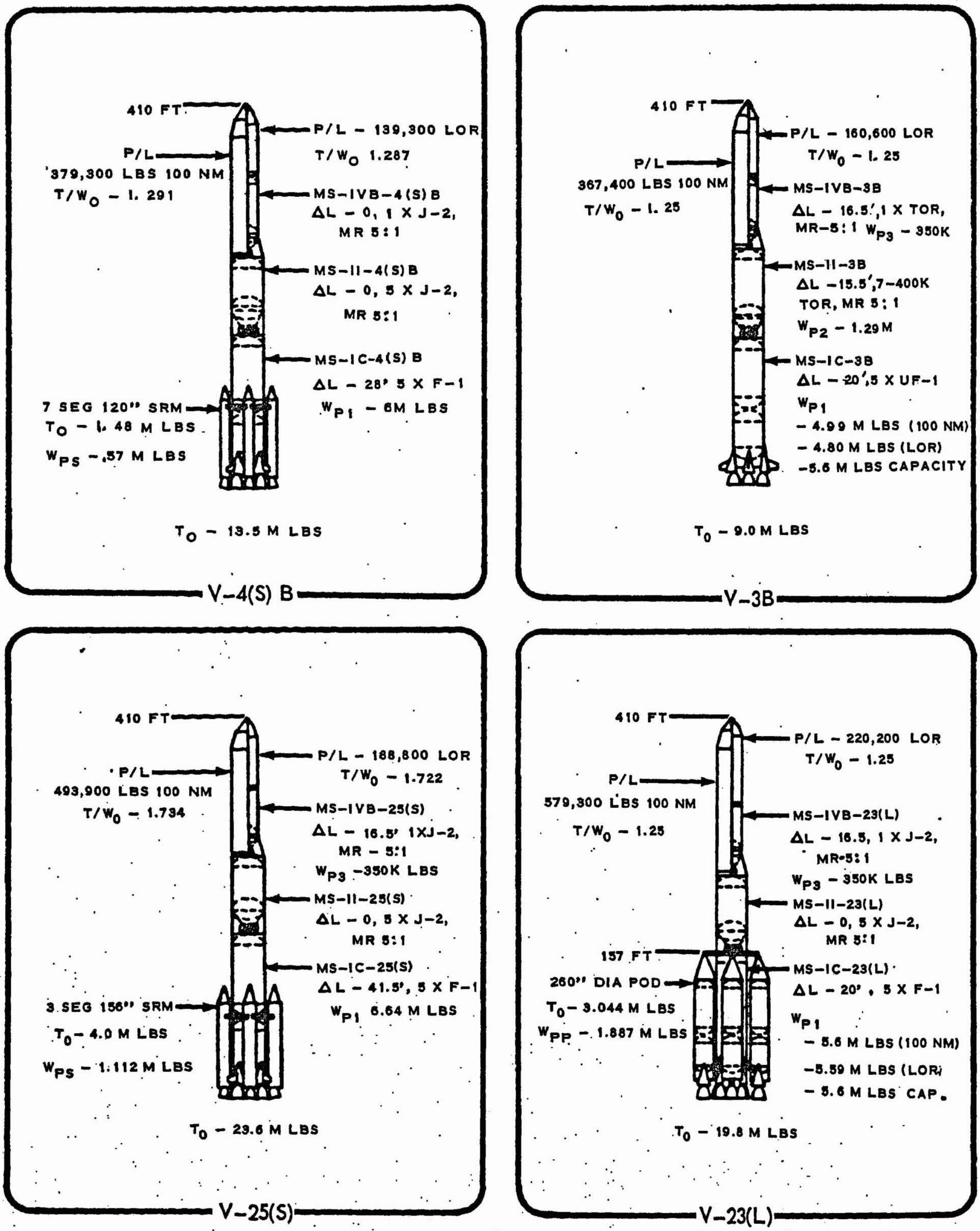


Figure 10. Selected Baseline Launch Vehicles

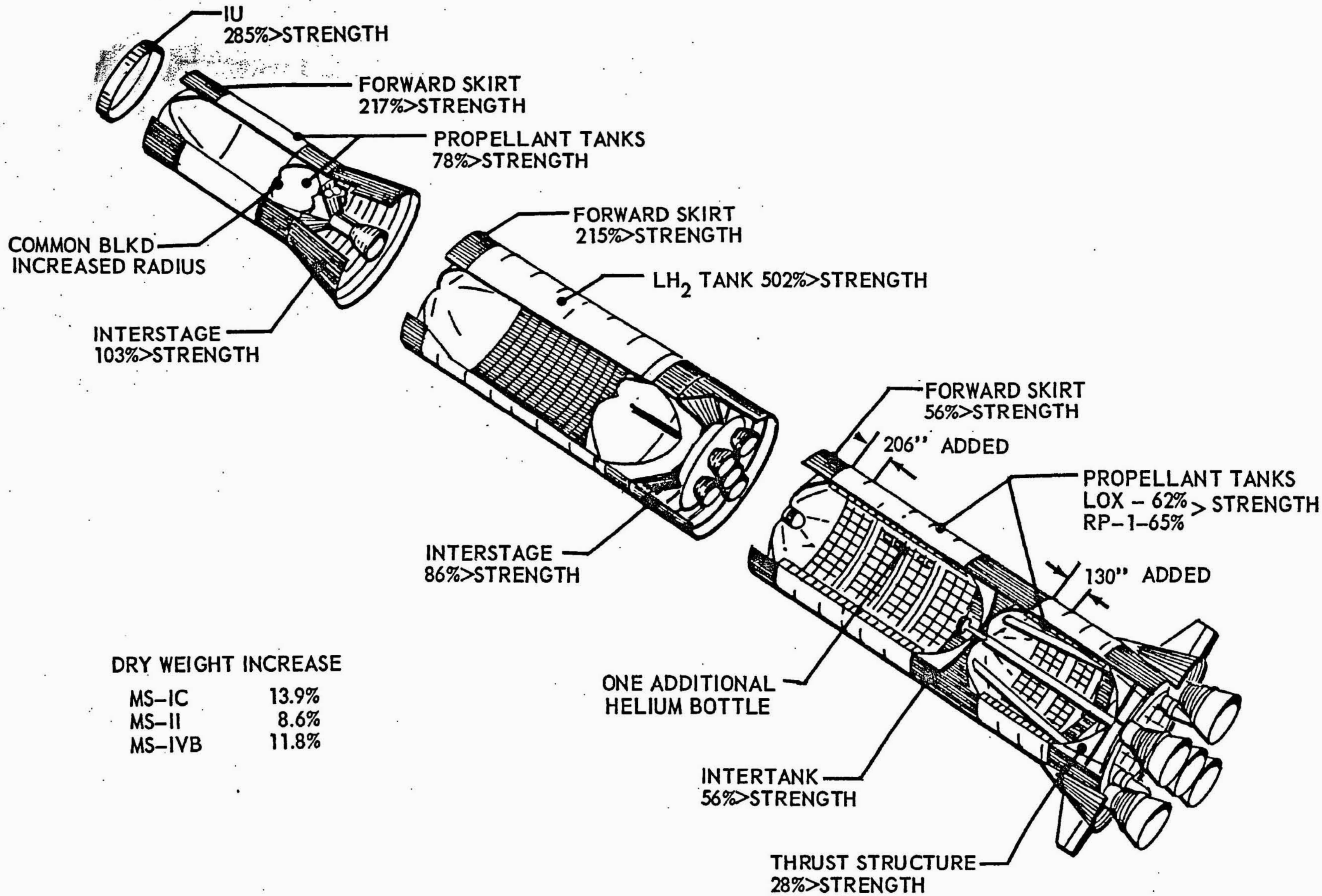
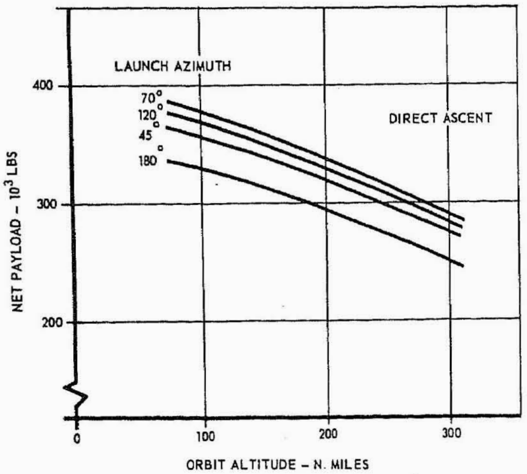
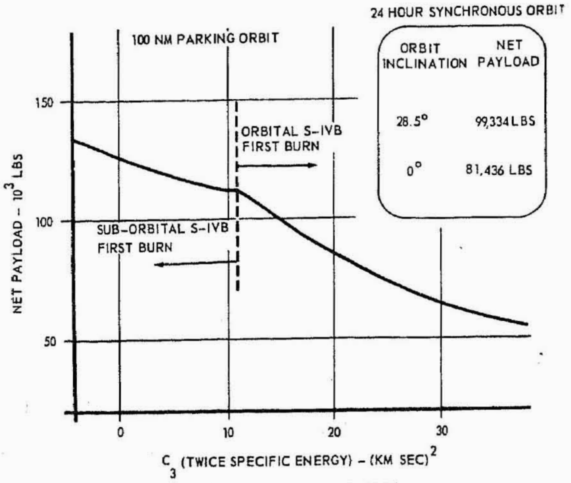


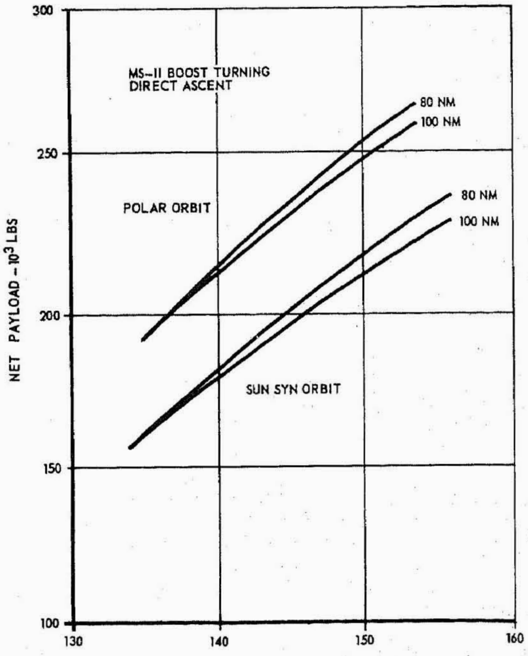
Figure 11. V-4(S)B Vehicle Impact.



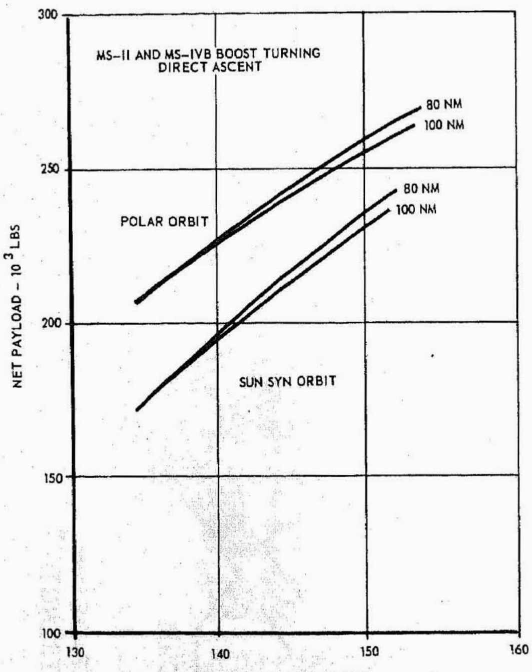
TWO-STAGE ORBIT ALTITUDE-AZIMUTH PAYLOAD CAPABILITY



THREE-STAGE HIGH ENERGY MISSION CAPABILITY



TWO-STAGE POLAR & SUN SYNCHRONOUS ORBIT PAYLOAD CAPABILITY



THREE-STAGE POLAR & SUN SYNCHRONOUS ORBIT PAYLOAD CAPABILITY

Figure 12. V-4(S)B Alternate Missions

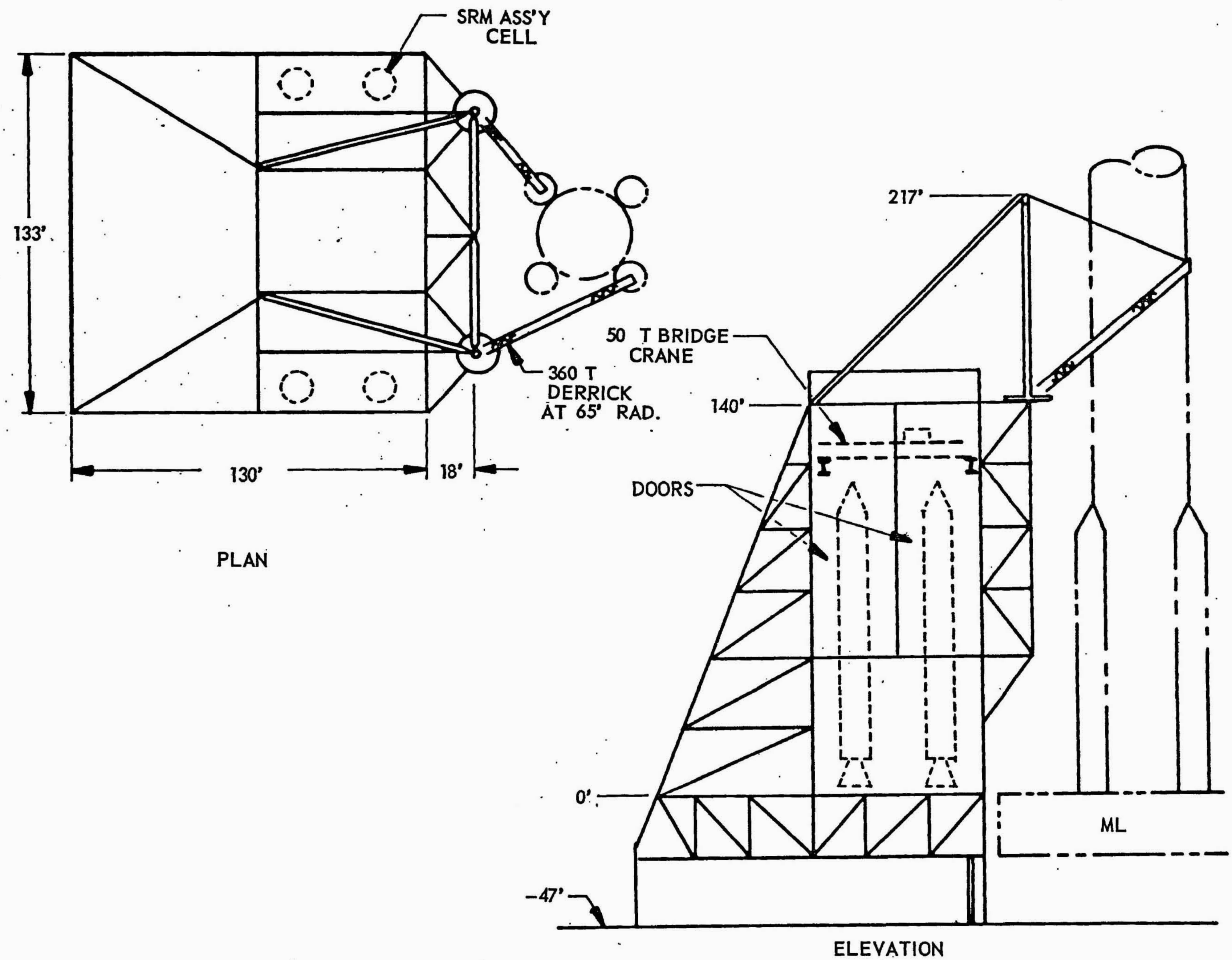


Figure 13. Mobile Assembly and Handling Structure.

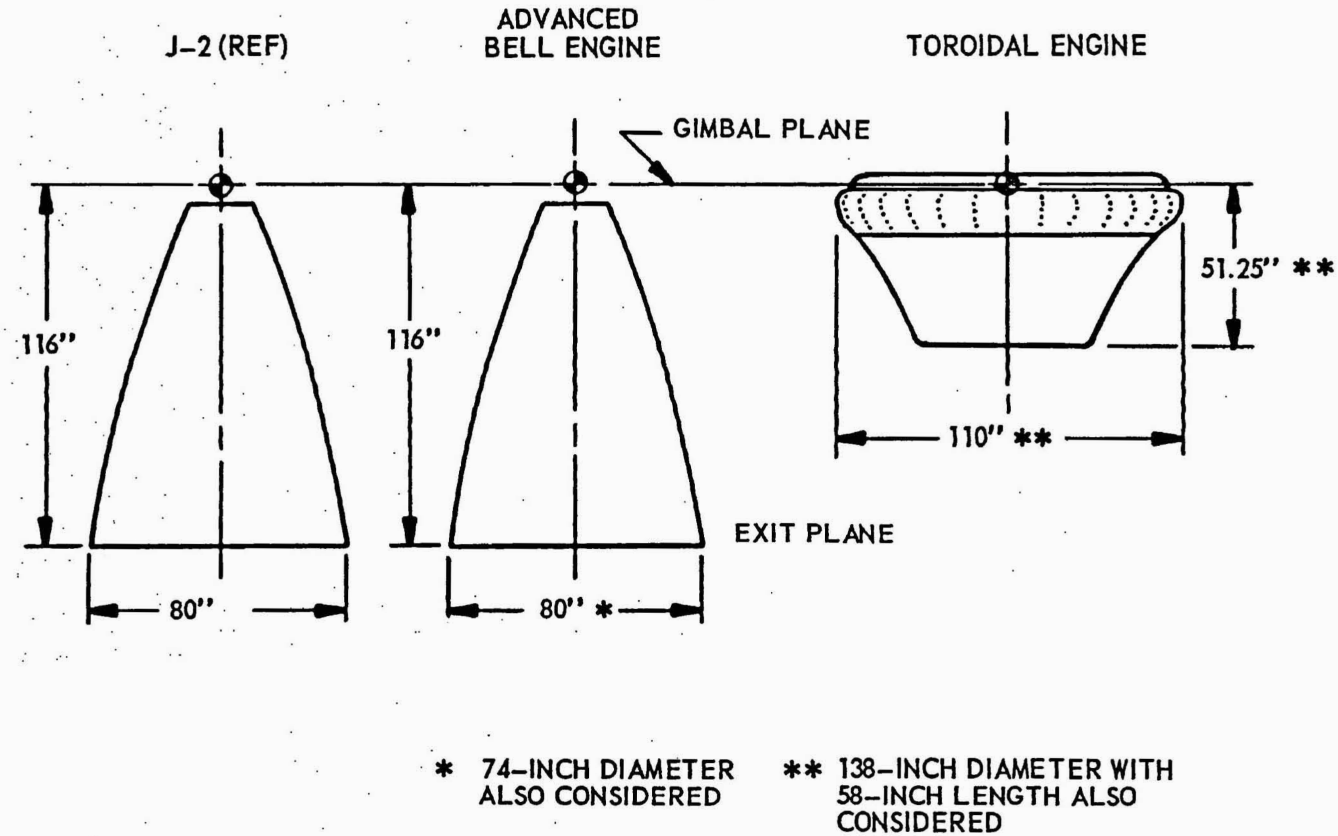


Figure 14. Candidate Upper Stage Engines.

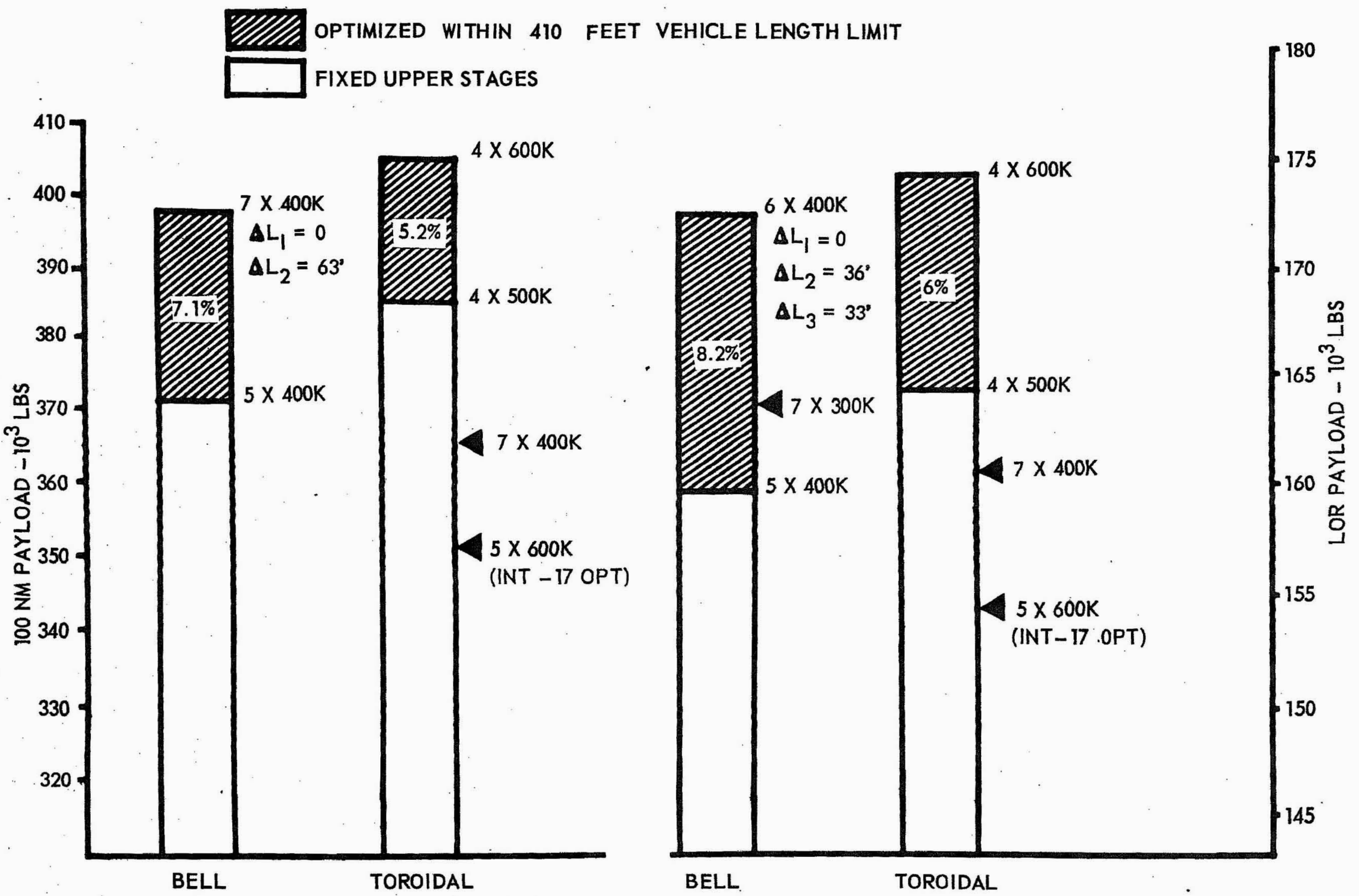


Figure 15. V-3B Vehicle Payload Comparison.

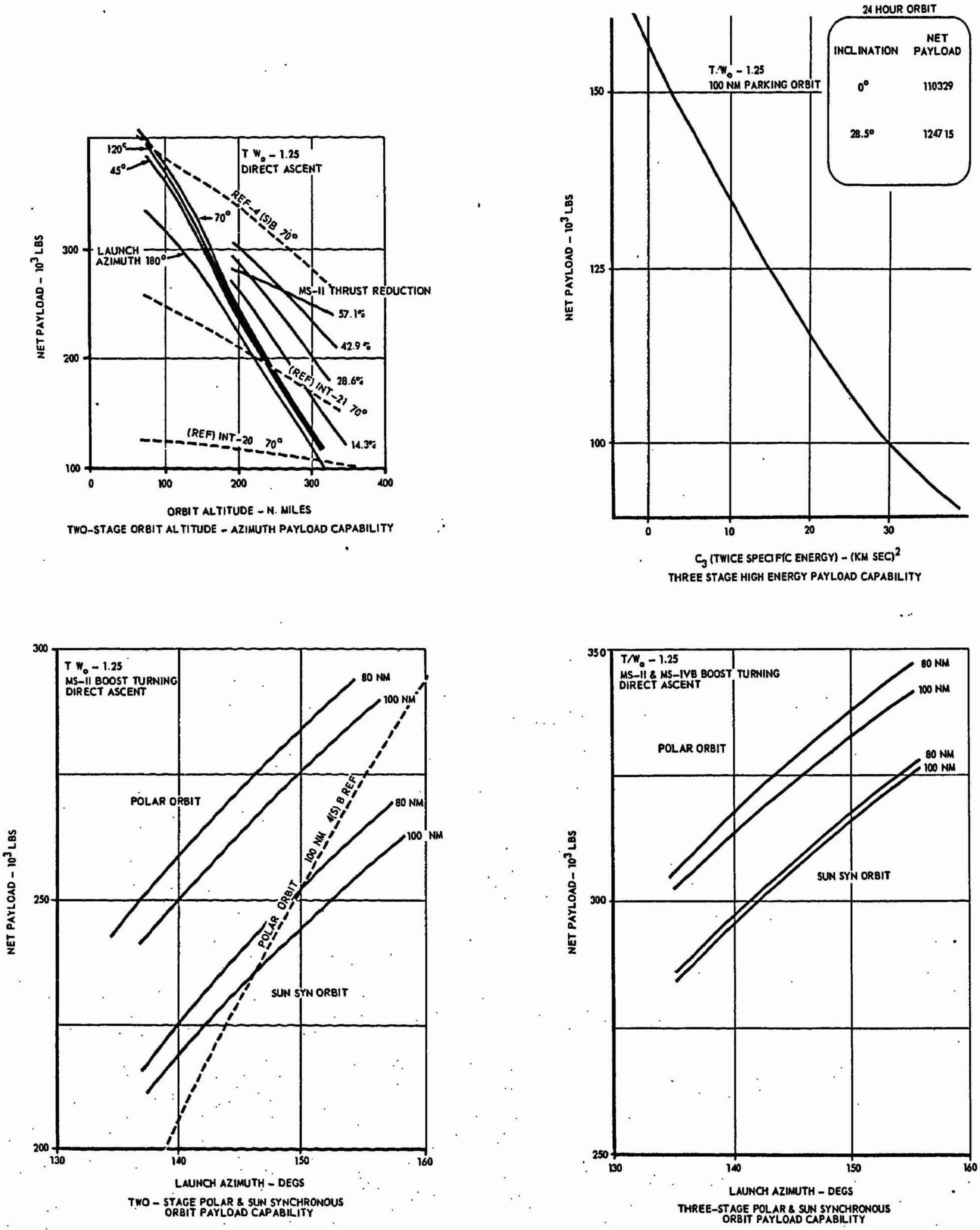


Figure 16. V-3B Alternate Mission.

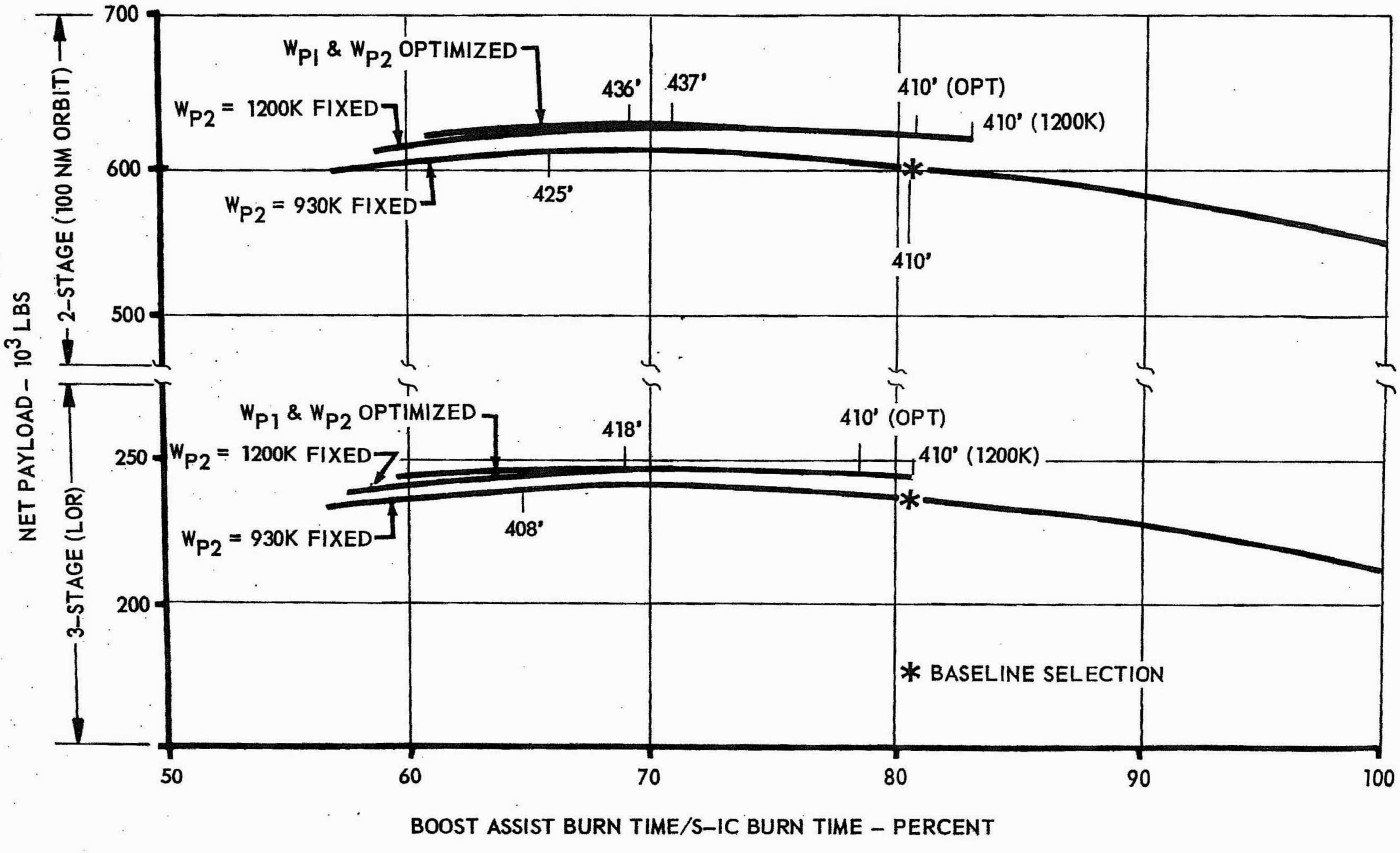
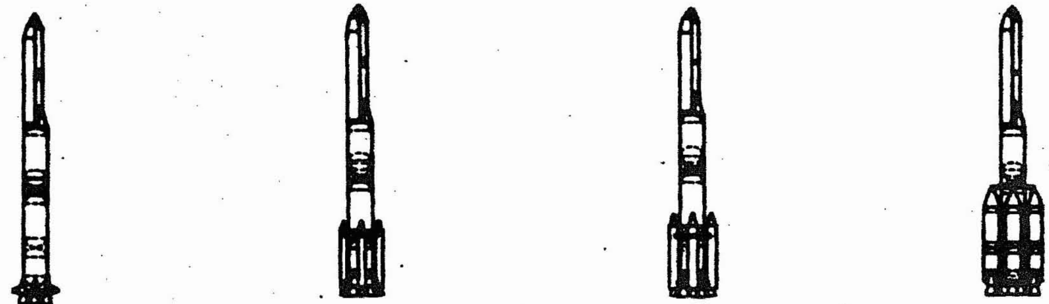


Figure 17. V-23(L) Performance Data Trades.



	V-3B 2 STG	V-3B 3 STG	V-4(S)B 2 STG	V-4(S)B 3 STG	V-25(S) 2 STG	V-25(S) 3 STG	V-23(L) 2 STG	V-23(L) 3 STG
DESIGN REVISION	1) LENGTHEN & STRENGTHEN STRUCTURE 2) UP-RATED & ADVANCED ENGINES		1) LENGTHEN & STRENGTHEN STRUCTURE 2) ATTACH SOLID ROCKET MOTORS		1) LENGTHEN & STRENGTHEN STRUCTURE 2) ATTACH SOLID ROCKET MOTORS		1) LENGTHEN & STRENGTHEN STRUCTURE 2) DESIGN & ATTACH LIQ. ROC	
FACILITIES IMPACT	1) MILA MOD. (MIN.) 2) 400K MFG. FACILITY		1) MOBILE SOLID MOTOR ASSY. BLDG. 2) MOBILE LAUNCHER 3) PAD & OTHER MODS.		1) MOBILE ERECTION & PROCESSING STRUCTURE 2) MOBILE LAUNCHER 3) PAD& OTHER MODS.		1) LIQ ROC MFG FACILITY 2) TWO CRAWLERS 3) MOBILE LAUNCHER 4) PAD & OTHER MODS.	
PAYLOAD – 10^3 LBS.	367	161	380	139	494	189	579	220
* DDT&E –		1097.6		431.6		603.1		944.9
* R&D FLIGHT VEHICLES – $M		325.6		279.1		324.2		413.0
* AVG. OPERATIONAL UNIT COST – $M	116.7	139.0	105.1	124.8	109.6	131.0	142.5	163.8
$M * OPERATIONAL COST EFFICIENCY – $/LB P_L	318	864	276	896	222	694	246	745
FIRST DELIVERY (YRS FROM ATP)	5.7		3.5		3.5		5.4	

Figure 18. Uprating Summary.

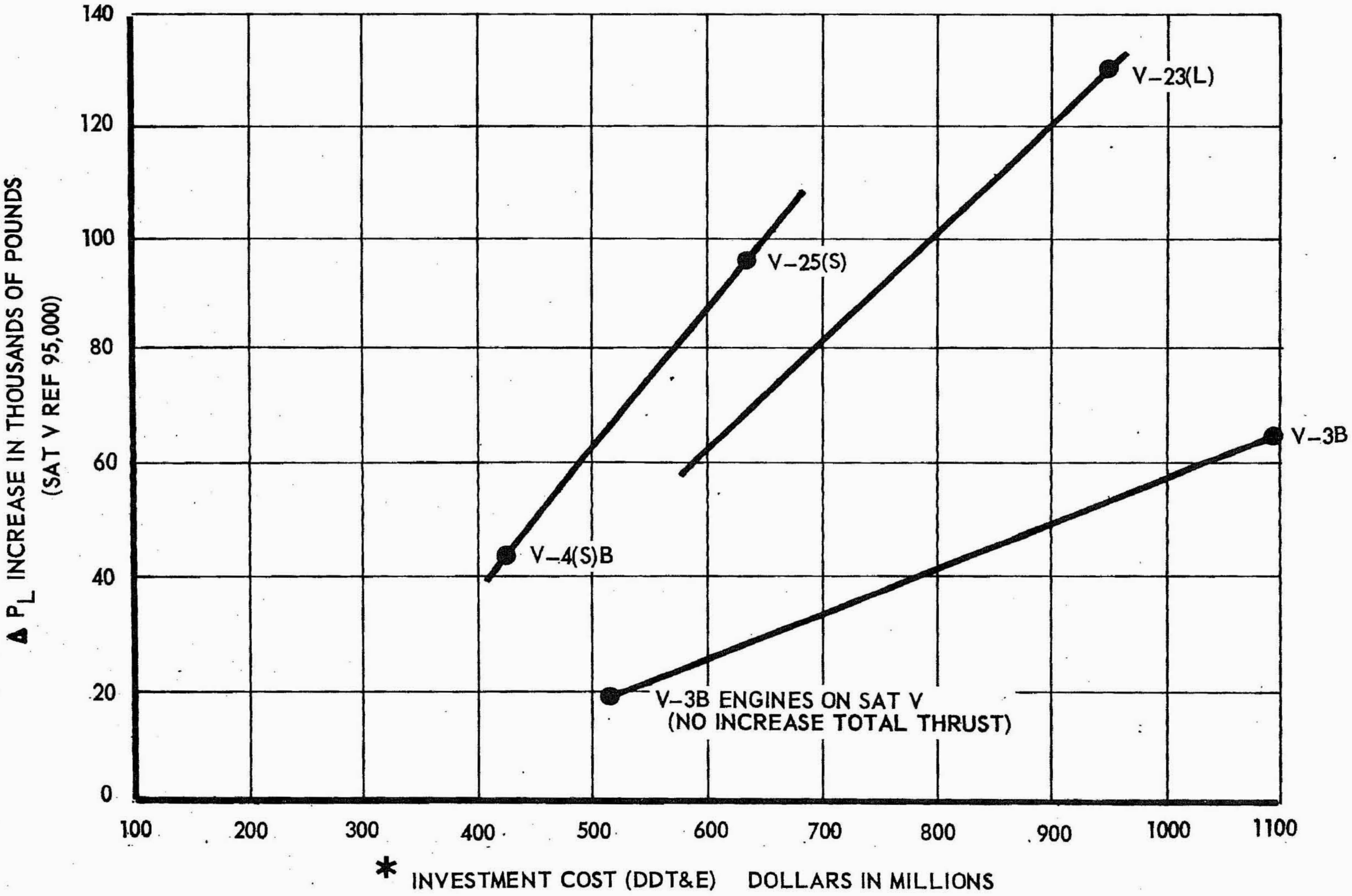


Figure 19. Investment Cost for Growth Vehicles.

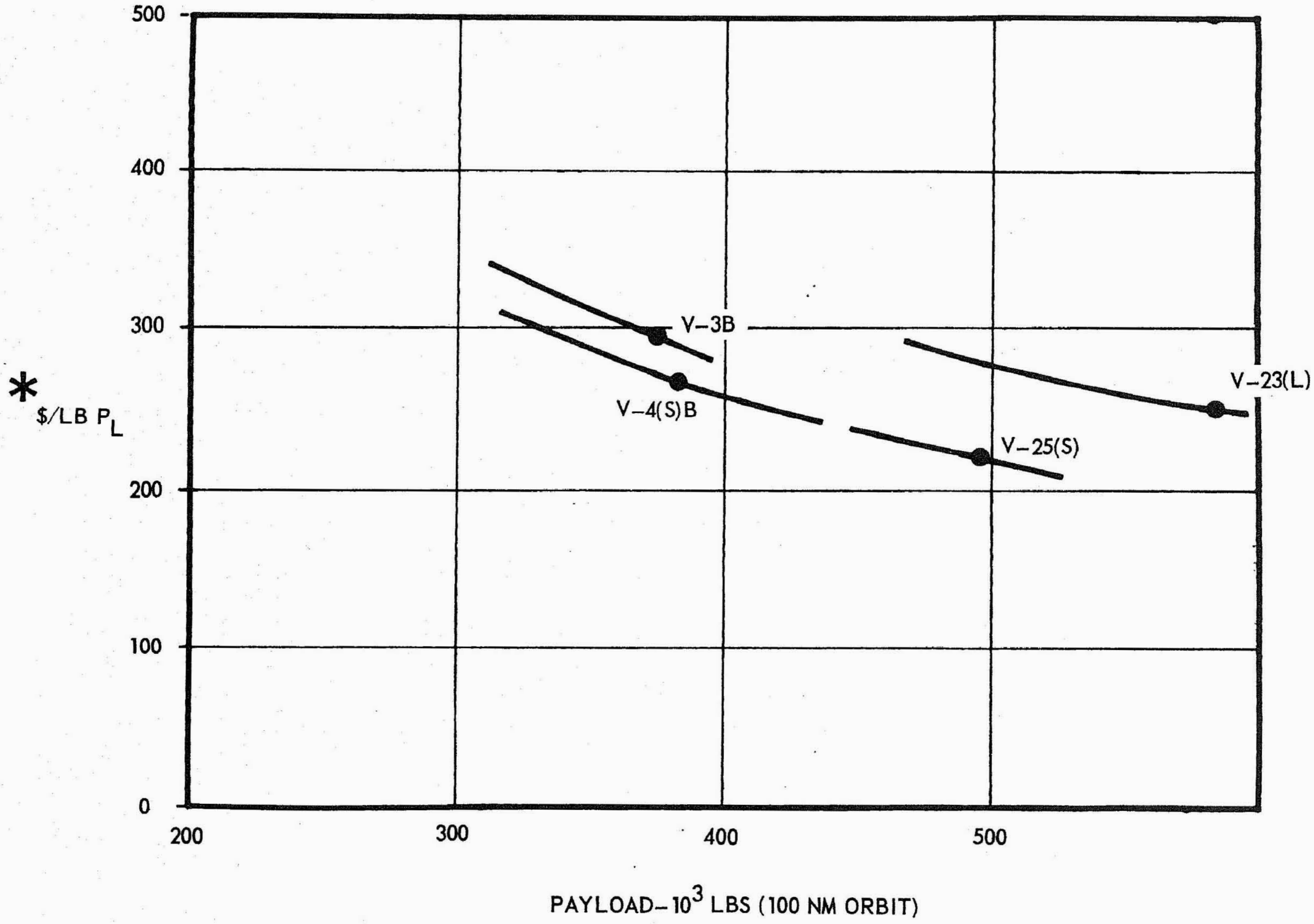


Figure 20. Two-Stage Payload Cost Efficiency.

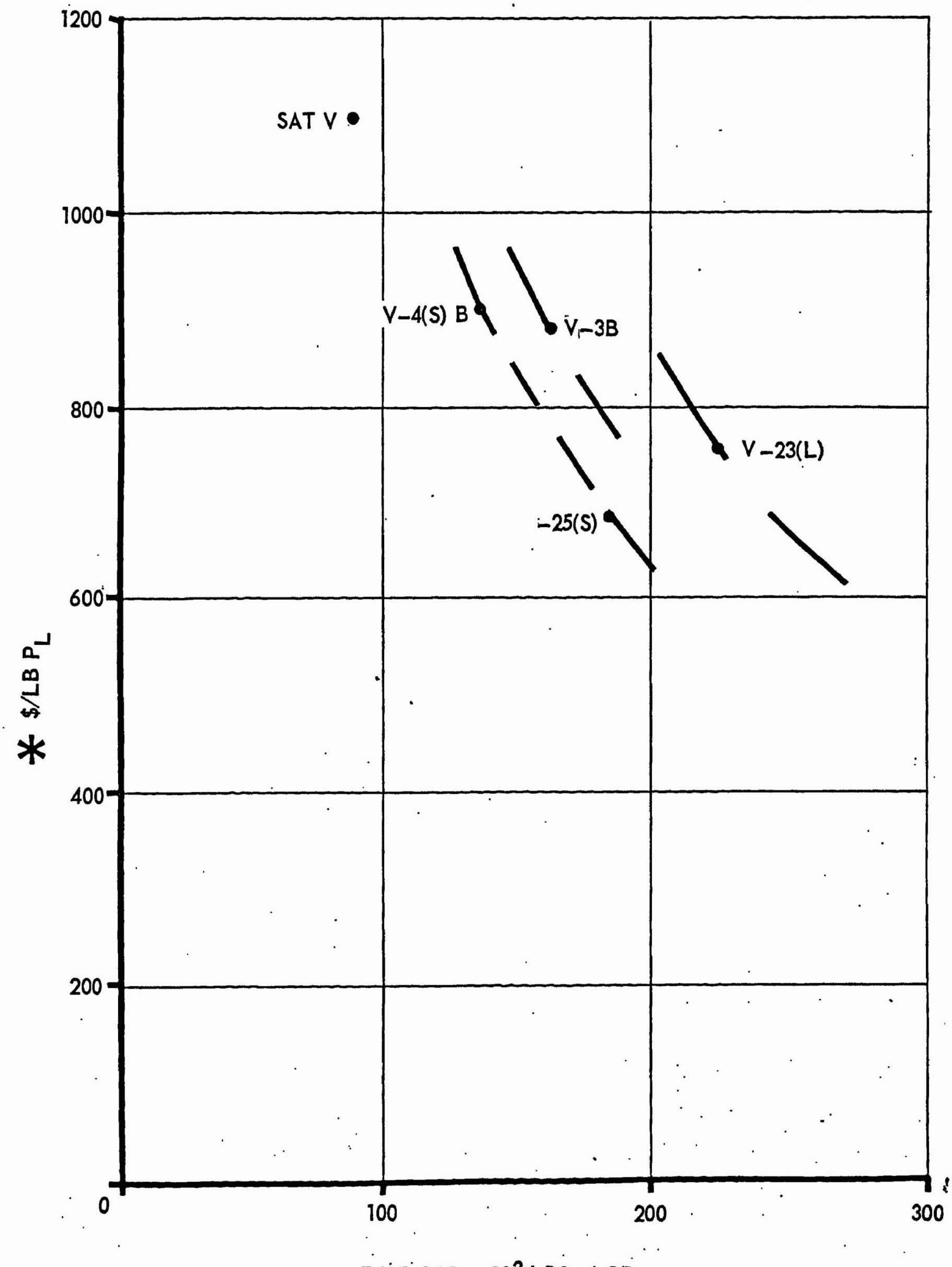


Figure 21. Three-Stage Payload Cost Efficiency.