LAUNCH VEHICLE REQUIREMENTS FOR REENTRY RESEARCH MISSIONS 40,000 to 60,000 FPS VELOCITY

LTV ASTRONAUTICS DIVISION
LTV AEROSPACE CORPORATION

TASK I RESULTS

FACILITY FORM 602

N66-87888
(ACCESSION NUMBER)

116
(PAGES)

CR-79296
(NASA CR OR TMX OR AD NUMBER)

(THRU)

None
(CODE)

(CATEGORY)

LAUNCH VEHICLE REQUIREMENTS
FOR RE-ENTRY RESEARCH MISSIONS
40,000 TO 60,000 FPS VELOCITY

NARRATIVE AND SLIDE PRINTS FOR

THE TASK I ORAL PRESENTATION

This document was prepared by LTV Astronautics Division, Dallas, Texas for the NASA, Langley Research Center under Contract NAS 1-6049.

LAUNCH VEHICLE REQUIREMENTS FOR REENTRY RESEARCH MISSIONS

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1.0 INTRODUCTION

It has long been proposed by many leaders of the U. S. Scientific and Engineering Community that the next logical steps in the national space effort after manned Lunar exploration should be extensive unmanned planetary exploration followed by manned exploration. In the early 1960's various government space planning agencies supported by the industrial technical community commenced investigation of launch vehicle requirements for planetary missions. Results of early investigations showed that velocity requirements would range from 36,000 feet per second upward with a large number of missions falling in the 40,000 to 60,000 feet per second velocity range as shown on Figure 1-1. The lower curve of Figure 1-1 roughly illustrates launch velocity to reach the various planets with minimum energy expenditure. Corresponding travel times are also shown. In addition, velocities required to reduce mission time to the outer planets are shown. Increasing velocities for missions to the near planets, Mars and Venus, opens the launch windows and reduces trip time. Design of spacecraft returning from planetary missions and reentering the Earth's atmosphere at these velocities will require extensive supporting research data obtained from flight and ground testing.

In early 1965 LTV recognized the need for a study to investigate increasing the velocity of the available national launch vehicles for conducting a broad spectrum of re-entry research test missions. A proposal submitted to NASA/LRC in June 1965 subsequently resulted in a contract award to LTV in April 1966.

The Contract (NAS 1-6049) is being administered by Mr. Herbert J. Pelton, NASA/LRC Contracts Administrator and technically directed by Mr. John E. Canady, Jr., NASA/LRC, Technical Representative.

The work is being performed at the LTV Astronautics Division plant in Dallas, Texas. Mr. Robert G. Edwards is the LTV Project Manager and Mr. Richard S. Huang is the LTV Project Engineer responsible for execution of the contract.

The specific purpose of this study is to examine the problem of providing launch vehicle capability to conduct Earth entry research at 40,000 to 60,000 ft/sec velocity utilizing existing flight hardware and facilities to the maximum extent possible as indicated on Figure 1-2. The results of the study are objectively to point the way to a "family" of research launch vehicles which, at minimum cost, could be provided to meet the needs for high speed re-entry research in the 1970-1980 time period.

2.1 DEFINITION OF TERMS

Since the various terms defining components of launch vehicle systems are not firmly standardized throughout the aerospace industry, the terminology used in this study has been defined to assure consistency and clarity. Figure 2-1 pictorially presents the terms which have been used to designate the major components of launch vehicle systems in the study.

Space Vehicle - The complete assembled vehicle consisting of the research launch vehicle and spacecraft.

Research Launch Vehicle - The total launch vehicle including the booster, velocity package, and the shroud.

Booster - The national launch vehicle in total or in parts. That portion of the research launch vehicle used to inject the velocity package to the desired conditions along the flight trajectory.

Shroud - The aerodynamic fairing used during ascent flight through the atmosphere to cover the spacecraft and all or part of the velocity package.

Velocity Package - The portion of the research launch vehicle mounted on top of the booster excluding the shroud. The velocity package is used during the descent powered phase of flight to provide the desired re-entry conditions to the spacecraft.

Spacecraft - The re-entry spacecraft and the necessary structure for adapting the spacecraft to the last stage of the velocity package. Spacecraft weight includes the spacecraft separation system.

Additional terms having specific definitions for this study are depicted on Figure 2-2.

Range at Re-entry - The great circle distance from the launch point to the 400,000 ft. altitude entry test point.

Program - A project requiring the procurement and launching of two to three research launch vehicles to accomplish project mission objectives.

Performance Effectiveness - The actual re-entry velocity obtained at 400,000 ft. altitude divided by the research launch vehicle total vacuum ideal velocity expressed in percent.

Mission Analysis - Those studies conducted to analyze all facets of a mission including all flight and supporting hardware, performance, accuracy, operations, integration, and range requirements including cost and schedule for the mission.

2.2 STUDY SCOPE

The period of performance of this study contract is 15 months inclusive of submission of the final report. The total contract involves the expenditures of approximately 13,000 man-hours, 30 IBM computer hours, and 23 trips for gathering data and reporting progress.

The work is subdivided into three major Tasks, each of approximately 4 months duration. The final three months of the study will be used to document the results of these Tasks. An oral presentation is required upon completion of each of the three major Tasks. This is the first of the three presentations to be given.

2.2.1 Task 1, which has been completed, consisted of the candidate Research Launch Vehicle selection. A summary of the work items performed under this Task is shown on Figure 2-3. In order to accomplish the study purpose of "establishing launch vehicle capability utilizing existing flight hardware to the maximum extent possible" it was necessary to conduct a thorough survey of launch vehicles, along with liquid and solid propellant motors that currently exist and are under funded development. Prior to execution of the Contract, LTV and NASA agreed upon the Boosters from the National Launch Vehicle Inventory which were to be included in the study. Through contacts with various government user agencies, private industrial sources, and with the assistance of NASA/LRC Booster performance input data were acquired.

In addition, propulsion and weights data were acquired for approximately fifty existing solid propellant motors, several solid propellant motors under development, and several existing liquid and solid Velocity Packages. Using LTV's best assessment of the projected improvement of solid propellant characteristics for the 1970 time period theoretical possible performance improvements were computed for several existing motors. Based on LTV's past experience in design and system integration of Velocity Packages and solid motor interstaging parametric Velocity Package weight data were computed for performance analyses. Preliminary guidance and control concepts were evaluated during this task including use of Booster upper stage attitude control systems to position the Velocity Package prior to Velocity Package ignition. A staging analysis was performed to establish the optimum Velocity Package motor sizes for one, two, and three stage Velocity Packages for each of the Boosters under consideration. Existing motors from the accumulated inventory were matched as closely as possible to the idealized motor requirements. Performance analyses were then conducted using the actual selected motor performance characteristics. Generally performance was also computed for other actual non-optimum motors on the various Boosters to insure that the results of the staging analyses were valid. The optimum range for each configuration was determined for a -15° entry angle mission by optimum utilization of the Booster liquid upper stages (i.e., Agena D, Centaur, Transtage, etc.) Performance of several Booster-existing Velocity Package combinations was computed and results compared to the optimum Booster-Velocity Package combinations. Performance comparisons were also made between existing Solid Propellant motors and the theoretical 1970 state-of-the-art motors. Finally selection of the most promising candidate Research Launch Vehicles was made based on comparative performance, reliability, Velocity Package motor development status and minimizing the number of Velocity Packages to be developed.

2.2.2 Task II will consist of detailed performance and cost evaluation of the Research Launch Vehicles selected from Task I, as shown on Figure 2-4.

Preliminary design and systems selection will be performed along with development of trajectories and design data. Performance effectiveness and error analyses will be conducted on each candidate Research Launch Vehicle. Cost data will be acquired for all Boosters and Velocity Packages and used to perform cost-performance tradeoffs. The results of this task will be selection of least cost Research Launch Vehicles for mission analysis in Task III.

2.2.3 Task III outlined on Figure 2-5 will involve performing mission analysis for up to three specific missions utilizing Research Launch Vehicles selected from Tasks I and II. This will include providing detailed design data for each Research Launch Vehicle, detailed performance data, and development plans.

2.3 PERFORMANCE OBJECTIVES

The performance objectives for this study are listed on Figure 2-6. Re-entry velocities from 40,000 ft/sec to 60,000 ft/sec are being investigated for spacecraft weights ranging from 50 to 1000 pounds. Re-entry velocity, flight path angle, angle-of-attack, and range are referenced to 400,000 foot altitude. Burnout of the last stage motor of the velocity package is to occur 10 seconds prior to 400,000 foot altitude. Re-entry flight path angles from -7 degrees to -25 degrees are to be investigated during Task II. All performance data are to be based on zero angle-of-attack at the reference re-entry altitude throughout the study.

2.4 BOOSTER AND RANGE CONSTRAINTS

During Task I the development of parametric performance data required investigation of a wide range of variables with minimum regard to vehicle or trajectory constraints; however, detailed consideration will be given to booster heat load, allowable dynamic pressure, gross weight capability, and allowable bending moments during Task II. The launch sites and targeting areas shown on Figure 2-7 will be used in the performance analysis of Task II.

3.0 SUMMARY OF TASK I RESULTS

The significant results from each of the major work items performed during execution of Task I are summarized in this section. A detailed description of the analyses performed to arrive at these results is presented in Section 5.0.

12 Boosters from the National Launch Vehicle Inventory, as shown on Figure 3-1, along with 4 modified versions of these launch vehicles were used in the study. Utilizing the latest available information from Booster manufacturers, user agencies, and NASA Headquarters a data package was assembled for each of these 16 Boosters. These packages contain the items listed on Figure 3-2. These packages along with dimensioned sketches of each booster will be included as an appendix in the technical report to be provided to NASA at contract completion.

Propulsion data was acquired for the motors listed on Figure 3-3 along with a brief description of the past and current applications, status, and vendor name. These motors range in size from 150 pounds to 50,000 pounds loaded weight and all meet the study requirement of specific impulse greater than 250 seconds and propellant mass fraction in excess of 0.80. A motor list containing the data shown on Figure 3-4 has been provided to NASA per Ref. 1. This listing is "Confidential" due to the classified nature of some of the data.

In addition to the solid propellant motors considered in the study several liquid propellant motor and solid motor "existing" Velocity Packages were also considered. Instead of parametric weights the actual weights of the existing Velocity Packages were used for performance analyses. The list of "existing" Velocity Packages considered is shown on Figure 3-5. The characteristics of these "existing" Velocity Packages were defined in sufficient detail to permit performance evaluation.

Parametric weights data for the Velocity Packages were generated from an analysis of all available data on existing flight proven vehicles. Guidance, telemetry, destruct, and ignition system weights were assumed to be non-size dependent. Provisions were made for either spin stabilized or guided velocity package weights. Preliminary layouts of structural adaptor dimensions were made to refine the structural weights. In addition parametric weights were generated for shrouds which were assumed to cover the Velocity Packages during ascent flight in the atmosphere.

Figure 3-6 shows a sample format of the staging analysis results. Idealized Velocity Package motor size requirements were computed for 16 Boosters as a function of spacecraft weight. The idealized size requirements were matched with the motor list and motor selected which most nearly matched the idealized size requirements. Non-optimum (i. e., larger and smaller) motors were also selected to use in subsequent performance analyses to verify the validity of the staging analysis.

As illustrated on Figure 3-7 the optimum range for each Booster, having re-start capability in the Upper Liquid Stage, was established by proportioning the burn time of the upper stage by varying amounts between the "up" and "down" legs of the powered flight. Range was optimized for maximum velocity. Re-entry performance was then computed for 86 candidate Research Launch Vehicles consisting of the 16 Boosters with one, two, and three stage Velocity Packages. Performance was computed for a re-entry angle of -15 degrees, angle of attack at 400,000 feet altitude of zero degrees, and Velocity Package burnout 10 seconds prior to reaching 400,000 feet altitude. Velocity Package parametric weights were based on an assumed spin stabilized Velocity Package. Performance curves, reentry velocity versus spacecraft weight, were plotted for each family of boosters.

Performance trade studies were also made as illustrated on Figure 3-8. Comparison of projected performance of "1970" state-of-the-art solid propellant motors revealed that overall Research Launch Vehicle Velocities can be increased by 2000 to 3000 feet per second. This is due to two factors: (1) the higher specific impulse of the "1970" motors and (2) being able to exactly match the idealized motor size requirements with a new motor. Two stage Velocity Packages showed a performance increase of 4000 to 5000 feet per second over a single stage for spacecraft weights of 400 pounds. Addition of a third stage to various Velocity Packages only increases velocity between 1000 to 2000 feet per second for the same spacecraft weight. All three stage Velocity Packages were subsequently eliminated from the study since the small performance gain was felt to be offset by the decreased reliability of the system with the additional stage. In general new optimized Velocity Packages showed better performance than the "existing" Velocity Packages evaluated for various boosters which was expected. However, significant performance can be obtained by adapting existing Velocity Packages to various boosters. As an example, the Fire Velocity Package on Titan III C will reenter a 220 pound spacecraft at 50,000 feet per second. However, spacecraft weight for the same velocity can be increased to 375 pounds by using a new X259/FW-4S Velocity Package on the same Booster. The solid motor versus liquid motor Velocity Package trade study revealed that greater performance can be obtained for this type of re-entry mission with solid motors. A high performance penalty is associated with the long burn time of a liquid motor Velocity Package. A re-entry velocity penalty of 1000 to 2000 feet per second is experienced by the addition of a guidance and control system to the Velocity Packages considered. This performance decrease, if not tolerable for a particular experiment, could be offset by use of a more advanced state-of-the-art motor with a higher specific impulse.

Review of the results of the performance analysis and trade studies led to the selection of 14 Research Launch Vehicles for Task II. Six Boosters were eliminated from the study, as shown on Figure 3-9, based on performance comparisons with other boosters. Thirteen candidate Velocity Packages evaluated in the performance analysis were reduced to the four shown on Figure 3-10. Elimination of Velocity Packages was primarily based on considerations of motor status and the objective of minimizing the number of Velocity Packages requiring development. Figure 3-10 illustrates the modular approach that can be used to design a few basic Velocity Packages which can be adapted to many boosters to perform a wide range of re-entry missions. Using the nine Boosters, Centaur Stage, and four Velocity Packages shown, fourteen Research Launch Vehicles can be composed to perform the entire spectrum of re-entry missions from 40000 to 60000 feet per second, except spacecraft weights greater than 400 pounds at 60,000 feet per second. Figure 3-11 shows the re-entry velocity capability for each of these fourteen Research Launch Vehicles as a function of spacecraft weight. They are ranked according to performance from the Atlas (SLV-3A)/X-259/FW-4S to the Saturn V/M56/TE-364-2. Note that several of the Research Launch Vehicles have competitive performance, such as the Saturn IB and Titan IIIC.

SUMMARY OF STUDY CONCLUSIONS

The major conclusions from Task I are summarized on Figure 3-12. They are as follows:

- The number of Velocity Packages required, in conjunction with existing Boosters, to accomplish re-entry research missions from 40,000 to 60,000 feet per second are few.
- Existing solid propellant motors are adequate for these Velocity Packages even though performance gains can be realized from future motor development.

- Performance objectives are achievable using existing launch sites and targeting areas.
- No unconventional trajectory shaping techniques, such as re-entry from parking orbit, will be required to alleviate range constraint problems.
- To fill the performance gap between Titan III C and Saturn V, the Centaur stage will have to be integrated with the Saturn IB or Modified Titan III C.
- The desired spectrum of mission objectives can be achieved with existing Booster stages and new Velocity Packages developed from existing solid propellant motors.

4.0 RECOMMENDATIONS AND PLANS FOR TASK II

Recommendations and plans for Task II are summarized on Figure 4-1. Five of the Research Launch Vehicle configurations being considered for Task II involve integration of the Centaur stage with the Saturn S-IVB stage and the Titan III, Core Stage II. Since definition of the systems requirements and development cost for the Centaur integration is expected to be a major difficulty in performing the task it is recommended that NASA seriously consider the desirability and practicability of retaining the hybrid configurations, with Centaur, in the study.

It is further recommended that NASA furnish LTV with more specific definition of possible spacecraft configurations during the early part of Task II. Estimated Spacecraft sizes will be required in order to establish the Shroud size requirements. Spacecraft body shapes (i. e., bodies of revolution or lifting bodies) are needed in order to establish whether Velocity Packages can be spin stabilized or must be guided.

LTV has now assembled the data necessary for performance comparisons of a great number of Research Launch Vehicles. It is suggested that NASA may wish

to extend this study to compare performance of Research Launch Vehicles for missions other than high velocity re-entry.

It is anticipated that NASA approval for LTV to proceed with Task II will be on or about August 29th. Internal planning documentation has been issued to the LTV engineering staff for proceeding with Task II in accordance with the contract statement of work. LTV commenced laying the ground work for acquiring Booster cost data needed for Task II during Task I execution. Due to the difficulties encountered in acquiring cost data on National Launch Vehicles, LTV has requested assistance from the NASA Contract Technical Representative. LTV gratefully acknowledges the assistance being given. Task II completion is scheduled for late December of 1966.

6.0 REFERENCES

(1) LTV Memorandum 3-52200/6IM-87, Revision A, "Preliminary Solid Rocket Motor Data For The 1970-1980 Booster Study Program" dated 25 May 1966. (TITLE UNCLASSIFIED)

SOLAR SYSTEM VELOCITY REQUIREMENTS

FLYBY MISSIONS OR ATMOSPHERIC BRAKING AT ARRIVAL

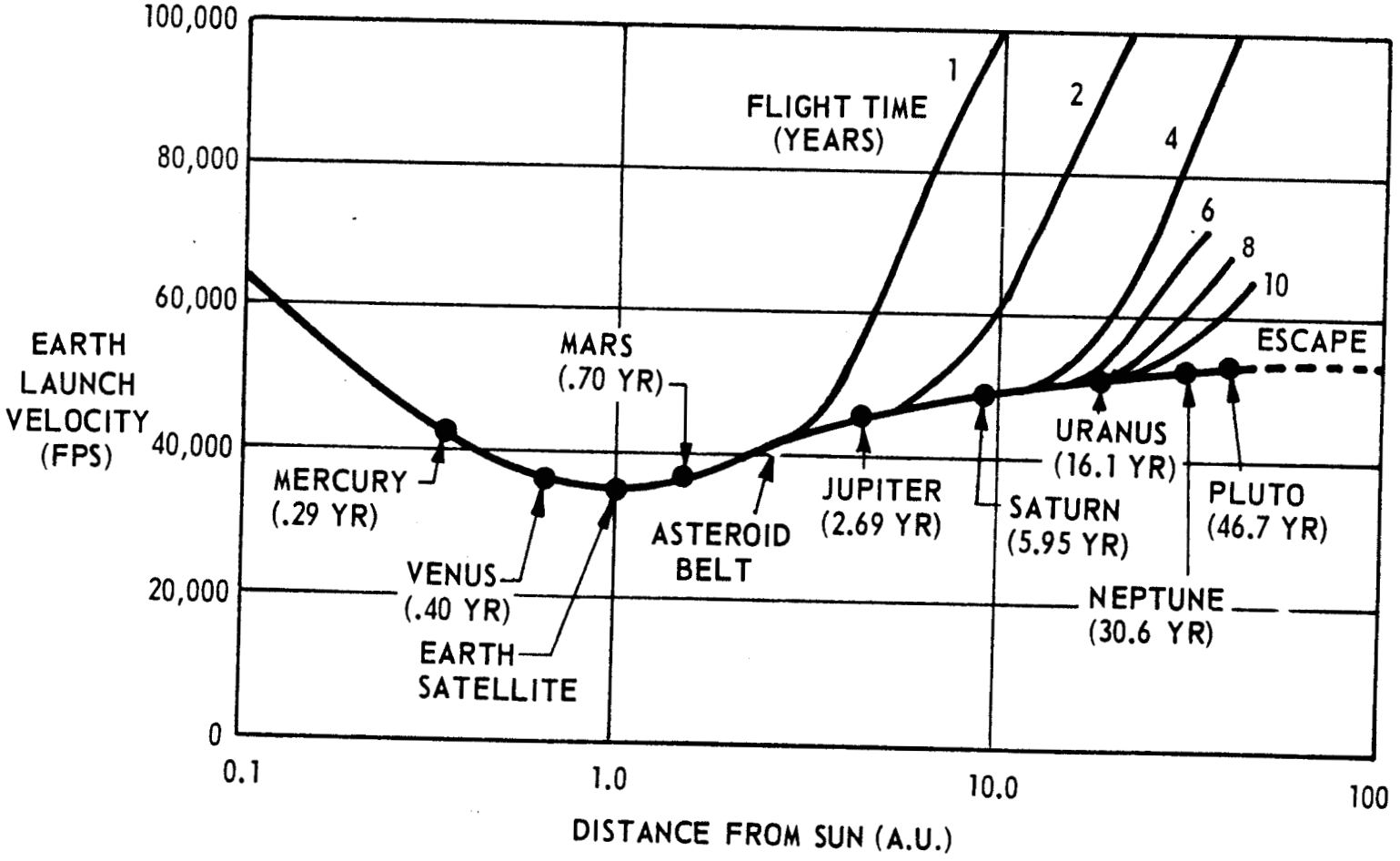


FIGURE 1-1

PURPOSE

EXAMINE GENERAL PROBLEM OF PROVIDING LAUNCH VEHICLE CAPABILITY TO CONDUCT EARTH ENTRY RESEARCH AT 40,000 TO 60,000 FT/SEC VELOCITY UTILIZING EXISTING FLIGHT HARDWARE AND FACILITIES TO THE MAXIMUM EXTENT POSSIBLE

FIGURE 1–2

DEFINITIONS

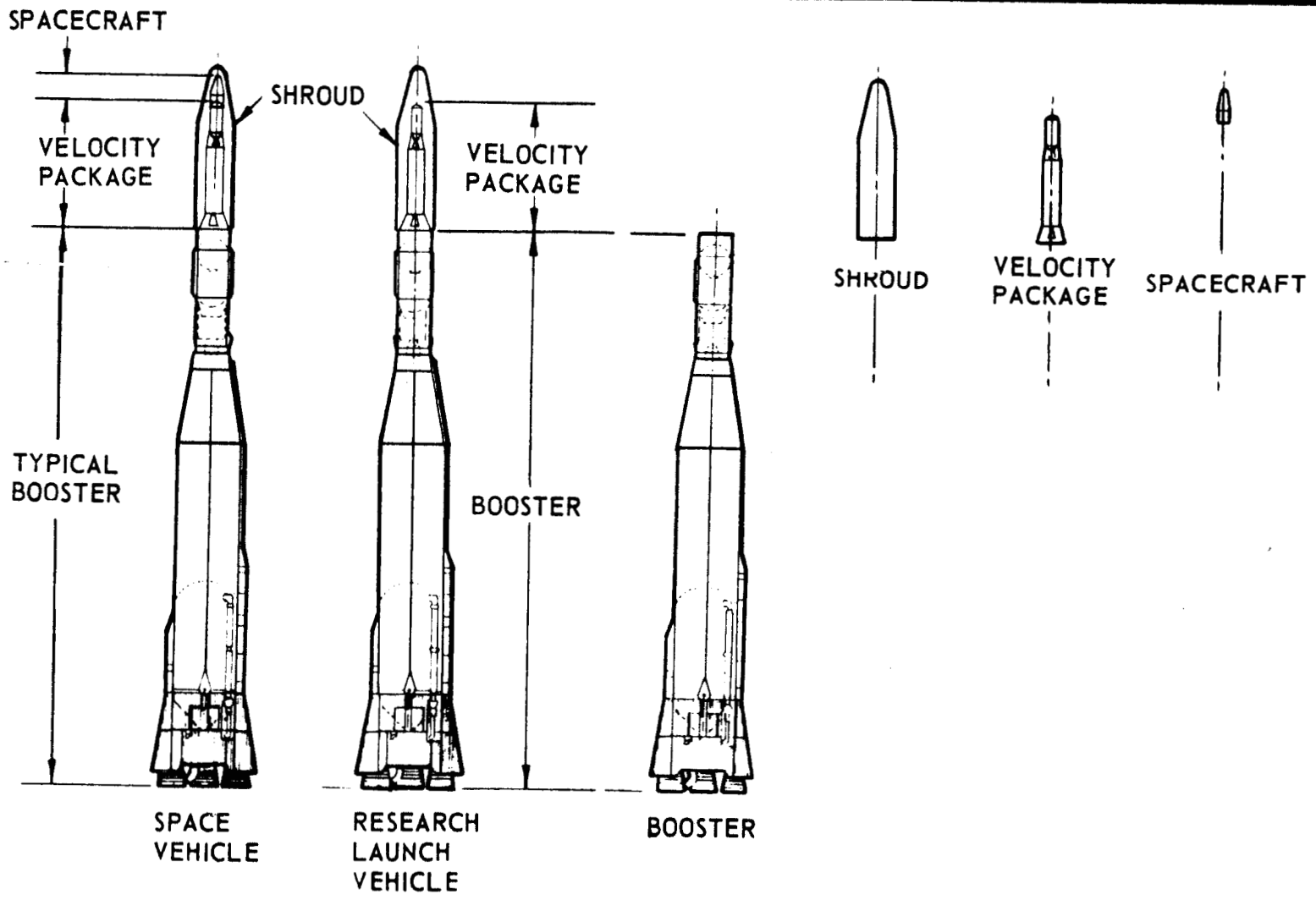
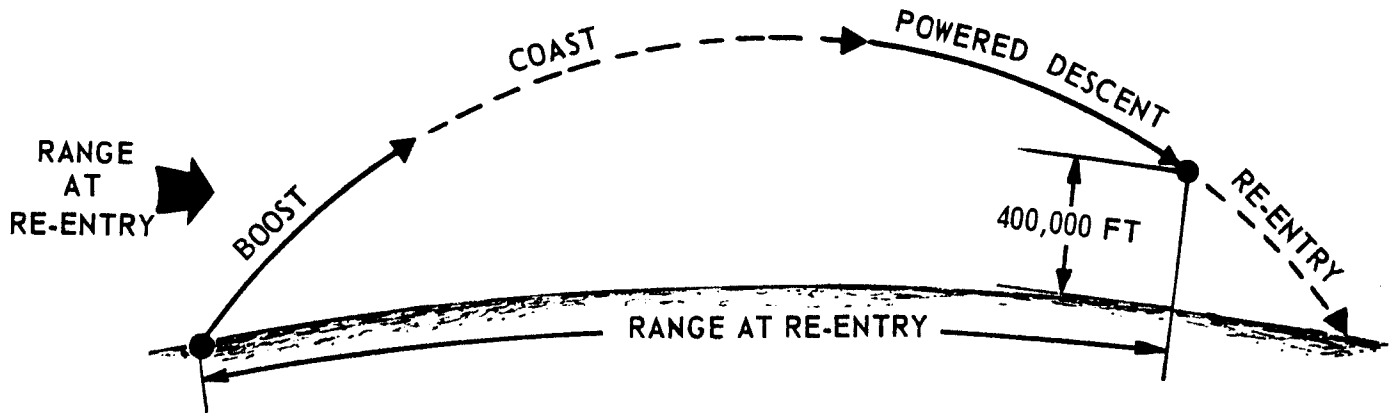
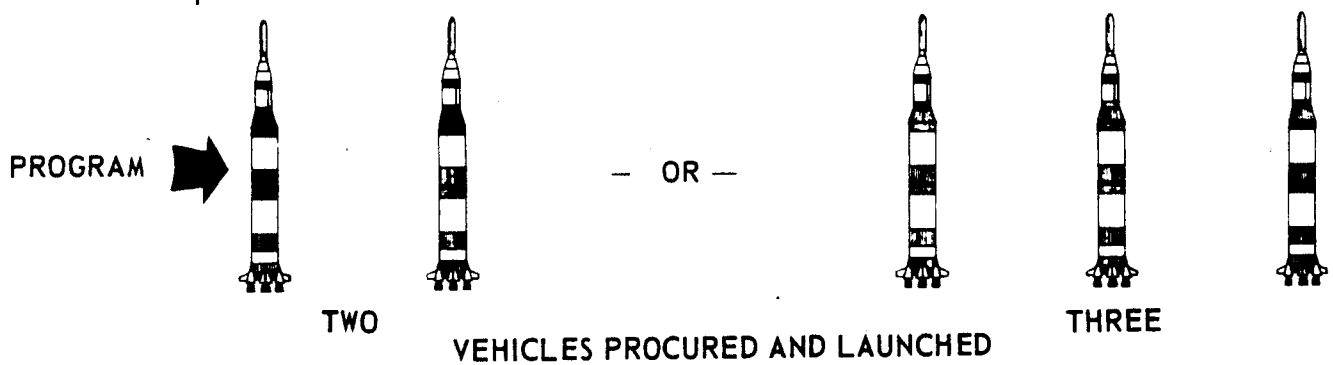


FIGURE 2-1

DEFINITIONS





$$\text{PERFORMANCE EFFECTIVENESS, \%} = \left(\frac{\text{TOTAL ACTUAL RE-ENTRY VELOCITY}}{\text{TOTAL VACUUM IDEAL VELOCITY}}\right)$$

MISSION ANALYSIS →

FLIGHT HARDWARE	ACCURACY	RANGE REQUIREMENTS
SUPPORT HARDWARE	OPERATIONS	COST
PERFORMANCE	INTERGRATION	SCHEDULE

FIGURE 2–2

TASK I
CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

- ACCUMULATION AND VERIFICATION OF BOOSTER PERFORMANCE INPUT DATA
- ACCUMULATION OF VELOCITY PACKAGE EXISTING MOTOR DATA
- PROJECTION OF VELOCITY PACKAGE 1970 STATE-OF-THE-ART MOTOR DATA
- ACCUMULATION OF PARAMETRIC VELOCITY PACKAGE WEIGHTS DATA
- EVALUATION OF VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS
- STAGING ANALYSIS
- PERFORMANCE ANALYSIS
- PERFORMANCE TRADE STUDIES
- RESEARCH LAUNCH VEHICLE SELECTION
- DOCUMENTATION

FIGURE 2–3

TASK II
CANDIDATE RESEARCH LAUNCH VEHICLE EVALUATION

- VELOCITY PACKAGE PRELIMINARY DESIGN
- PERFORMANCE AND DISPERSION ANALYSIS
- COST DATA ACCUMULATION
- COST ANALYSIS
- RESEARCH LAUNCH VEHICLE PERFORMANCE, DISPERSIONS AND COST COMPARISONS
- DOCUMENTATION

FIGURE 2–4

TASK III
MISSION ANALYSIS FOR SPECIFIC RESEARCH LAUNCH VEHICLES

- DESIGN DATA
- PERFORMANCE DATA
- DEVELOPMENT PLANS

FIGURE 2–5

PERFORMANCE OBJECTIVES

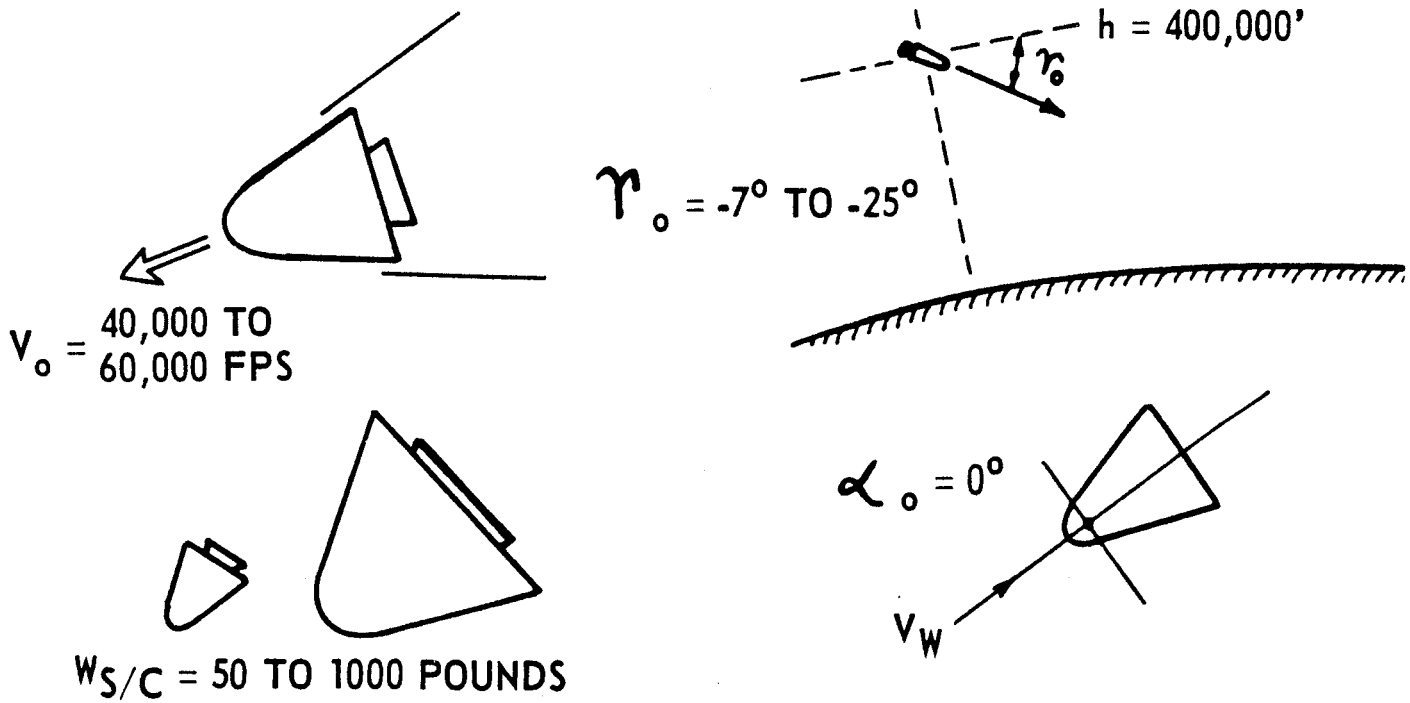


FIGURE 2–6

LAUNCH SITES AND TARGETING AREAS

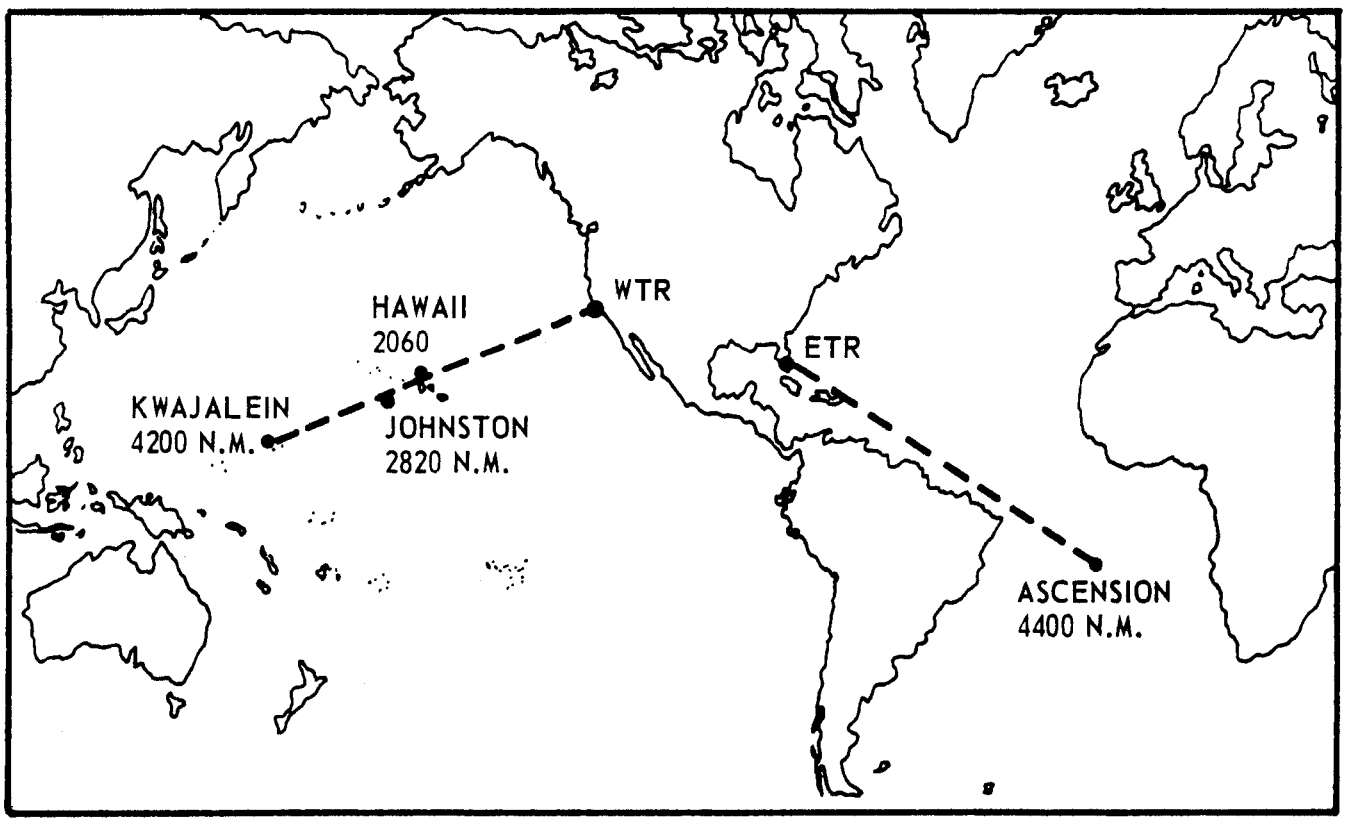


FIGURE 2–7

CANDIDATE BOOSTERS

- FROM NATIONAL LAUNCH VEHICLE INVENTORY

– TAT/DELTA	(DSV–2L/IMP. DELTA)
– THOR/AGENA	(DSV–2K/AGENA D)
– TAT/AGENA	(DSV–2L/AGENA D)
– ATLAS	(SLV–3A)
– ATLAS/AGENA	(SLV–3A/AGENA)
– ATLAS/CENTAUR	(SLV–3C/CENTAUR)
– TITAN II	(GLV)
– TITAN IIIA	(SLV–5A)
– TITAN IIIB	(SLV–5B)
– TITAN IIIC	(SLV–5C)
– SATURN 1B	
– SATURN V	

- MODIFIED VERSIONS OF NATIONAL LAUNCH VEHICLES

– TITAN IIIC/CENTAUR	(CENTAUR REPLACING TRANSTAGE)
– TITAN IIIA/CENTAUR	(CENTAUR REPLACING TRANSTAGE)
– SATURN 1B/CENTAUR	(CENTAUR ADDED)
– SATURN V/CENTAUR	(CENTAUR ADDED)

FIGURE 3–1

BOOSTER DATA PACKAGE

- SEQUENTIAL WEIGHT STATEMENT
- PROPULSION MODEL
- PROPELLANT FLOW RATES
- SEQUENCE OF EVENTS FROM LIFT-OFF
- AERODYNAMIC DRAG COEFFICIENTS
- PITCH PROGRAM NOTES
- VEHICLE CONSTRAINTS

FIGURE 3–2

CANDIDATE SOLID PROPELLANT MOTORS FOR VELOCITY PACKAGES

1. XM-85
2. TE-M-479
3. BE-3-A4
4. PHOENIX
5. X248-A5
6. TE-M-184-3
7. MG 18
8. X258-E6
9. TE-M-442
10. FW-4S
11. XM-86
12. TE-M-442-1
13. TX-306
14. TE-M-442-2
15. FW-3S
16. ALCOR IB
17. TE-M-442-3
18. TE-M-442-4
19. TE-M-364-1
20. TE-M-364-2
21. X254-A1
22. MG-30
23. TE-M-364-4
24. TX - 261-3
25. X259-A3
26. TX-175 CC
27. XM-81
28. FW-10
29. TM-4-C2
30. M57-F1
31. TX-174 CC
32. XM 80
33. TX-238-6
34. XM-33-E5
35. TX-354-3
36. POLARIS A3, STAGE II
37. M56-F1
38. ALGOL IIB
39. POLARIS A3, STAGE I
40. M55-F1
41. POSEIDON, STAGE I
42. POSEIDON, STAGE II
43. IMPROVED MM, STAGE III
44. SPRINT
45. HIBEX

NOTE: (1) MASS FRACTION > 0.80, ALL MOTORS
(2) SPECIFIC IMPULSE > 250 SEC., ALL MOTORS

FIGURE 3-3

SOLID PROPELLANT MOTOR DATA PACKAGE

- VACUUM TOTAL IMPULSE
- VACUUM SPECIFIC IMPULSE
- PROPELLANT MASS FRACTION
- LOADED WEIGHT
- CONSUMED WEIGHT
- BURN TIME
- DIAMETER
- VENDOR
- STATUS
- APPLICATION

FIGURE 3–4

CANDIDATE EXISTING VELOCITY PACKAGES

SOLID MOTORS	
• ATHENA "D"	ATLANTIC RESEARCH CORP.
• BURNER II (MODEL 946)	BOEING AERO SPACE DIVISION
• FIRE	LTV ASTRONAUTICS DIVISION
• SPARTA	LTV ASTRONAUTICS DIVISION
LIQUID MOTORS	
• AGENA "D" (SS-01B)	LOCKHEED, M & SD
• CENTAUR	GENERAL DYNAMICS/CONVAIR
• DELTA II	DOUGLAS
• TRANSTAGE	MARTIN/AEROJET
• ABLE STAR	AEROJET GENERAL

FIGURE 3-5

RESULTS OF STAGING ANALYSIS

SIZING ANALYSIS FOR 200 POUND SPACECRAFT					
	TWO STAGE V/P			ONE STAGE V/P	
BOOSTERS	V/P GROSS WEIGHT	Wc1	Wc2	V/P GROSS WEIGHT	Wc1
DSV-2K/AGENA	2500	1610 (TE-364)	460 (MG-18)	1800	1450 (TE-364)
DSV-2K/DELTA	3100	2100 (TE-364)	520 (MG-18)	2200	1780 (TE-364-4)
TITAN IIIB	3900	2620 (X-259)	635 (FW-4)	1700	1350 (TE-364-2)

- IDEALIZED V/P MOTOR SIZE REQUIREMENTS GENERATED FOR 16 BOOSTERS
- IDEALIZED MOTOR REQUIREMENTS MATCHED WITH MOTOR LIST
- NON-OPTIMUM V/P MOTORS ALSO SELECTED TO VERIFY STAGING ANALYSIS

FIGURE 3-6

RESULTS OF PERFORMANCE ANALYSIS

- OPTIMUM RANGE FOR BOOSTERS ESTABLISHED
  - PROPORTIONING BURN OF "RE-START" ENGINES
  - MAXIMIZING REENTRY VELOCITY
- CONVENTIONAL TRAJECTORY SHAPING TECHNIQUES VERIFIED
  - CONVENTIONAL REENTRY VS REENTRY FROM ORBIT
  - OPTIMUM RANGES VS DESIRED TARGETING AREAS
- PERFORMANCE FOR 86 CANDIDATE RESEARCH LAUNCH VEHICLES COMPUTED
  - COMMON BASIS FOR PERFORMANCE
    ($\gamma_o = -15^\circ$ $W_{GS} = 0$)
  - VELOCITY PACKAGES
    (OPTIMUM AND NON-OPTIMUM MOTOR SIZES)

FIGURE 3–7

RESULTS OF PERFORMANCE TRADE STUDIES

TRADE	RESULTS
EXISTING SOLID MOTORS VS "1970" SOLID MOTORS	$+\Delta V$ = 2000 – 3000 FPS "1970" MOTORS
1, 2, OR 3 STAGE V/P'S	2 STAGE SELECTED
"EXISTING" V/P'S VS "NEW" V/P'S	NEW V/P'S – GREATER PERFORMANCE EXISTING V/P'S – WILL PERFORM SOME MISSIONS
LIQUID V/P'S VS SOLID V/P'S	"SOLID" – GREATER PERFORMANCE
GUIDED V/P'S VS UNGUIDED V/P'S	$-\Delta V$ = 1000 – 2000 FPS FOR GUIDED V/P'S

FIGURE 3–8

RESULTS OF RESEARCH LAUNCH VEHICLE SELECTION

- 6 BOOSTERS ELIMINATED
  - THOR/AGENA
  - TAT/AGENA
  - TAD/DELTA
  - SATURN V/CENTAUR
  - TITAN II
  - TITAN III A
- 13 CANDIDATE V/P'S REDUCED TO 4
- 14 RESEARCH LAUNCH VEHICLES SELECTED

FIGURE 3–9

INTERFACE DIAGRAM 14 SELECTED RESEARCH LAUNCH VEHICLES

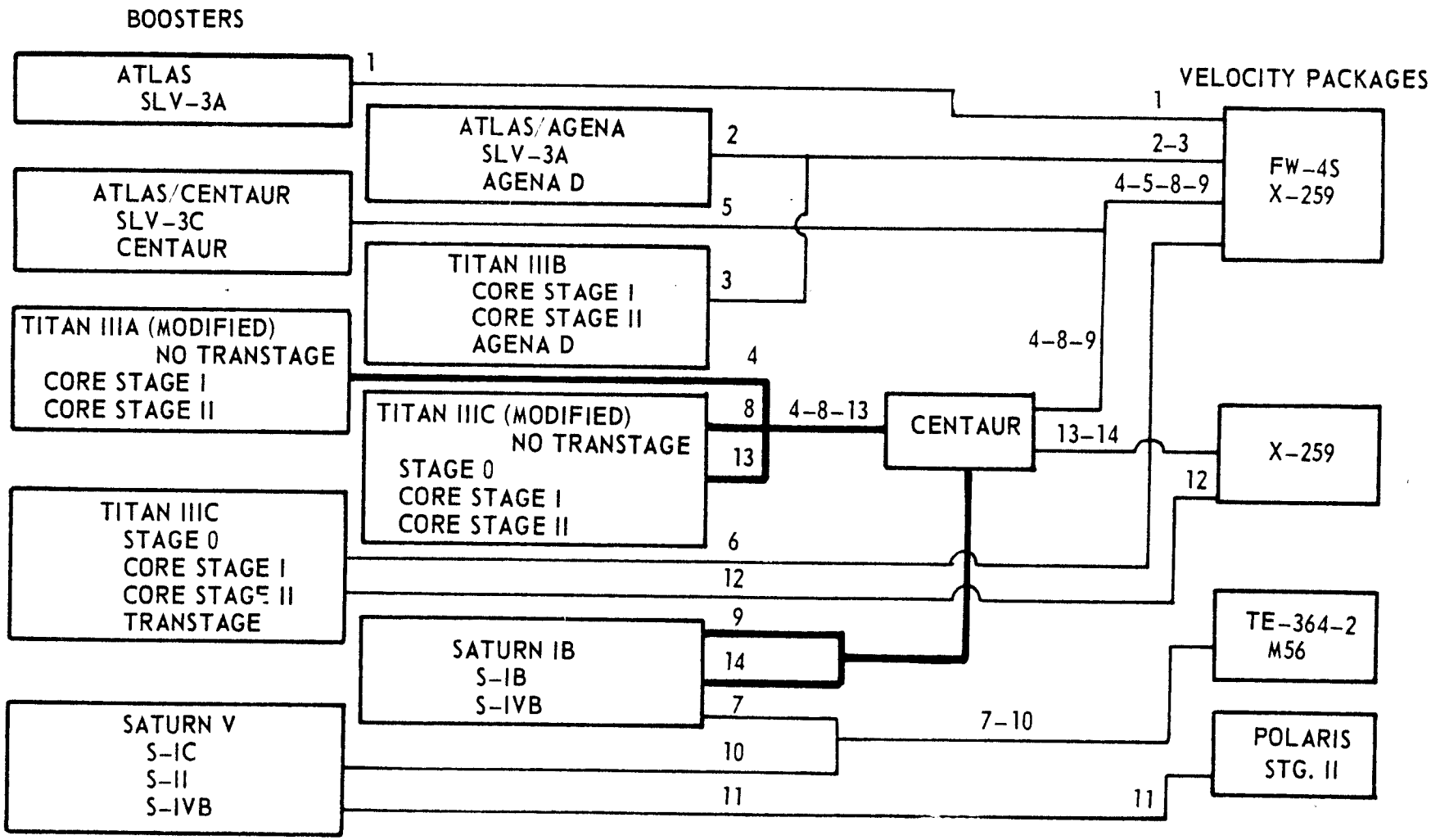


FIGURE 3-10

RE-ENTRY VELOCITY CAPABILITY
14 SELECTED RESEARCH LAUNCH VEHICLES

RESEARCH LAUNCH VEHICLE		REENTRY VELOCITY – 1000 FPS		
BOOSTER	VELOCITY PACKAGE	SPACECRAFT WEIGHT 200#	SPACECRAFT WEIGHT 500#	SPACECRAFT WEIGHT 1000#
ATLAS	FW-4S/X-259	44.1	38.8	34.6
ATLAS/AGENA	FW-4S/X-259	47.2	41.7	37.2
TITAN IIIB	FW-4S/X-259	48.2	42.7	38.2
ATLAS/CENTAUR	FW-4S/X-259	49.6	44.2	39.8
TITAN IIIA (MODIFIED)/CENTAUR	FW-4S/X-259	50.1	44.6	40.0
TITAN IIIC	X-259	49.6	46.4	43.0
SATURN IB	TE-364-2/M56	52.2	47.8	43.8
TITAN IIIC	FW-4S/X-259	53.5	48.2	43.8
TITAN IIIC (MODIFIED)/CENTAUR	X-259	52.5	49.0	45.4
TITAN IIIC (MODIFIED)/CENTAUR	FW-4S/X-259	56.2	50.7	46.2
SATURN IB/CENTAUR	X-259	54.3	50.9	47.2
SATURN IB/CENTAUR	FW-4S/X-259	57.6	52.0	47.6
SATURN V	POLARIS A3 STAGE II	56.5	54.7	52.4
SATURN V	TE-364-2/M-56	63.5	59.1	55.2

FIGURE 3-11

MAJOR STUDY CONCLUSIONS

- NUMBER OF V/P'S REQUIRED IS SMALL
- EXISTING SOLID MOTORS ARE ADEQUATE
- EXISTING RANGES CAN BE USED
- UNCONVENTIONAL TRAJECTORY SHAPING NOT REQUIRED
- CENTAUR INTERGRATION TO TITAN III OR SATURN IB REQUIRED TO FILL PERFORMANCE GAP
- EXISTING BOOSTERS + NEW V/P'S WILL PERFORM ALMOST ALL MISSIONS IN DESIRED SPECTRUM

FIGURE 3–12

RECOMMENDATIONS

- NASA MAKE EARLY DECISION ON KEEPING CENTAUR INTEGRATION IN THE STUDY
- NASA GIVE LTV MORE SPECIFIC DEFINITION OF POSSIBLE SPACECRAFT CONFIGURATIONS
- NASA CONSIDER EXTENSION OF STUDY TO OTHER MISSIONS FOR SELECTED RLV'S

TASK II PLANS

- ANTICIPATED GO-AHEAD _ _ _ _ _ _ _ AUGUST 29
- PROCEED PER S.O.W.
- ANTICIPATED COMPLETION _ _ _ _ _ _ DECEMBER 20

FIGURE 4-1

5.0 DETAILED REVIEW OF TASK I PARAMETRIC STUDIES

This section contains a more detailed description of the work completed under Task I of this study contract as was summarized in Section 3.0. The narrative discussion on each of the Figures contained in this section is brief and intended only to clarify the Figures presented during the oral presentation to NASA/LRC.

5.1 BOOSTER DEFINITION

The injection velocity at 100 n. mi. of the 16 listed Boosters were computed and verified with NASA certified data. The results of this analysis are presented in Figure 5-5.

For the 100 n. mi. injection altitude shown, several boosters can deliver over 500 lbs. to 40,000 ft./sec. However, only the Saturn V/Centaur shows velocity capability beyond 50,000 ft./sec.

In order to obtain injection and reentry velocities beyond 50,000 ft./sec. on Boosters smaller than the Saturn V/Centaur, additional stages (Velocity Packages) are required.

5.2 COMPILATION OF VELOCITY PACKAGE PROPULSION DATA

5.2.1 SOLID PROPELLANT MOTOR SURVEY

An industry survey was conducted to obtain possible Velocity Packages candidate solid propellant motors. In order to be considered as a candidate a given motor had to have specific impulse greater than 250 sec. and motor propellant weight fraction greater than 0.80.

As shown in Figure 5-7, 46 motors were compiled that meet or exceed the stated requirements. The majority of these motors are existing designs and the remainder are either in development or proposed improvements to existing designs.

The 46 motors range in size from 150 pounds to over 45,000 pounds. Additional classified propulsion characteristics are available but have been deleted to keep this an unclassified presentation.

5.2.2 SURVEY OF EXISTING SOLID AND LIQUID STAGES

The results of an additional industry survey for existing solid and liquid stages for use as possible Velocity Package candidates are presented in Figure 5-8.

Except for the "Delta", the 7 liquid propellant candidates are all single stage designs with re-start capability. These range in size from 5000 pounds to approximately 50,000 pounds and contain a guidance and control system.

The 4 solid propellant candidates are a mixture of various design approaches. The Boeing Burner II is a single-stage package that contains its own guidance, control and vernier velocity systems and is a non-spinning design. The LTV Sparta and ARC Athena are both two-stage spin-stabilized Velocity Packages that depend on the Booster for attitude stabilization during boost and coast periods prior to spin-up. The LTV Fire Velocity Package is a single stage spin-stabilized design that has a self contained pitch programmer and coast attitude control system that is dropped before V/P ignition.

5.2.3 PROJECTED 1970 STATE-OF-THE-ART SOLID PROPELLANT MOTOR CHARACTERISTICS

The projected 1970 state-of-the-art solid propellant motor characteristics are shown in Figure 5-9. These data are presented in parametric form so that motors from 500 to 15,000 lbs. can be easily defined.

If a requirement, the user must decide on the proper burning time in order to meet acceleration limits.

The specific impulse obtainable for a 1970 motor operating in vacuum condition is projected between 290 sec. to 300 sec.

As an example, for 8500 lbs. propellant, 40 sec. burning time, and 295 sec. specific impulse a typical 1970 motor would have the following characteristics:

+	Inert Weight =	700 Lbs.
	Propellant Weight =	8500 Lbs.
	Loaded Weight =	9200 Lbs.
	Burning Time = 40 Sec.	
+	Vacuum Total Impulse = 2,500,000. Lb-Sec.	
+	Vacuum Thrust = 62,500 Lbs.	

+ Items Read from Figure 5-9

5.3 PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.3.1 V/P STAGE INERT WEIGHTS AS A FUNCTION OF MOTOR SIZE

Parametric weight data for both guided and spin-stabilized Velocity Packages were generated from analysis of available data on existing, flight proven vehicles. These data were normalized to the same set of design ground rules and the results are presented in Figure 5-11. The subsystems inert weights exclusive of motor inert weights are shown as a function of loaded motor weight.

The ground rules utilized to obtain a set of normalized data are as follows:

- Size dependent parameters were separated from non-size dependent parameters.

- Unique design features of some vehicles that are not compatible with this study (e.g., Aerodynamic Fins) were isolated or modified.

- The spin-stabilized designs include structure, wiring and balance weights as size dependent parameters; the guided designs add a H_2O_2 control system as a function of size.

5.3.2 NON-SIZE DEPENDENT SUB SYSTEM WEIGHTS

A typical set of non-size dependent systems weights are presented in Figure 5-12.

The proper location of these subsystems is dependent upon the Velocity Package design concept utilized. As an example the guidance package is generally located in the final stage to guide the complete vehicle while the spin system can be dropped at Velocity Package ignition and would therefore be charged to Booster inert weight.

5.3.3 REPRESENTATIVE V/P WEIGHT SUMMARY

Figures 5-13 and 5-14 summarizes the weights utilized for the candidate one and two stage Velocity Packages respectively.

The step inert weights were obtained from Figures 5-11 and 5-12 after selecting the V/P motor. The V/P motor weights were obtained from the solid propellant motor survey data.

5.3.4 AERODYNAMIC SHROUD WEIGHTS AS A FUNCTION OF AREA

Figure 5-15 presents weight data as a function of Shroud area for two types of construction, clamshell and single piece.

Generally, existing Shroud weights range between 2 to 2.5 pounds per square foot.

5.4 EVALUATION OF VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.4.1 DETERMINE THE FEASIBILITY OF UTILIZING BOOSTER GUIDANCE SYSTEMS FOR REENTRY MISSIONS AND V/P POSITIONING.

A brief description of the Booster guidance systems are summarized in Figure 5-17. Except for the Atlas and Titan II, it is feasible to utilize the other Booster guidance systems to perform reentry missions up to V/P ignition. By adding a coast control and guidance systems to the Velocity Package (i.e., Atlas/Fire Concept) the Atlas and Titan II Boosters can also perform reentry missions.

For Boosters with re-start capability, a uniquely simple Velocity Package design is possible. This V/P design would utilize spin-stabilization and a timer to provide spin-up and ignition discretes. The Booster would provide an upward powered phase followed by a ballistic coast phase. At the proper time the Booster would be re-started to furnish a portion of the downward reentry powered phase and to position the Velocity Package for spin-up and ignition to obtain the desired reentry conditions.

5.4.2 SUMMARY OF VARIOUS V/P GUIDANCE AND CONTROL CONCEPTS

The trade-off between weight, volume, power consumption and drift (approx. accuracy) of four Velocity Package guidance systems are presented in Figure 5-18.

These four feasible concepts for Velocity Package guidance show the varying degrees of complexity and accuracy which can be obtained. Selection of the particular guidance concepts to be evaluated during Task II requires more precise definition of the spacecraft mission requirements.

5.5 VELOCITY PACKAGE STAGING ANALYSIS

5.5.1 DETERMINE PROPULSION SYSTEM REQUIREMENTS BASED ON IDEALIZED STAGING ANALYSIS

Using 46 candidate motors and 15 Boosters, over 16,000 one and two-stage Velocity Package plus Boosters (RLV) configurations are possible. By performing a staging analysis one is assured that the best performance capabilities are contained within 75 configurations - a two order of magnitude reduction in the performance analysis task.

Figure 5-20 presents a typical Velocity Package sizing procedure at a fixed total velocity. In the upper portion of the figure Velocity Package gross weight is plotted as a function of Booster velocity "available" and V/P velocity "required"

when the sum of the "available" and "required" velocities is the specified RLV "total velocity". As the gross weight of the V/P (Booster Payload) is increased, the "available" velocity from the Booster decreases and the "required" velocity from the V/P increases. The bottom portion of Figure 5-20 shows the variation of spacecraft weight as a function of V/P velocity "required". Thus, it is possible to relate V/P velocity "required" to V/P gross weight and spacecraft weight because for a fixed gross weight and velocity "required" the amount of propellant and motor size is defined for the specified values of specific impulse and propellant weight fraction,(pwf). For small required velocities the V/P gross weight is small and consequently the spacecraft weight is also small. The spacecraft weight continues to increase as the velocity required and V/P gross weight increases until a peak value of spacecraft weight is reached. Beyond this peak the velocity required and V/P gross weight continues to increase but the spacecraft weight shows a sharp drop. This occurs because the velocity "required" is so large that the complete V/P is approaching a propulsion unit where no weight is available for payload or spacecraft.

The "optimum" point illustrated in Figure 5-20 can be computed for several RLV total velocities for a given Booster to define a complete "family" of optimum Velocity Packages. A typical optimum one-stage, V/P family is shown in Figure 5-21. These optimum V/P families were determined for all the specified Boosters and utilized to define the Velocity Package propulsion system requirements. As an example, from Figure 5-21,at a spacecraft weight of 200 pounds, the optimum motor consumed (propellant) weight is 1750 pounds and Velocity Package gross weight is 2100 pounds.

Utilizing the V/P sizing data previously discussed, the Velocity Package propulsion system requirements were determined for a 200 pound spacecraft.

These data are presented in Figure 5-22 for both one-stage and two-stage Velocity Packages and 15 specified Boosters or a total of 45 propulsion systems. A detailed examination of this figure shows that many motors of approximately the same size or propellant weight requirement occur more than once which indicated that the propellant weights could be categorized into various limits to reduce the number of propulsion systems.

5.5.2 REALISTIC V/P'S BASED ON IDEALIZED RESULTS

The consumed weight of the 45 optimum size motors are listed in order of increasing weight in Figure 5-23. The consumed weights were then divided into 12 specific weight categories as shown. The consumed weight variation, within each category was limited to approximately 10% variation from nominal for the small size motors to approximately 20% variation for the large size motors. As illustrated in the previously discussed solid propellant motor survey, there are more small and medium size motors than there are large motors. For this reason a lower percentage variation about the small and medium size motors was chosen in order to include more of these designs for evaluation. Finally, these propellant weight variations in conjunction with the motor survey data were utilized to select the best motors in terms of availability, development status, specific impulse, and propellant weight fraction within each weight category.

The candidate motors from Figure 5-23 were matched as nearly as possible with the propellant requirements of Figure 5-22 to obtain a family of near-optimum Research Launch Vehicles. The results of this matching procedure are presented in Figure 5-24.

5.5.3 VALIDATION OF ASSUMPTIONS FOR THE STAGING ANALYSIS

The staging analysis methods and assumptions have been described in detail. However, each assumption has been evaluated to determine its effect on the overall solution. Specifically, the values used for specific impulse, stage

propellant weight fraction, and the design spacecraft weight.

The effects of specific impulse (I_{sp}) and stage propellant weight fraction (pwf) on Velocity Package motor size requirements are shown in Figure 5-25 for a two stage V/P. For 10 seconds change in I_{sp} the stage-one V/P propellant weight changes 300 lbs. and the stage-two propellant weight changes 20 lbs. For approximately 20% change in stage inert weights (from 0.90 to 0.88) the stage-one propellant weight changes 600 lbs. and the stage-two propellant weight changes 40 lbs. In a more exacting analysis of the classical vehicle optimization equations these deviations in propellant weights would not result in a completely rigorous solution. However, these deviations in the assumed values of I_{sp} and pwf can be tolerated because the same two motors (X-259/FW-4) would be selected.

The effects of design, spacecraft weight on Velocity Package motor size is shown in Figure 5-26 for a single-stage Velocity Package on the SLV-3C/ Centaur Booster. For this example, the TE-364-4 motor was selected for the 200 pound design spacecraft weight. The figure shows that this motor would be near-optimum for spacecraft weights between 150 and 400 pounds. For spacecraft weights greater than 400 pounds the larger X-259 motor would have been selected and for spacecraft weights less than 150 pounds the smaller TE-364-2 motor would have been selected. Similar trends are exhibited for two-stage Velocity Packages. Generally speaking, three Velocity Package sizes would cover the spacecraft range from 50 to 1000 pounds. Therefore, in order to determine the effects of spacecraft weight for a given booster, more than one V/P was selected for the detailed performance analyses.

5.5.4 CONFIGURATIONS CHOSEN FOR DETAILED ANALYSIS

The family of 10 near-optimum Research Launch Vehicles defined previously in Figures 5-24 are presented in Figure 5-27 in a different format. These RLV's can be identified with the letter "O" in Figure 5-27. The letter "A" indicates that a particular V/P - Booster combination was analyzed in

detail for performance capability. The performance analysis technique will be discussed in a subsequent section. It should be noted that an average of 5 Velocity Packages was chosen to be analyzed with each Booster for a total of 75 configurations. This was done to provide a further check of the assumed design spacecraft weight, specific impulse, and stage propellant weight fractions. Figure 5-27 also shows that two near-optimum V/P's were eliminated because these two V/P's only occurred once as near-optimum configurations.

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

The feasibility and practicability of various trajectory flight profiles were first examined and a primary flight mode was selected. The range control capability of each Booster was evaluated to determine the effects of range on velocity. The performance capability of the 72 candidate configurations was computed and performance trade studies of 1970 motors, number of V/P stages, existing solid and liquid stages, and "guided" V/P were conducted.

5.6.1 BALLISTIC RE-ENTRY TRAJECTORIES VERSUS UNCONVENTIONAL FLIGHT PROFILES

The conventional ballistic trajectory flight profile and two unconventional flight profiles are shown in Figure 5-29. This analysis was conducted to investigate possible performance increases and to alleviate any range constraint problems. The trajectory shaping techniques are as follows:

- Ballistic Reentry (Method 1) - Conventional trajectory shaping which consist of a powered ascent boost phase followed by a ballistic coast phase and a re-start descent powered phase.

- Parking Orbit (Method 2) - A powered boost into a low circular orbit is followed by a coast phase and injection into an elliptical parking orbit. Near perigee of the elliptical parking orbit the Booster and Velocity Package are re-started for a third burn. The re-start point and pitch attitude angle are programmed to obtain the desired reentry conditions: namely, range, reentry path angle, and burnout altitude.

- Parking Orbit (Method 3) - The flight profile of this trajectory shaping method is the same as Method 2 from launch to elliptical parking orbit. Near apogee of the elliptical parking orbit a third Booster burn to propellant depletion is accomplished in order to turn the parking orbit trajectory to a new ellipse that provides the desired reentry angle. The Velocity Package ΔV is added along this new ellipse after a coast phase to achieve the desired velocity vector and burnout altitude.

A comparison of the three trajectory shaping methods is presented in Figure 5-30. The following conclusions can be made from the available data:

- The desired reentry range of 2000 to 5000 n. mi. can be obtained with any of the three trajectory shaping methods.

- The ballistic reentry trajectory offers the highest reentry velocity and the lowest impact dispersion of the three trajectory profiles.

- Because of its conventional flight profile and short flight time, the ballistic reentry trajectory will have the best probability of mission success in terms of in-flight and terminal tracking and reentry data acquisition.

- For smaller reentry angles the parking orbit trajectory shaping methods will probably show a more favorable reentry velocity over the ballistic reentry trajectory because the velocity vector turning losses will be reduced.

- Because of the stated advantages, the ballistic flight profile was utilized to determine the performance capabilities of all Research Launch Vehicle configurations.

5.6.2 THE EFFECTS OF TRAJECTORY RANGE CONTROL

The effect of range on reentry velocity for a representative RLV and fixed spacecraft weight is shown in Figure 5-31 utilizing the selected ballistic reentry flight mode. For this RLV (SLV-3C/Centaur/X-259/FW-4) the maximum reentry velocity occurs at approximately 3000 n. mi. from launch and requires

a two-burn Centaur sequence. 67.5% of the Centaur propellants are expended in the Ascent powered phase and 32.5% of the propellants are used for the second Centaur burn in the descent powered phase. Deviations from optimum range between 2000 to 6000 n. miles causes only a 500 ft./sec. velocity penalty.

Figure 5-32 is a summary of the optimum range analysis performed. These ranges vary from 1800 nautical miles for the THOR to 6800 nautical miles for the Titan II.

5.6.3 PERFORMANCE COMPUTATION OF CANDIDATE CONFIGURATIONS

In view of the large number of configurations (72) that required performance analyses, a trajectory computation technique that employed both ideal velocity methods and integrated trajectory simulations was utilized to generate the desired results and to reduce the engineering effort. This technique simplified the trajectory analysis task without sacrificing the accuracy. Basically, forward and reverse integrated trajectories were matched at apogee to obtain a realistic simulation for a specific spacecraft weight and reentry condition. The ideal velocity equation was then employed to determine the shape of the spacecraft weight versus reentry velocity curve and passed through the match point. The matching of the integrated trajectories are illustrated in Figure 5-33.

The accuracy of the performance analysis technique was checked by computing two additional matched points at the extreme limits of the specified spacecraft weights. These data are presented in Figure 5-34. As can be seen the velocity error is less than 150 ft./sec.

The performance capabilities of the 72 candidate configurations are presented in Figures 5-36 through 5-43 based on the constraints shown in Figure 5-35. For a 300 pound spacecraft the following range of reentry velocities are shown:

THOR/one Stage V/P	33,400 to 38,300 ft/sec.
ATLAS/one stage V/P	37,900 to 45,400 ft/sec.
TITAN/one stage V/P	35,600 to 51,400 ft/sec.
SATURN/one stage V/P	42,800 to 55,800 ft/sec.
THOR/two stage V/P	35,700 to 40,500 ft/sec.
ATLAS/two stage V/P	41,800 to 47,500 ft/sec.
TITAN/two-stage V/P	40,000 to 53,900 ft/sec.
SATURN/two-stage V/P	45,600 to 61,800 ft/sec.

5.6.4 PERFORMANCE TRADE STUDIES

Performance studies were conducted to examine the trade-off between existing and projected 1970 state-of-the-art motors, the number of Velocity Package stages, the near-optimum V/P's and existing solid and liquid stages and spin-stabilized and guided Velocity Packages.

Propellant characteristics for projected "1970-state-of-the-art" motors were used to compare performance capabilities with existing motors. Comparative performance curves for three boosters with one-stage Velocity Packages are shown on Figure 5-44. For a spacecraft weight of 300 pounds, velocity increases up to 3000 feet per second were obtained using projected 1970 propellant improvements for typical existing motors such as the X-259 and Polaris A3, Stage II (260 A3).

Performance trade-off as a function of number of Velocity Package Stages is shown for three Boosters in Figure 5-45. Two-stage Velocity Packages show performance increases of 4000 to 6000 feet per second over one-stage V/P's for a 300 pound spacecraft. Addition of a third stage to the various Velocity Packages only increases velocity between 1000 to 2000 feet per second for the same spacecraft weight.

Performance comparison of existing solid propellant stages to near-optimum V/P's were conducted with the Titan IIIC Booster. As shown in Figure 5-46, equal or better performance can be obtained with the near-optimum designs

for equal number of V/P stages.

Performance comparison of existing liquid stages to near-optimum V/P's were conducted using the Saturn IB and Saturn V Boosters. As shown in Figure 5-47 equal or better performance can be obtained with the near-optimum design.

The performance penalty for using a guided Velocity Package was compared to the spin-stabilized design on the Titan IIIC/X-259 Research Launch Vehicle. Figure 5-48 shows a loss of 2000 ft/sec. for a 300 pound spacecraft. More detailed consideration will be given to guidance and control system weight reduction during Task II in order to reduce the performance losses. The parametric weight data presented in Section 5.3 can be applied to any Velocity Package of interest to evaluate the velocity or weight degradation due to addition of a guidance and control system.

5.7.0 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

After computing the performance capabilities of each Research Launch Vehicle configuration and conducting various trade studies, an initial screening was performed to select the best one and two stage Velocity Packages for each booster. Further eliminations were made based on technical feasibility, practicability, and performance capability to reduce the recommended configurations to 14.

5.7.1 BEST ONE AND TWO STAGE VELOCITY PACKAGES

Figures 5-50 and 5-51 presents the performance capabilities of the best one and two stage Velocity Package configurations respectively. These 34 configurations were derived from the configurations shown in Figures 5-36 through 5-43. For a given booster the selection criteria was simply the best performance capability. In some cases where the performance was nearly equal both V/P configurations were selected for further evaluation. That is why there are more

than 30 configurations shown in Figures 5-50 and 5-51.

5.7.2 SELECTION AND ELIMINATION PROCEDURES

The selection and elimination procedures were divided into eight steps:

Step 1, Figure 5-52, - All three-stage Velocity Packages were eliminated because the inherent complexity of three-stages does not offer sufficient performance improvement over a two-stage Velocity Package.

Step 2, Figure 5-53, - All liquid Velocity Packages used as a final stage of a Research Launch Vehicle were eliminated since equal or better performance can be obtained with a one-stage Velocity Package.

Step 3, Figure 5-54, - The THOR family of Research Launch Vehicles was eliminated since the existing Atlas/Fire has better performance capability.

Step 4, Figure 5-55 - The Titan II Booster was eliminated because the existing Atlas/Fire shows better performance than the Titan II/X-259 and a SLV-3A/X-259/FW-4 shows better performance than a Titan II/X-259/FW-4.

Step 5, Figure 5-56, - All one-stage Velocity Packages that do not have significant payload capability at 50,000 ft./sec. were eliminated.

Step 6, Figure 5-57, - The Titan IIIA (with Transtage) configurations were eliminated because better performance can be obtained by adding an additional V/P stage to the existing Atlas/Fire (SLV-3A/X-259/FW-4). Additionally, the smaller Titan/Agena (Titan IIIB) configuration shows greater performance capability.

Step 7, Figure 5-58, - On the Saturn IB/Centaur and Titan IIIC/Centaur the near-optimum single-stage V/P requires the TE-364-4, Stretched Surveyor motor. Because the TE-364-4 is an unfunded motor program, it was replaced by the existing X-259 with little loss in performance.

Step 8, Figure 5-59, On the Titan IIIC Booster the XM-80/23KS11000 V/P was replaced by the X-259/FW-4 V/P because the XM-80 is out of production and not spin qualified. Again, the performance loss is small.

5.7.3 RECOMMEND CONFIGURATIONS

Based on the stated reasons used to eliminate the various configurations, 14 Research Launch Vehicles survived the screening process. The performance capabilities of these configurations are shown in Figure 5-60. These are the recommended Research Launch Vehicles to be analyzed in Task II. Significantly, these 14 RLV's can perform reentry missions from 40,000 ft/sec. to 55,000 ft/sec. with spacecraft weights of 50 lbs. to 1000 lbs. 60,000 ft/sec. reentry missions are possible for spacecraft weights from 50 lbs to 400 lbs.

5.8.0 CONCLUSIONS

5.8.1 THE NUMBER OF VELOCITY PACKAGES REQUIRED IS SMALL AND DO NOT EXCEED TWO-STAGES.

A family of Velocity Packages which can be used with existing space Boosters to satisfy reentry research missions from 40,000 to 60,000 fps has been defined. This family consists of only four Velocity Packages - (2) single-stage and (2) two-stage configurations - that are utilized with various Boosters to make up the 14 selected Research Launch Vehicles.

5.8.2 EXISTING SOLID PROPELLANT MOTORS ARE ADEQUATE FOR V/P PROPULSION

The selected Velocity Package family is composed of 5 existing flight proven motors - the FW-4, the TE-364-2, the X-259, the 260 A3, and the M-56. Additional performance gains can be realized from motor improvement or future development programs.

5.8.3 COMPLEX GUIDANCE OF THE VELOCITY PACKAGE IS NOT REQUIRED

For the eight selected boosters with re-start capability, the Velocity Package can utilize to the maximum extent feasible the booster guidance and control system. The SLV-3A Booster can utilize the coast control guidance and control system developed for the "Fire" program.

5.8.4 CONVENTIONAL BALLISTIC TRAJECTORY FLIGHT MODES ARE SUPERIOR TO UNCONVENTIONAL PARKING ORBIT FLIGHT MODES

The conventional ballistic trajectory flight mode is superior in terms of accuracy, performance, and tracking requirements. Additionally the ballistic trajectory does not impose any range constraints.

5.8.5 EXISTING RANGE COMPLEXES CAN BE USED

For the Boosters with re-start capability (8 out of 9 selected), conventional ballistic trajectories can be employed to utilize existing targeting areas with less than 1000 fps velocity loss.

SCOPE

DETERMINE RESEARCH LAUNCH VEHICLE REQUIREMENTS FOR CONDUCTING REENTRY TESTS AT HIGH VELOCITIES WITH THE FOLLOWING:

- TEST CONDITIONS
  - ALTITUDE = 400,000 FEET
  - VELOCITY = 40,000 TO 60,000 FT. SEC.
  - REENTRY ANGLE = -7 TO -25 DEGS.
  - NOMINAL ANGLE-OF-ATTACK = 0 DEGS.
  - MINIMUM COAST TIME = 10 SEC. FROM V/P BURNOUT TO REENTRY
- BOOSTER CHARACTERISTICS – UTILIZE CURRENT NATIONAL LAUNCH VEHICLES IN TOTAL OR IN PARTS. SPECIFICALLY, THE THOR, ATLAS, TITAN AND SATURN FAMILIES
- VELOCITY PACKAGE CHARACTERISTICS
  - MAXIMUM STAGES $\leq$ FOUR
  - V/P PROPULSION – EXISTING OR IN DEVELOPMENT MOTORS OR STAGES WITH SPECIFIC IMPULSE $>$ 250 SEC. AND PROPELLANT WEIGHT FRACTION $>$ 0.80
- SPACECRAFT DEFINITION
  - WEIGHT = 50, 100, 200, 400, AND 1000 LBS.
  - S/C WEIGHTS INCLUDES ADAPTOR AND SEPARATION SYSTEM

DETERMINE THE FEASIBILITY AND EFFECTS OF UTILIZING EXISTING RANGE COMPLEX TARGETING AREAS ON

- VELOCITY CAPABILITY
- GUIDANCE AND CONTROL SYSTEMS
- TRAJECTORY SHAPING REQUIREMENTS

ON THE BASIS OF PERFORMANCE AND TECHNICAL FEASIBILITY SELECT RESEARCH LAUNCH VEHICLE CONFIGURATIONS FOR FURTHER STUDY AND ANALYSIS

FIGURE 5–1

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5--2

APPROACH

5.1 BOOSTER DEFINITION DATA

5.1.1 COMPILE REFINING CHARACTERISTICS OF EACH BOOSTER

5.1.2 VERIFY INJECTION PERFORMANCE AT 100 N.M.

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5-3

BOOSTER DEFINITION DATA

- COMPILE DEFINING CHARACTERISTICS OF EACH BOOSTER IN TERMS OF:
  - MASS PROPERTIES
  - AERODYNAMIC CHARACTERISTICS
  - PROPULSION MODEL
  - FLIGHT SEQUENCE OF EVENTS
  - TRAJECTORY AND VEHICLE CONSTRAINTS
- THE PERFORMANCE CAPABILITIES OF EACH BOOSTER LISTED BELOW WAS VERIFIED

BOOSTER	DESIGNATION
1. THOR/AGENA	DSV-2K/AGENA D
2. TAT/AGENA	DSV-2L/AGENA D
3. TAD/IMP. DELTA	DSV-2L/IMP. DELTA
4. ATLAS	SLV-3A
5. ATLAS/AGENA	SLV-3A/AGENA D
6. ATLAS/CENTAUR	SLV-3C/CENTAUR
7. TITAN II	GLV
8. TITAN IIIA	SLV-5A
9. TITAN IIIB	SLV-5B
10. TITAN IIIA/CENTAUR	SLV-5A/LESS TRANSTAGE/CENTAUR
11. TITAN IIIC	SLV-5C
12. TITAN IIIC/CENTAUR	SLV-5C/LESS TRANSTAGE/CENTAUR
13. SATURN 1B	S-1B/S-IVB
14. SATURN 1B/CENTAUR	S-1B/S-IVB/CENTAUR
15. SATURN V	S-1C/S-II/S-IVB
16. SATURN V/CENTAUR	S-IC/S-II/S-IVB/CENTAUR

FIGURE 5-4

BOOSTER PERFORMANCE CAPABILITY AT 100 N.MI. INJECTION ALTITUDE

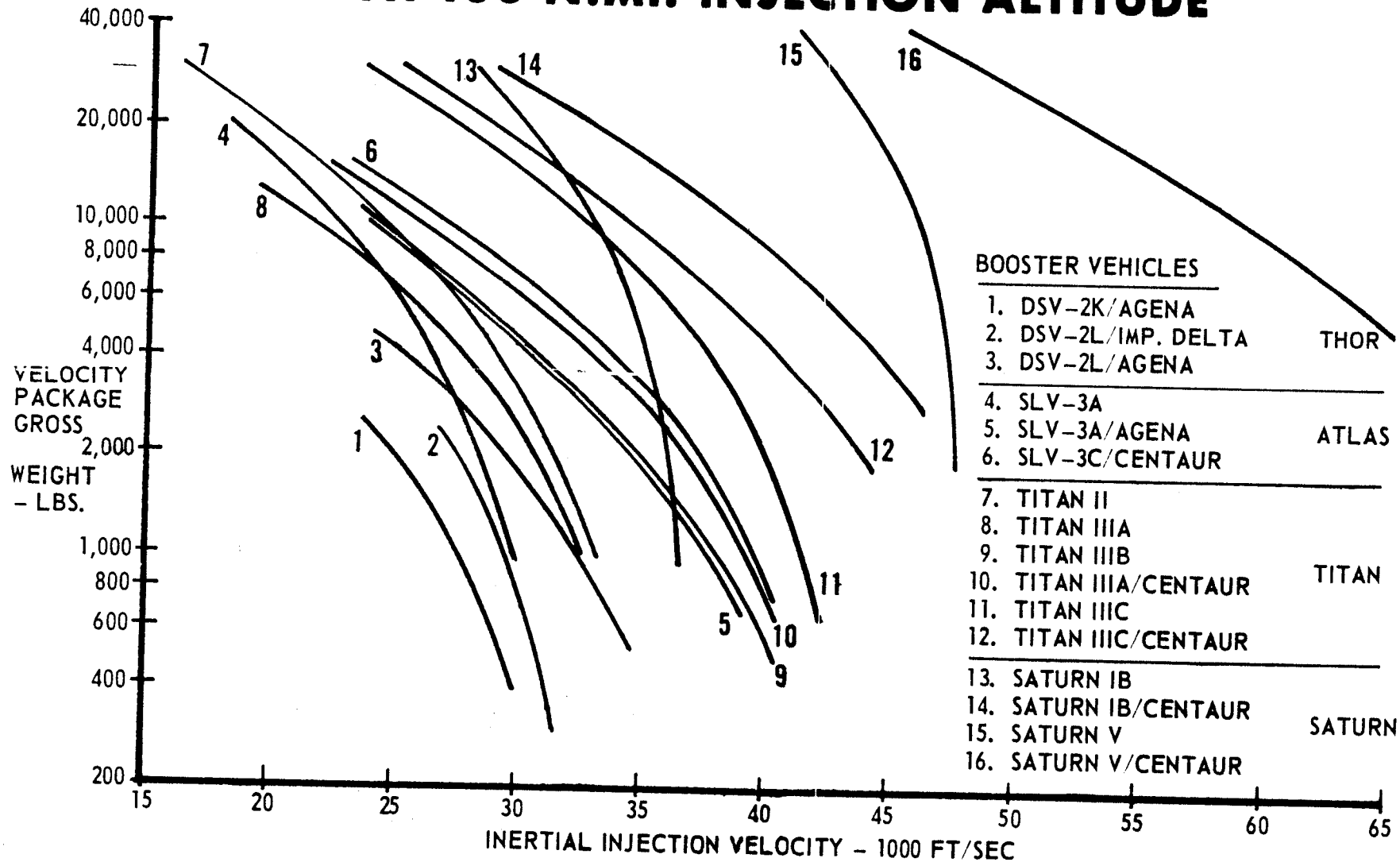


FIGURE 5–5

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA:

- 5.2.1 SOLID PROPELLANT MOTOR SURVEY
- 5.2.2 EXISTING SOLID AND LIQUID STAGES
- 5.2.3 PROJECTED 1970 STATE-OF-THE-ART SOLID PROPELLANT MOTOR CHARACTERISTICS

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5-6

SOLID PROPELLANT MOTOR SURVEY

- THE FOLLOWING CANDIDATES WERE COMPILED FROM EXISTING OR IN DEVELOPMENT MOTORS WITH I_{sp} > 250 SEC. AND PWF > 0.80:

NAME	CONSUMED WEIGHT	NAME	CONSUMED WEIGHT
1. XM-85	134.	24. MG-30	2,054.
2. TE-M-479	151.	25. X-254	2,113.
3. BE-3-A4	193.	26. TE-364-4	2,099
4. PHOENIX	376.	27. TX-261-3	2,324.
5. X-248	464.	28. X-259	2,582.
6. TE-M-184	478.	29. XM-81	2,744.
7. MG-18	481.	30. FW-10	2,754.
8. X-258	510.	31. TX-175	2,814
9. TE-M-442	518.	32. TM-4-C2	2,900.
10. FW-4S	608.	33. SPRINT 1ST	3,736.
11. XM-86	635.	34. M57-F1	3,750.
12. TE-442-1	668.	35. TX-174	4,479.
13. TX-306	690.	36. XM-80	5,522.
14. FW-3S	821.	37. NEW MM 3RD	NOT AVAILABLE
15. TE-442-2	840.	38. TX-238-6	6,799.
16. ALCOR IB	917.	39. XM-33-ES	7,452.
17. SPRINT 2ND	1001.	40. TX-354-3	8,261.
18. TE-442-3	1004.	41. 260 A3	8,872.
19. TE-442-4	1172.	42. M56-F1	13,995.
20. TE-364-1	1214.	43. POSEIDON 2ND	15,757.
21. TE-364-2	1402.	44. POLARIS A3 1ST	20,730.
22. TE-364-3	1454.	45. ALGOL IIB	21,399.
23. HIBEX	1747.	46. M55-F1	46,079.

FIGURE 5-7

SURVEY OF EXISTING SOLID AND LIQUID STAGES

- CANDIDATE LIQUID STAGES

NAME	CONSUMED WT. (LBS.)	STG. PWF.	I_{sp} (SEC.)
1. DELTA	4,562.	0.759	267.0
2. ABLESTAR	8,331.	0.846	277.5
3. IMPROVED DELTA	10,634.	0.863	274.1
4. AGENA D	13,452.	0.910	292.1
5. TRANSTAGE	22,765.	0.830	305.2
6. CENTAUR	29,748.	0.870	443.7
7. APOLLO SERV. MODULE	44,455.	0.780	318.0

- CANDIDATE SOLID STAGES

NAME	CONSUMED WT. (LBS.)	STG. PWF.	I_{sp} (SEC.)
1. ATHENA D			
STG. 1 (23KS11000)	917.	0.860	281.3
STG. 2 (BE-3)	193.	0.731	272.4
2. BURNER II (TE-364-2)	1,411.	0.831	287.1
3. FIRE (X-259)	2,582.	0.920	278.7
4. SPARTA			
STG. 1 (X-259)	2,582.	0.896	278.7
STG. 2 (BE-3)	193.	0.763	272.4

FIGURE 5-8

PROJECTED 1970 STATE-OF-THE-ART SOLID PROPELLANT MOTOR CHARACTERISTICS

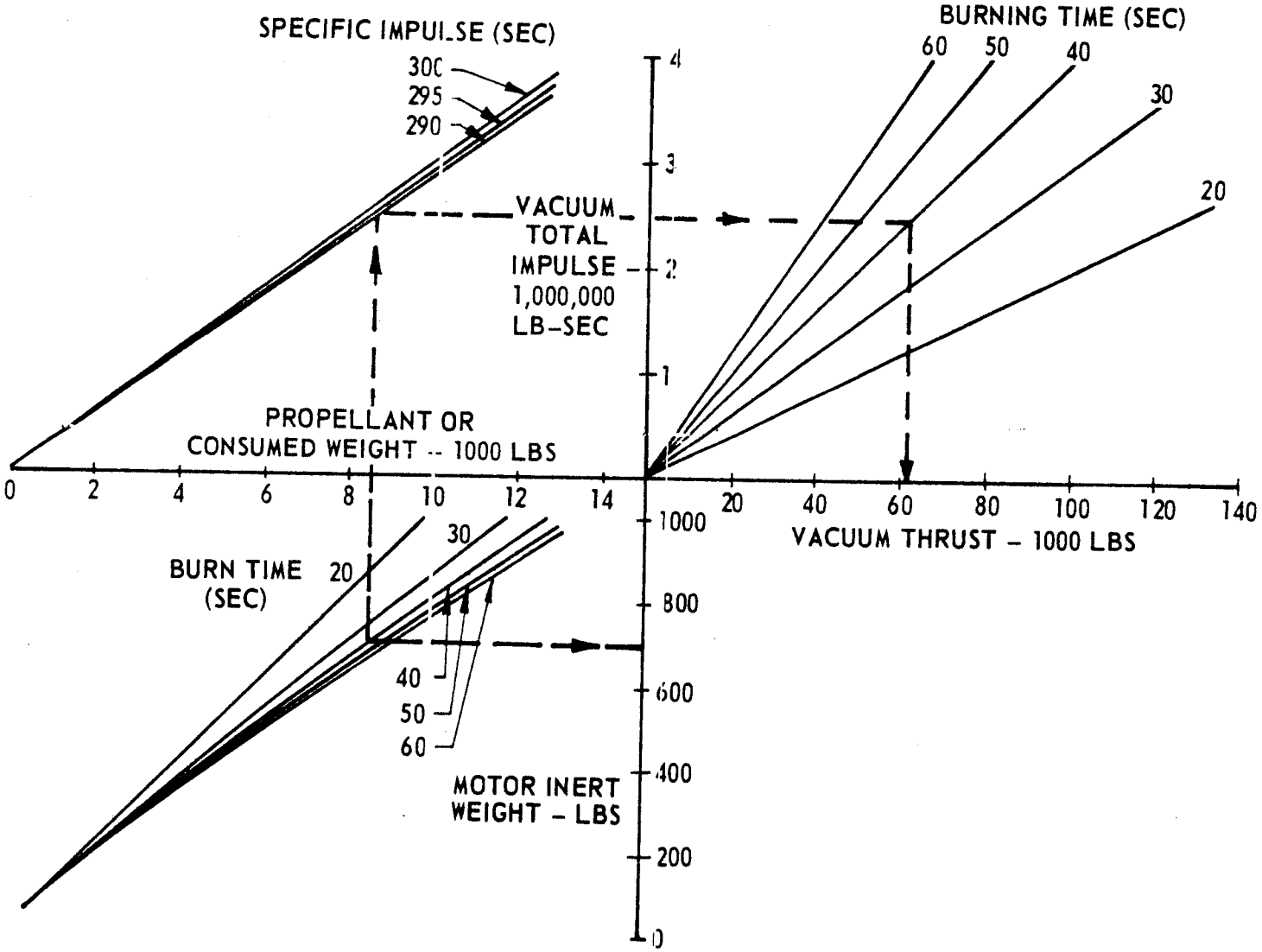


FIGURE 5-9

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

- 5.3.1 V/P STAGE INERT WEIGHTS AS A FUNCTION OF MOTOR SIZE
- 5.3.2 NON-SIZE DEPENDENT SUBSYSTEMS WEIGHTS
- 5.3.3 REPRESENTATIVE V/P WEIGHT SUMMARY
- 5.3.4 SHROUD WEIGHTS AS A FUNCTION OF AREA

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

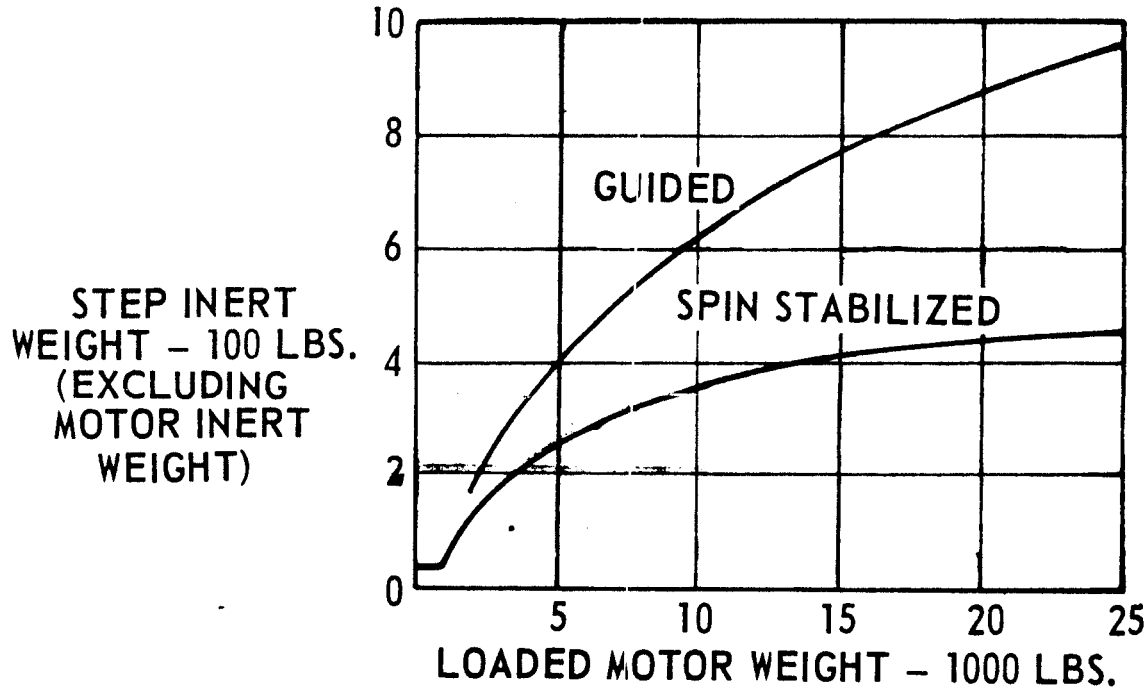
5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5–10

PARAMETRIC STEP INERT WEIGHTS BASED ON EXISTING DESIGNS



NOTES:

(1) STEP INERT WEIGHTS FOR SPIN STABILIZED V/P'S INCLUDE STRUCTURE, WIRING AND BALANCE WEIGHTS; GUIDED V/P'S ALSO INCLUDE REACTION CONTROL SYSTEM

(2) SPIN SYSTEM LOCATED ON BOOSTER

FIGURE 5–11

NON-SIZE DEPENDENT SUB-SYSTEMS WEIGHTS

- TYPICAL NON-SIZE DEPENDENT WEIGHTS ARE:
  - GUIDANCE SYSTEM = 100 LBS.
  - TELEMETRY SYSTEM = 80 LBS.
  - DESTRUCT SYSTEM = 25 LBS.
  - IGNITION SYSTEM = 20 LBS.
- SPIN SYSTEM WEIGHTS ARE AS FOLLOWS:
  - 40 LBS. FOR V/P GROSS WEIGHT BETWEEN 500 AND 5000 LBS.
  - 60 LBS. FOR V/P GROSS WEIGHT BETWEEN 5000 AND 20000 LBS.

FIGURE 5–12

CANDIDATE VELOCITY PACKAGE SUMMARY WEIGHTS

ONE STAGE VELOCITY PACKAGES

V/P MOTORS	TE-364-2	TE-364-4	X-259	XM-80	260A3
SPACECRAFT	0.	0.	0.	0.	0.
STAGE 1					
MOTOR INERT	123.	138.	188.	563.	617.
STEP INERT	71.	135.	160.	276.	344.
BURNOUT	194.	275.	348.	839.	961.
CONSUMED	1402.	2099.	2582.	5522.	8872.
IGNITION	1596.	2374.	2930.	6361.	9833.
V/P ADAPTOR					
AGENA D	270.	270.	90.	–	–
CENTAUR	270.	270.	90.	–	–
IMPROVED DELTA	270.	270.	90.	–	–
TITAN II	370.	370.	190.	–	–
SLV-3A	–	–	190.	285.	480.
TRANSTAGE	–	270.	90.	185.	–
S-IV B	–	–	90.	185.	380.
SYSTEM					
V/P HEAT SHROUD	200.	200.	200.	250.	200.
SPIN SYSTEM	40.	40.	40.	60.	60.

NOTES: (1) TITAN II AND SLV-3A ADAPTOR WEIGHTS INCLUDE 100 LBS. OF GUIDANCE
(2) V/P'S ARE SPIN STABILIZED

FIGURE 5-13

CANDIDATE VELOCITY PACKAGE SUMMARY WEIGHTS
TWO STAGE VELOCITY PACKAGES

V/P MOTORS	MG-18 TE-364-2	FW-4 X-259	23KS1100 XM-80	TE-364-2 M56-F1
SPACECRAFT	0.	0.	0.	0.
STAGE 1				
MOTOR INERT	64.	52.	83.	123.
STAGE INERT	35.	35.	35.	71.
BURNOUT	99.	87.	118.	194.
CONSUMED	481.	608.	917.	1402.
IGNITION	580.	695.	1035.	1596.
STAGE 2				
MOTOR INERT	138.	188.	563.	1520.
STAGE INERT	137.	180.	294.	432.
BURNOUT	875.	1063.	1892.	3548.
CONSUMED	2099.	2582.	5522.	13995.
IGNITION	2974.	3645.	7414.	17543.
TOTAL V/P DROP WEIGHTS				
AGENA D	330.	330.	330.	–
CENTAUR	310.	310.	540.	–
IMPROVED DELTA	320.	–	–	–
TITAN II	575.	575.	575.	–
SLV-3A	–	720.	720.	720.
TRANSTAGE	–	610.	610.	–
S-IV B	–	2790.	2790.	2790.

NOTES: (1) V/P DROP WEIGHTS INCLUDE ADAPTOR AND SPIN SYSTEM
(2) TITAN II AND SLV-3A DROP WEIGHTS ALSO INCLUDE 100 LBS. OF GUIDANCE SYSTEM
(3) V/P'S ARE SPIN STABILIZED

FIGURE 5-14

PARAMETRIC SHROUD WEIGHTS AS A FUNCTION OF AREA

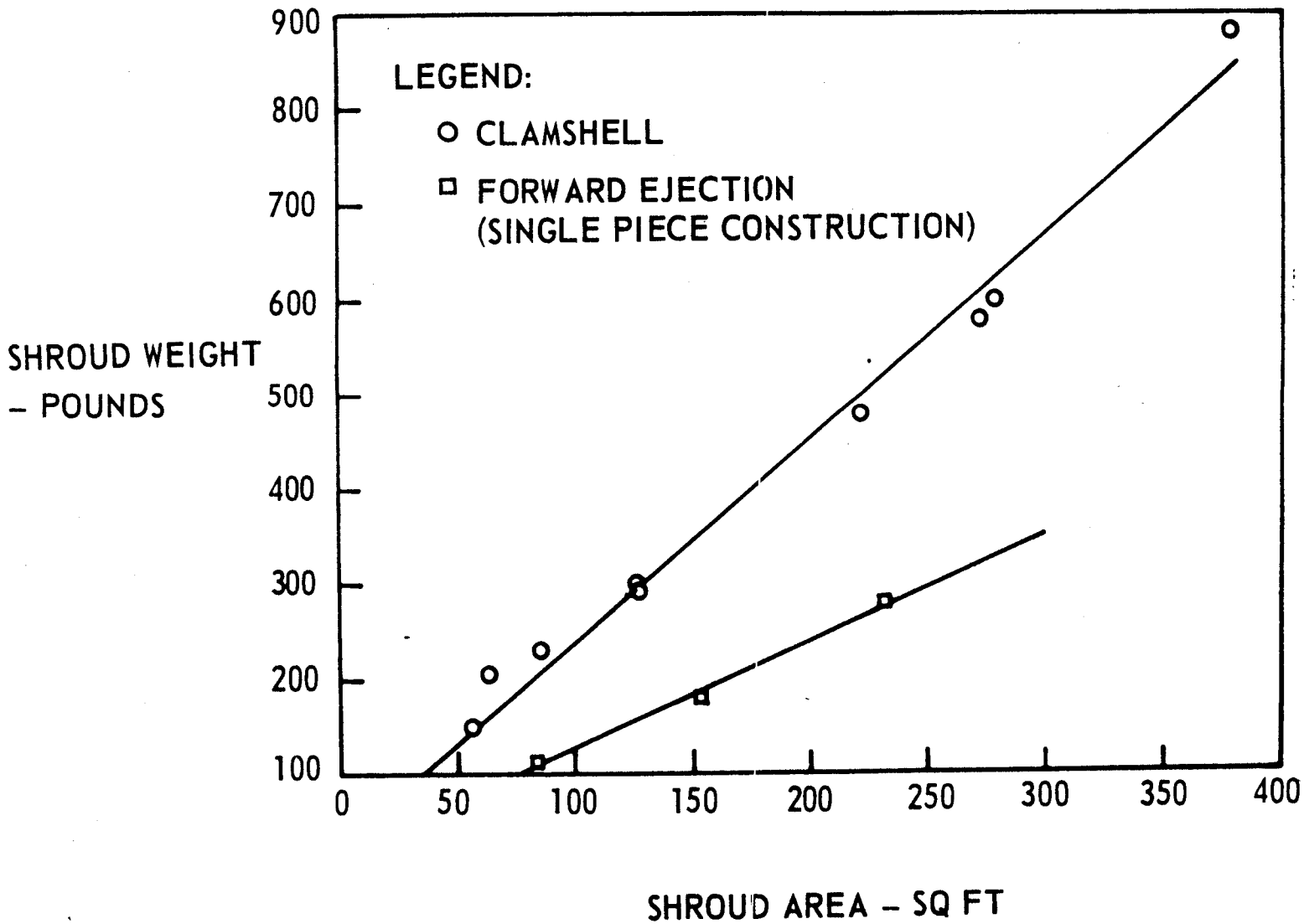


FIGURE 5–15

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

- 5.4.1 DETERMINE THE FEASIBILITY OF UTILIZING BOOSTER GUIDANCE SYSTEMS FOR REENTRY MISSIONS AND V/P POSITIONING
- 5.4.2 SUMMARY OF VARIOUS V/P GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5–16

BOOSTER GUIDANCE SUMMARY

BOOSTER	GUIDANCE TYPE	MAJOR SUBSYSTEMS	GUIDANCE CONTRACTOR	WEIGHT LBS.	VOL. FT^3	REENTRY MISSION CAPABILITY
ATLAS	RADIO*	RATE BEACON DECODER PULSE BEACON	G.E.	45.6	1.5	CANNOT PROVIDE ATTITUDE CONTROL AFTER BURNOUT
TITAN II	RADIO*	RATE BEACON DECODER PULSE BEACON	G.E.	45.6	1.5	CANNOT PROVIDE ATTITUDE CONTROL AFTER BURNOUT
TITAN III	INERTIAL	INERTIAL PLATFORM GUIDANCE COMPUTER	A.C. SPARK PLUG	852		CAN PROVIDE CONTROL DURING ALL PHASES OF MISSION
SATURN 1B AND V	INERTIAL	INERTIAL PLATFORM GUIDANCE COMPUTER FLIGHT CONTROL COMPUTER	BENDIX ECLIPSE-PIONEER	560	20.	IF S1VB IS PROVIDED WITH SUFFICIENT CONTROL PROPELLANT AND POWER IT CAN PROVIDE CONTROL DURING ALL MISSION PHASES
CENTAUR	INERTIAL	INERTIAL PLATFORM PLATFORM ELECTRONICS SIGNAL CONDITIONER COUPLER	HONEYWELL	184.5	5.64	CAN PROVIDE CONTROL DURING ALL PHASES OF MISSION
AGENA	STRAPDOWN INERTIAL	INERTIAL REFERENCE PACKAGE PROGRAMMER 1 R HORIZON SENSORS	HONEYWELL – GYROS BARNES – 1R SENSORS LOCKHEED – SYSTEM ASSEMBLY			CAN PROVIDE CONTROL DURING ALL PHASES OF MISSION
THOR/ DELTA	STRAPDOWN INERTIAL & RADIO	INERTIAL REFERENCE PACKAGE PROGRAMMER ELECTRONICS BTL GUIDANCE PACKAGE	HONEYWELL – INERTIAL SYSTEM BTL–RADIO GUIDANCE SYSTEM	DELTA =101 THOR =274 TOTAL =375		CAN PROVIDE CONTROL DURING ALL PHASES OF MISSION

*SOME OF THESE VEHICLES ARE INERTIALLY GUIDED
**CLASSIFIED ACCURACY DATA HAS BEEN DELETED

FIGURE 5–17

SUMMARY OF VELOCITY PACKAGE GUIDANCE AND ATTITUDE REFERENCE SYSTEMS

TYPE	COMPONENTS	WEIGHT* (LBS)	POWER (WATTS)	VOLUME (FT^3)	ATT. REF. DRIFT ‡ (DEG/MIN)	COMMENTS
UNGUIDED SPIN STABILIZED	TIMER	5 5 TOTAL	6 6 TOTAL	0.5	NOT APPL.	THE VELOCITY PACKAGE IS SPIN STABILIZED AND MUST TAKE THE BOOSTER ATTITUDE REFERENCE AT SPIN-UP.
STRAPDOWN INERTIAL	GYRO PACKAGE TIMER PROGRAMMER	14 5 6 25 TOTAL	30** 6 6 42 TOTAL	2.5	0.03	ORIENTS AND STABILIZES THE VELOCITY PACKAGE AFTER BOOSTER BURNOUT. SIMILAR TO FIRE CONCEPT.
FULL INERTIAL	INERTIAL PLATFORM ELECTRONICS ASSY.	15 13 28 TOTAL	27 23 50 TOTAL	3.0	0.01	THIS SYSTEM PROVIDES ACCURATE AND FLEXIBLE ATTITUDE REFERENCE AT THE COST OF GREATER COMPLEXITY AND UNIT COST.
FREE GYRO REFERENCE	SINGLE DEGREE OF FREEDOM GYRO TWO DOF GYRO TIMER ELECTRONICS ASSY.	2 5 5 5 17 TOTAL	4 15 6 5 30 TOTAL	1.0	0.75	LIGHTWEIGHT, SMALL VOLUME, AND LOW COST ARE ACHIEVED AT THE EXPENSE OF REDUCED ACCURACY

*WEIGHTS OF POWER SUPPLIES AND STRUCTURAL MOUNTING ARE NOT INCLUDED.
**DOES NOT INCLUDE 70 WATTS OF INTERMITTANT GYRO HEATING POWER.
‡ NON G SENSITIVE DRIFT ONLY.

FIGURE 5–18

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

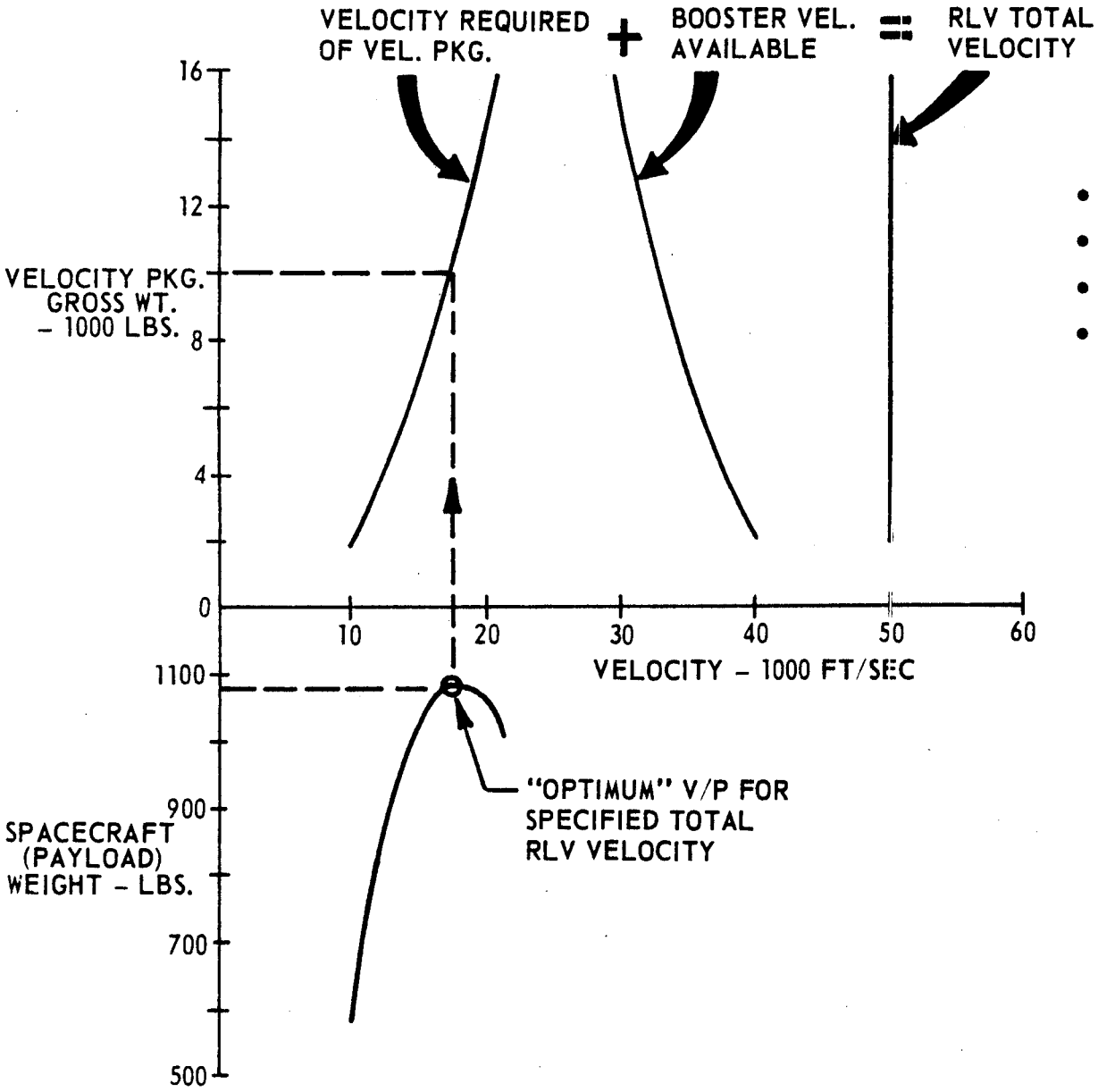
- 5.5.1 DETERMINE PROPULSION SYSTEM REQUIREMENTS BASED ON IDEALIZED STAGING ANALYSIS
- 5.5.2 REALISTIC V/P'S BASED ON IDEALIZED RESULTS
- 5.5.3 VALIDATION OF ASSUMPTIONS
- 5.5.4 CONFIGURATIONS CHOSEN FOR DETAILED ANALYSES

5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5–19

TYPICAL VELOCITY PACKAGE SIZING PROCEDURE



- RLV TOTAL VELOCITY = 50,000 FT/SEC
- TITAN IIIC BOOSTER
- TWO-STAGE VELOCITY PACKAGE
- ASSUMED STAGING PARAMETERS:
  - EQUAL Isp AND PWF BETWEEN STGS.
  - SPECIFIC IMPULSE = 290 SEC.
  - PROP. WT. FRACTION = 0.90

FIGURE 5–20

OPTIMUM ONE STAGE V/P FAMILY

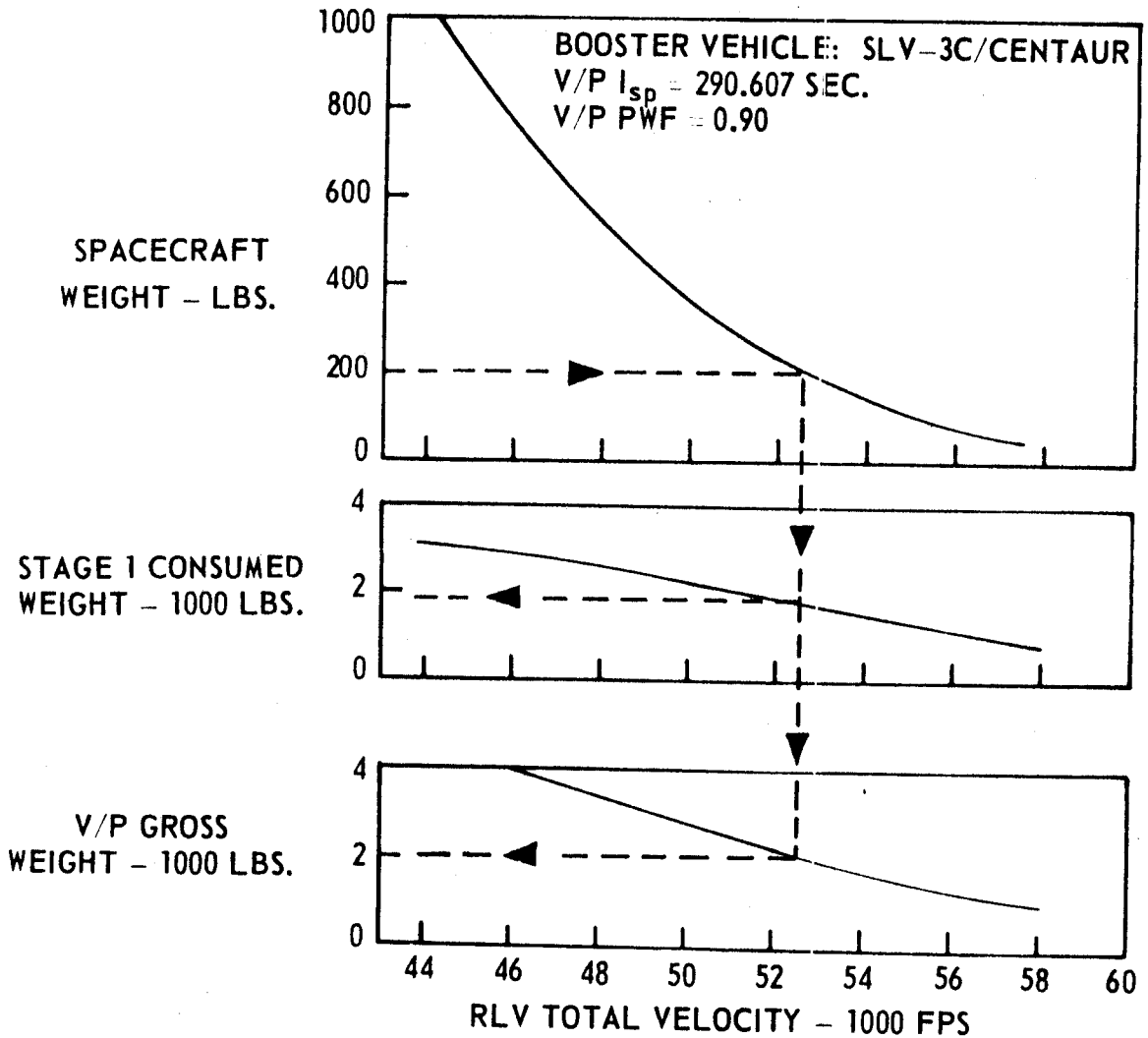


FIGURE 5-21

RESULTS OF V/P SIZING ANALYSIS FOR A 200 POUND DESIGN SPACECRAFT WEIGHT

BOOSTER VEHICLE	TWO STAGE V/P'S			ONE STAGE V/P'	
	V/P GROSS WT. (LBS)	W_{C1} (LBS)	W_{C2} (LBS)	V/P GROSS WT. (LBS)	W_{C1} (LBS)
DSV-2K/AGENA	2500	1610	460	1800	1450
DSV-2L/IMP. DELTA	3100	2100	520	2200	1780
DSV-2L/AGENA	3000	2000	520	1880	1500
SLV-3A	11700	8350	1130	3630	3100
SLV-3A/AGENA	3770	2520	600	1700	1350
SLV-3C/CENTAUR	4300	3050	670	2120	1750
TITAN II (GLV)	8310	6110	990	2950	2430
TITAN IIIA	5000	3700	720	2500	2100
TITAN IIIB	3900	2620	635	1700	1350
TITAN IIIC	7100	5350	880	2950	2450
TITAN IIIA/CENTAUR (TRNSTG. REMOVED)	4300	3050	670	2120	1750
TITAN IIIC/CENTAUR (TRNSTG. REMOVED)	5750	4200	800	2600	2200
SATURN IB	16400	13200	1450	7630	6600
SATURN IB/CENTAUR	5750	4200	800	2600	2200
SATURN V	22000	17800	1700	8700	7700

FIGURE 5--22

SELECTION OF CANDIDATE MOTORS BASED ON IDEALIZED STAGING RESULTS

OPTIMUM CONSUMED WEIGHT (LBS.)	CONSUMED WEIGHT CATEGORY (LBS.)	BEST MOTOR FROM SURVEY DATA
	150 TO 200	BE-3
	300 TO 400	PHOENIX
460 520 520	450 TO 550	MG-18
600 635 670 670 720	600 TO 750	FW-4
800 800 880 990	800 TO 1000	23KS11000
1,130 1,350 1,350 1,450 1,450 1,500	1100 TO 1500	TE-364-2
1,610 1,700 1,750 1,750 1,780 2,000 2,100 2,100 2,200 2,200	1600 TO 2300	TE-364-4
2,430 2,450 2,520 2,620 3,050 3,050 3,100	2300 TO 3200	X-259
3,700	3150 TO 4150	MMIII, M57
4,200 4,200 5,100 5,350 6,110	4200 TO 6200	XM-80
7,700 8,350	6500 TO 9000	260A3
13,200 17,800	12,000 TO 18,000	MMII, M56

FIGURE 5-23

MATCHING OF CANDIDATE MOTORS TO VARIOUS BOOSTERS

	BOOSTER VEHICLE	TWO STAGE V/P'S CANDIDATE MOTOR, STG. 1	TWO STAGE V/P'S CANDIDATE MOTOR, STG. 2	ONE STAGE V/P'S CANDIDATE MOTOR
THOR	DSV-2K/AGENA	TE-364-4	MG-18	TE-364-2
	DSV-2L/IMP. DELTA	TE-364-4	MG-18	TE-364-4
	DSV-2L/AGENA	TE-364-4	MG-18	TE-364-2
ATLAS	SLV-3A	260-A3	TE-364-2	X-259
	SLV-3A/AGENA	X-259	FW-4	TE-364-2
	SLV-3C/CENTAUR	X-259	FW-4	TE-364-4
TITAN	TITAN II (GLV)	XM-80	23KS11000	X-259
	TITAN IIIA	M-57	FW-4	TE-364-4
	TITAN IIIB	X-259	FW-4	TE-364-2
	TITAN IIIA/CENTAUR (TRANSTAGE REMOVED)	X-259	FW-4	TE-364-4
	TITAN IIIC	XM-80	23KS11000	X-259
	TITAN IIIC/CENTAUR (TRANSTAGE REMOVED)	XM-80	23KS11000	TE-364-4
SAT'N	SATURN IB	M-56	TE-364-2	260-A3
	SATURN IB/CENTAUR	XM-80	23KS11000	TE-364-4
	SATURN V	M-56	TE-364-4	260-A3

FIGURE 5-24

THE EFFECTS OF ASSUMED SPECIFIC IMPULSE AND PROPELLANT WEIGHT FRACTION ON VELOCITY PACKAGE SIZE AT A CONSTANT SPACECRAFT WEIGHT OF 200 POUNDS

(SLV-3C/CENTAUR)

SPECIFIC IMPULSE I_{sp} (SEC)	PROP. WEIGHT FRACTION PWF	RLV TOTAL VELOCITY (FPS)	STAGE 1 CONSUMED WEIGHT (LBS)	STAGE 2 CONSUMED WEIGHT (LBS)	V/P GROSS WEIGHT (LBS)
290*	0.90*	56,000	3050	670	4300
285	0.90	55,600	2890	660	4140
280	0.90	55,200	2750	650	3980
290*	0.90*	56,000	3050	670	4300
290	0.89	55,620	2750	649	3950
290	0.88	55,240	2460	629	3620

* ASSUMED VALUES

FIGURE 5-25

THE EFFECTS OF SPACECRAFT WEIGHT ON VELOCITY PACKAGE SIZE

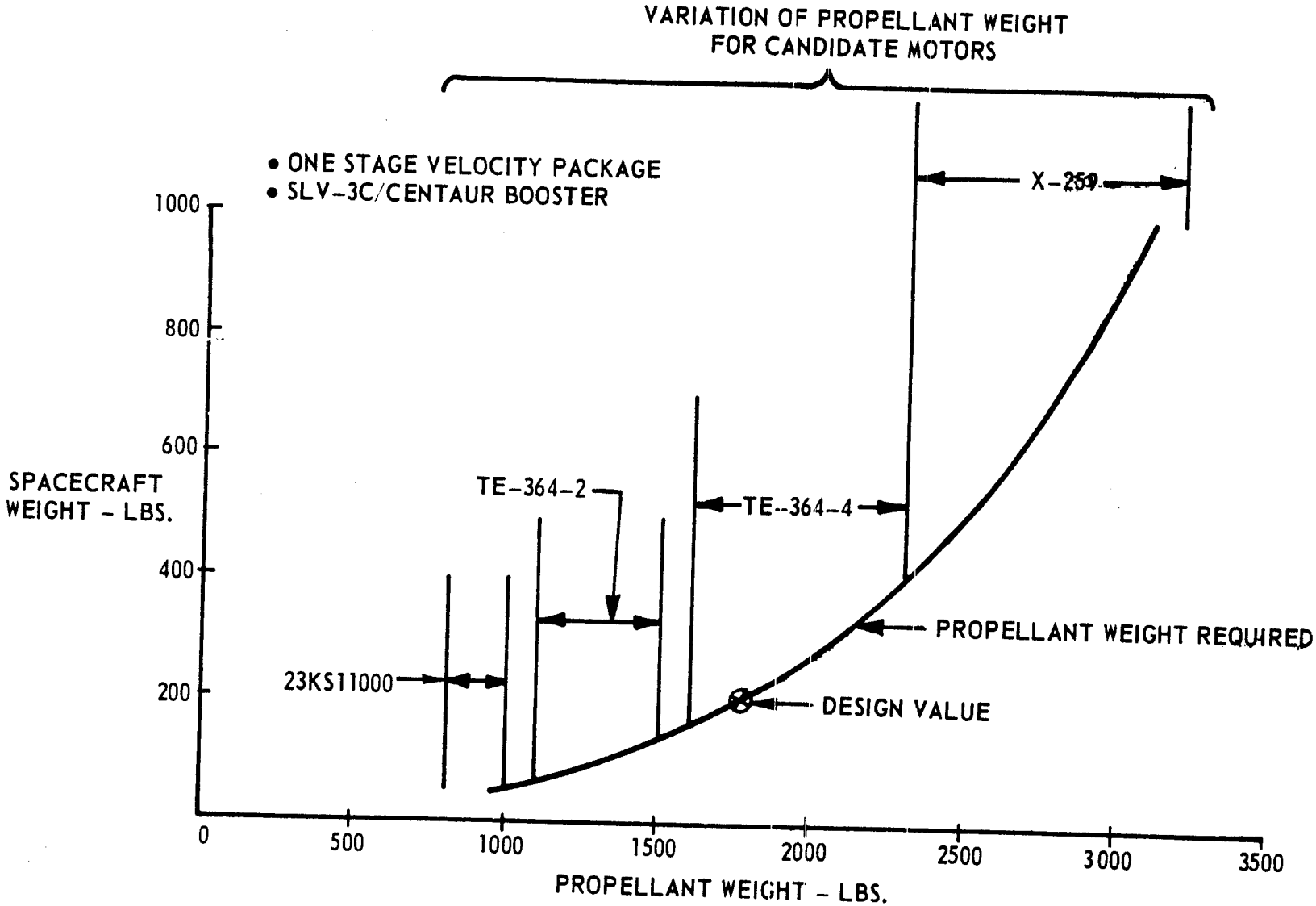


FIGURE 5-26

CONFIGURATIONS CHOSEN FOR DETAILED PERFORMANCE ANALYSIS

BOOSTER	ONE STAGE VELOCITY PACKAGES					TWO STAGE VELOCITY PACKAGES					
	TE-364-2 (1600)	TE-364-4 (2400)	X-259 (2900)	XM-80 (6400)	260-A3 (9800)	MG-18 / TE-364-4 (8000)	FW-4 / X-259 (3600)	FW-4 / M 57 (5100)	23KS11000 / XM 80 (7400)	TE-364-2 / 260-A3 (11,400)	TE-364-2 / M 56 (17,500)
THOR/AGENA (DSV-2K/AGENA D)	A, ●	A	A			A, ●					
TAT/AGENA (DSV-2L/AGENA D)	A, ●	A	A			A, ●	A				
TAD/DELTA (DSV-2L/IMP. DELTA)	A	A, ●	A			A ●					
ATLAS (SLV-3A)			A, ●	A	A		A		A	●	A
ATLAS/AGENA (SLV-3A/AGENA D)	A, ●	A	A			A	A, ●		A		
ATLAS/CENTAUR (SLV-3C/CENTAUR)	A	A, ●	A			A	A, ●				
TITAN II (GLV)	A	A	A, ●			A	A		A, ●		
TITAN IIIA (SLV-5A)		A, ●	A				A	●	A		
TITAN IIIB (SLV-5B)	A, ●		A			A	A, ●				
TITAN IIIC/CENTAUR (SLV-5C LESS TRANSTAGE/CENTAUR)		A, ●					A, ●				
TITAN IIIC (SLV-5C)		A	A, ●	A			A		A, ●		
TITAN IIIC/CENTAUR (SLV-5C LESS TRANSTAGE/CENTAUR)	A	A, ●	A				A		A, ●		
SATURN IB (S-IB/S IVB)			A	A	A, ●		A		A		A, ●
SATURN IB/CENTAUR (S-IB/S IVB/CENTAUR)	A	A, ●	A				A		A, ●		
SATURN V S-IC/S-II/S-IVB			A	A	A, ●				A		A, ●

A CONFIGURATIONS SELECTED FOR DETAILED PERFORMANCE ANALYSIS
● NEAR-OPTIMUM CONFIGURATIONS BASED ON STAGING ANALYSIS
( ) APPROXIMATE VELOCITY PACKAGE GROSS WEIGHT-LBS.

FIGURE 5-27

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

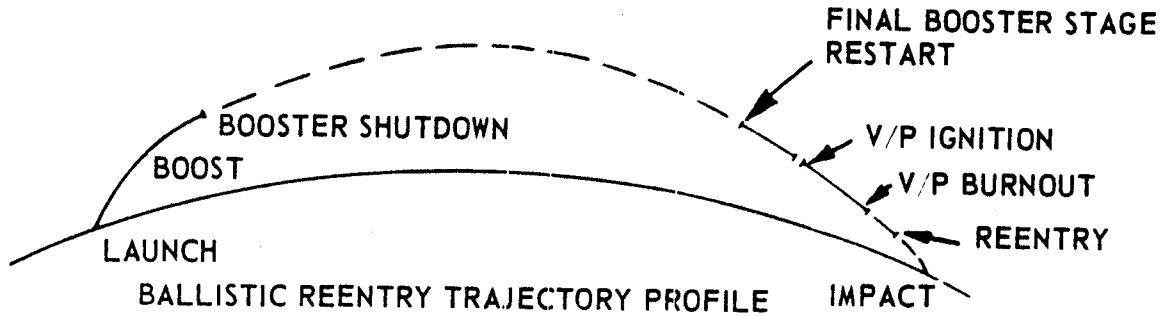
5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

- 5.6.1 BALLISTIC REENTRY TRAJECTORIES VERSUS UNCONVENTIONAL FLIGHT PROFILES
- 5.6.2 THE EFFECTS OF TRAJECTORY RANGE CONTROL
- 5.6.3 PERFORMANCE COMPUTATION OF CANDIDATE CONFIGURATIONS
- 5.6.4 PERFORMANCE TRADE STUDIES

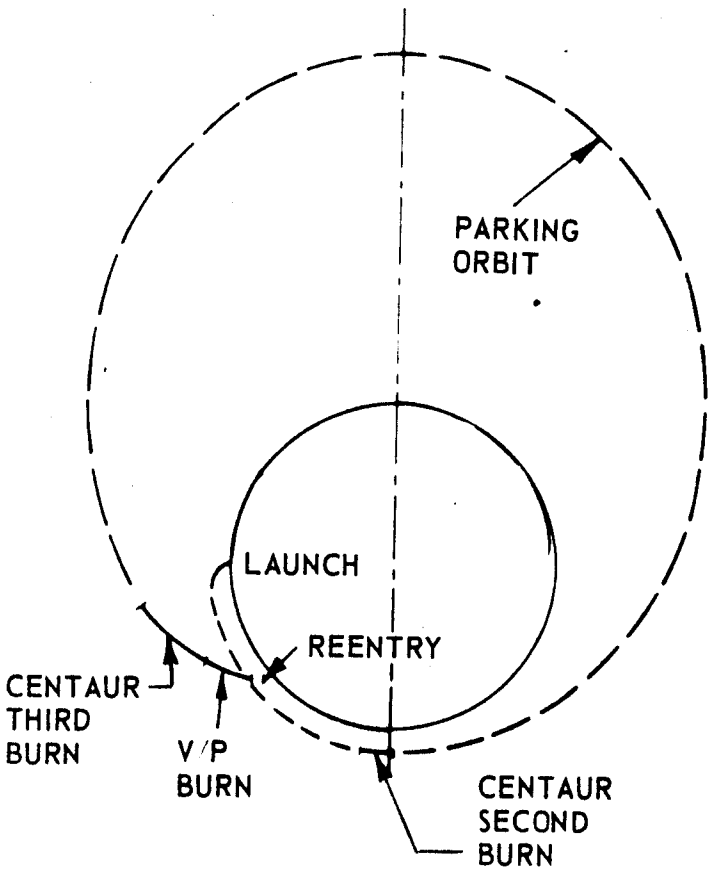
5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

FIGURE 5-28

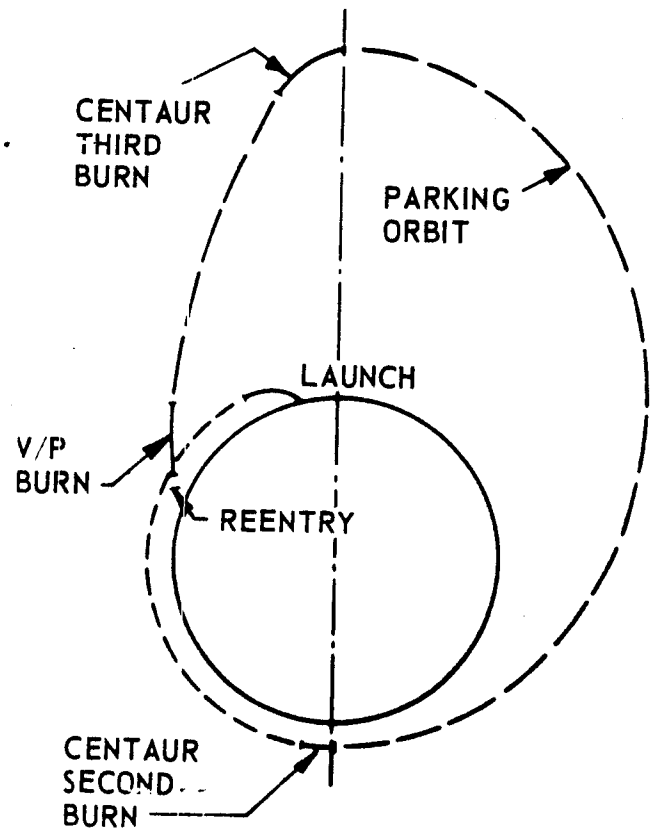
TRAJECTORY SHAPING TECHNIQUES



BALLISTIC REENTRY TRAJECTORY PROFILE
METHOD 1



PARKING ORBIT PROFILE
METHOD 2



PARKING ORBIT PROFILE
METHOD 3

FIGURE 5-29

COMPARISON OF REENTRY TRAJECTORY SHAPING METHODS

PARAMETER	BALLISTIC METHOD 1	PARKING ORBIT METHOD 2	PARKING ORBIT METHOD 3
VELOCITY (FT/SEC)	55,300.	53,050.	55,050.
FLIGHT TIME (MIN.)	24.	132.	216.
MAXIMUM ALT. (N.M.)	528.	1,257.	5,280.
REENTRY RANGE (N.M.)	2,900.	2,900.	2,900.
APPROX. IMPACT DISPERSION (N.M.)	± 35	± 56	± 187

- REENTRY CONDITIONS:
  - ALTITUDE = 400,000 FT.
  - PATH ANGLE = -15 DEGS.
  - ANGLE-OF-ATTACK = 0 DEGS.
- SPACECRAFT WEIGHT = 50 LBS.
- RESEARCH LAUNCH VEHICLE = SLV-3C/CENTAUR/X-259/FW-4

FIGURE 5--30

EFFECT OF RANGE ON VELOCITY

(SLV-3C/CENTAUR/X-259/FW-4
S/C WT. = 200 LBS)

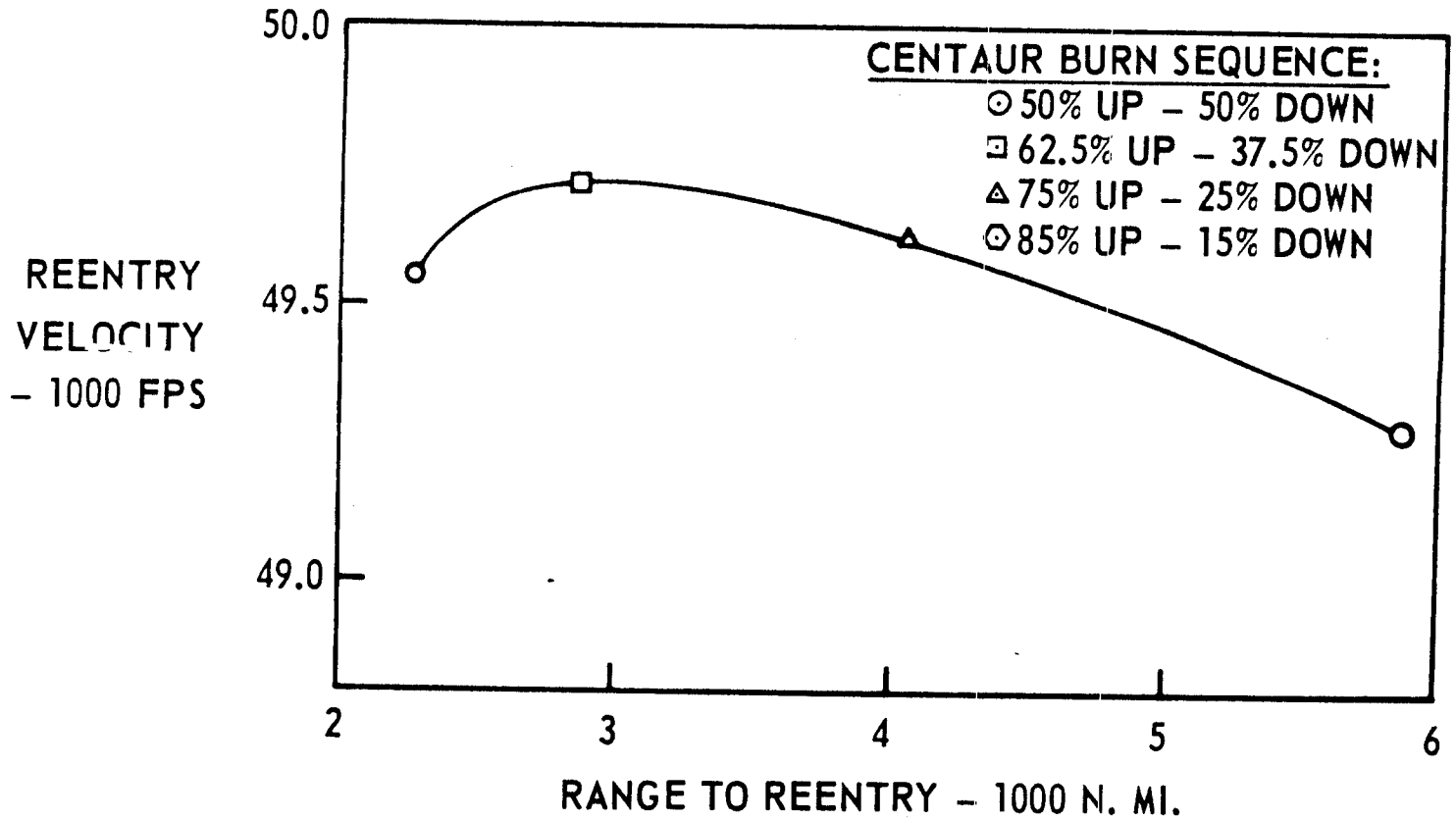


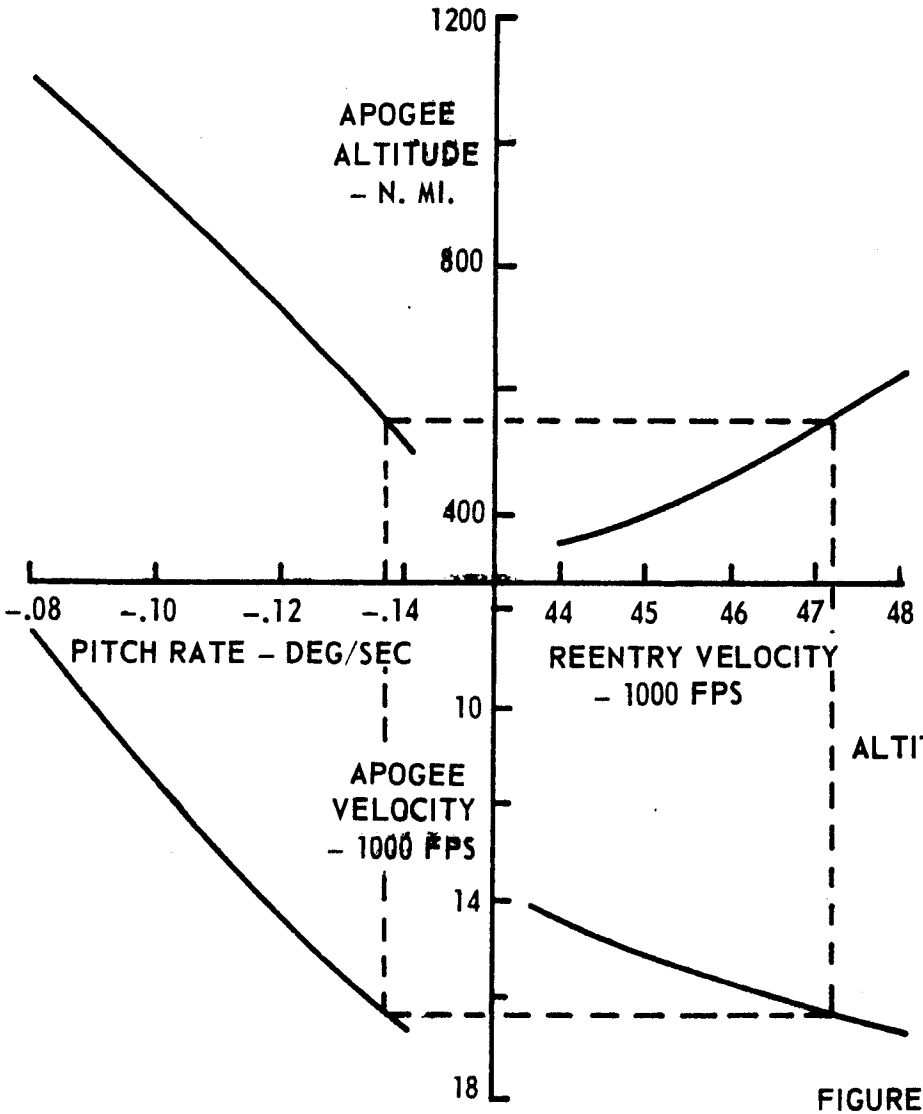
FIGURE 5-31

SUMMARY OF OPTIMUM RANGE ANALYSES

BOOSTER	RESEARCH LAUNCH VEHICLE	OPTIMUM RANGE (N. MI.)
THOR	DSV-2L/IMP. DELTA/TE-364-4/MG-18	1820.
	DSV-2L/AGENA/TE-364-4/MG-18	2420.
ATLAS	SLV-3A/AGENA/X-259/FW-4	3750.
	SLV-3C/CENTAUR/X-259/FW-4	2875.
TITAN	TITAN II/XM80/23KS11000	6760.
	TITAN IIIA/XM80/23KS11000	1850.
	TITAN IIIA/CENTAUR/X-259/FW-4 (NO TRANSTAGE)	3140.
	TITAN IIIB/X-259/FW-4	4340.
	TITAN IIIC/XM80/23KS11000	6450.
	TITAN IIIC/CENTAUR/XM80/23KS11000 (TRANSTAGE REMOVED)	3750.
SATURN	SATURN IB/M56/TE-364-2	2625.
	SATURN IB/CENTAUR/XM-80/23KS11000	3740.
	SATURN V/M56/TE-364-2	4370.
	SATURN V/CENTAUR	5900.

FIGURE 5-32

REENTRY VELOCITY MATCHING FOR FIXED S/C WEIGHT AND REENTRY CONDITIONS



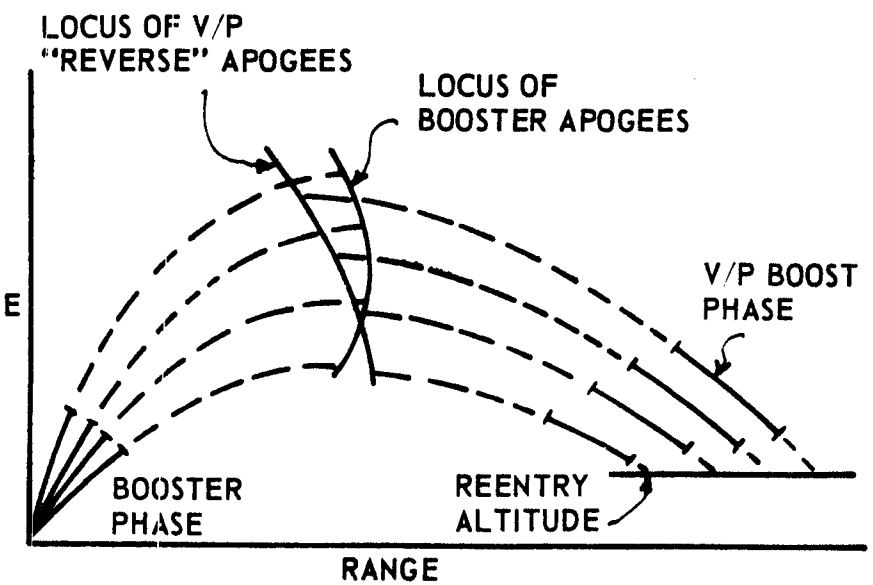


FIGURE 5–33

CHECK OF PERFORMANCE COMPUTATION METHOD

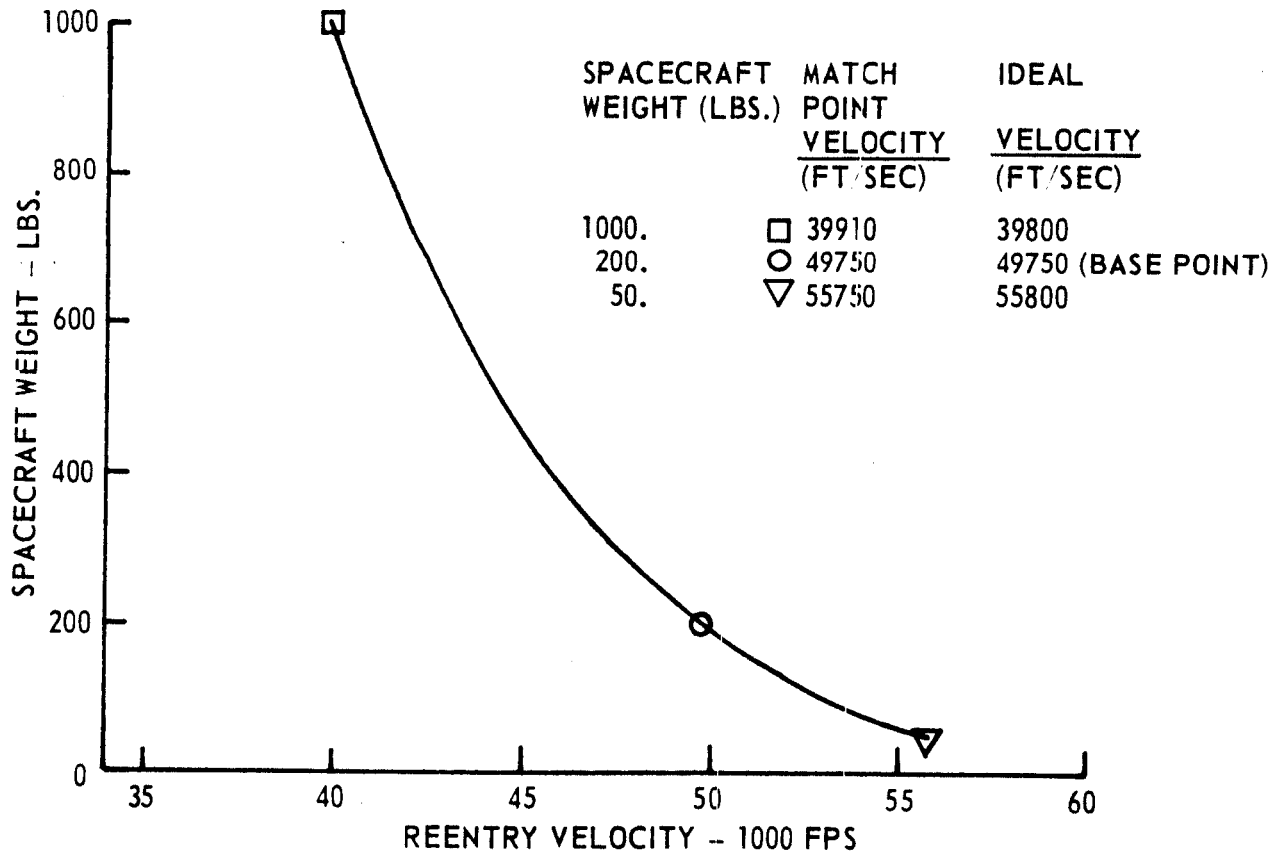


FIGURE 5-34

ALL PERFORMANCE DATA PRESENTED ARE BASED ON THE FOLLOWING:

- REENTRY CONDITIONS:
  - ALTITUDE = 400,000 FT.
  - FLIGHT PATH ANGLE = -15 DEGS.
  - NOMINAL ANGLE-OF-ATTACK = 0 DEGREES
- COAST TIME = 10 SEC. FROM V/P BURNOUT TO REENTRY
- OPTIMUM RANGE UTILIZED FOR BOOSTERS WITH FINAL-STAGE RE-START CAPABILITY
- TITAN II AND SLV-3A LIMITED TO MAXIMUM RANGE OF 8000 N.M.
- ALL TRAJECTORY SIMULATIONS BASED ON 90 DEGREE LAUNCH AZIMUTH FROM ETR.
- SPIN-STABILIZED VELOCITY PACKAGES

FIGURE 5-35

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE THOR BOOSTER FAMILY SINGLE STAGE VELOCITY PACKAGES

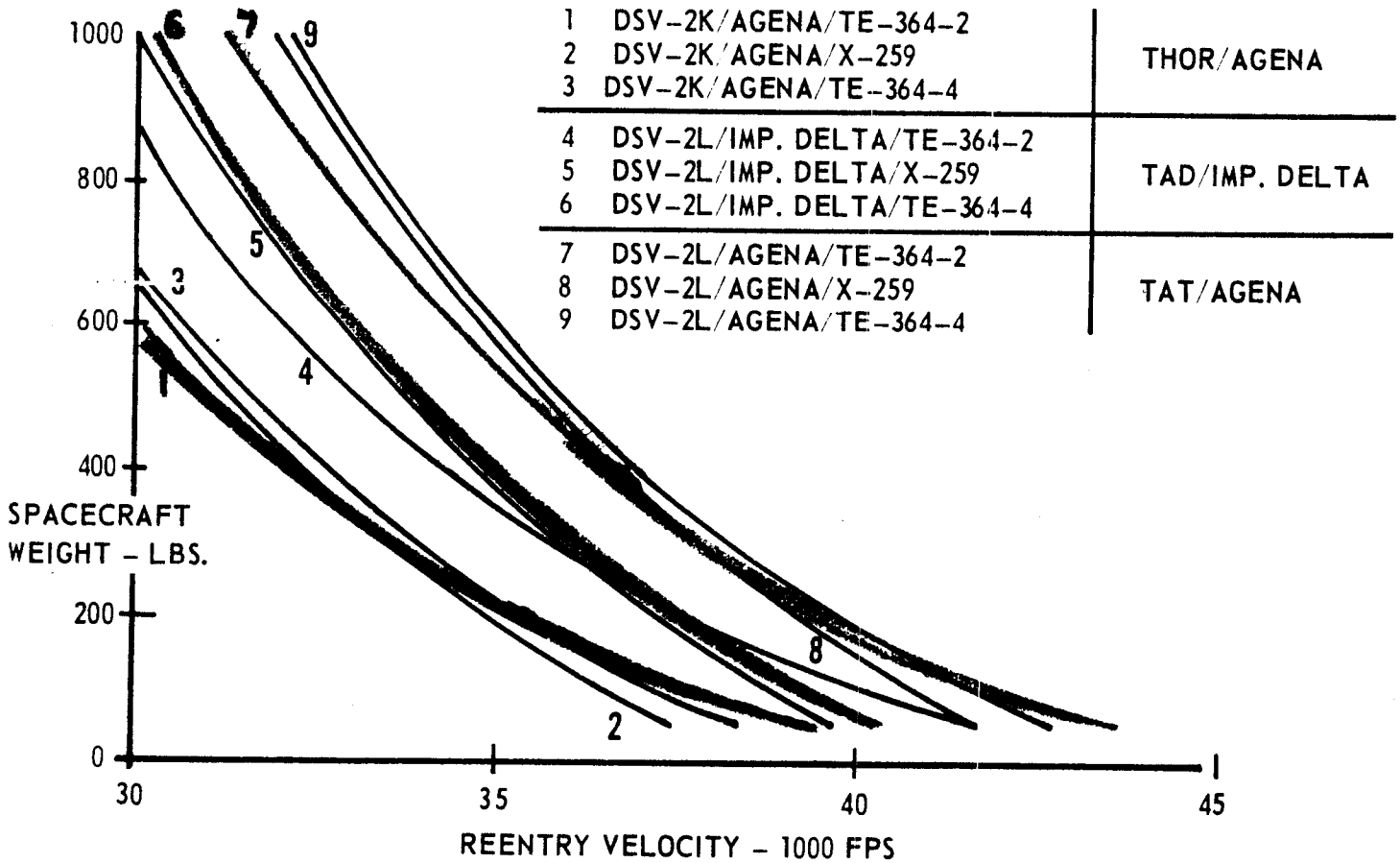


FIGURE 5-36

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE ATLAS BOOSTER FAMILY

SINGLE STAGE VELOCITY PACKAGES

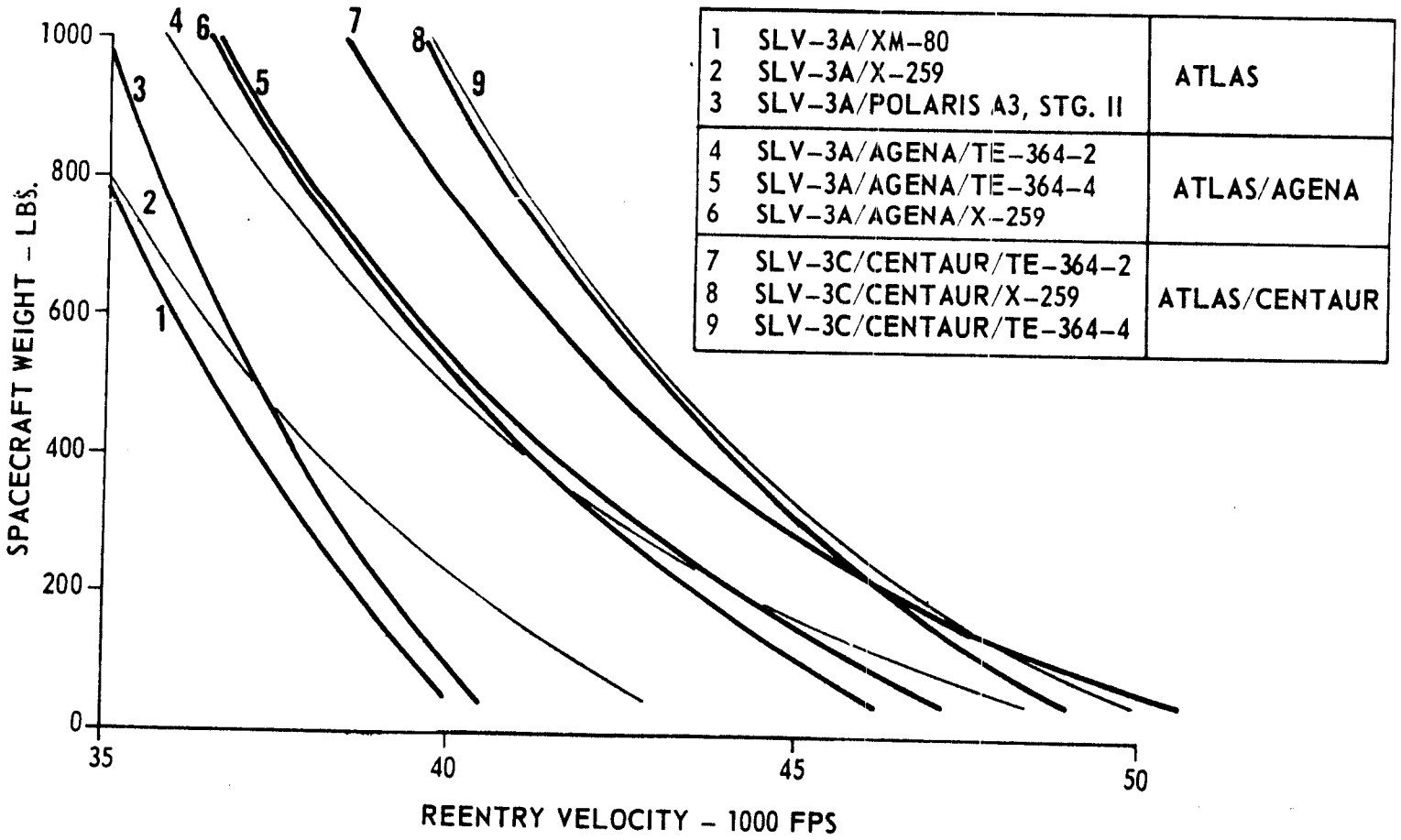
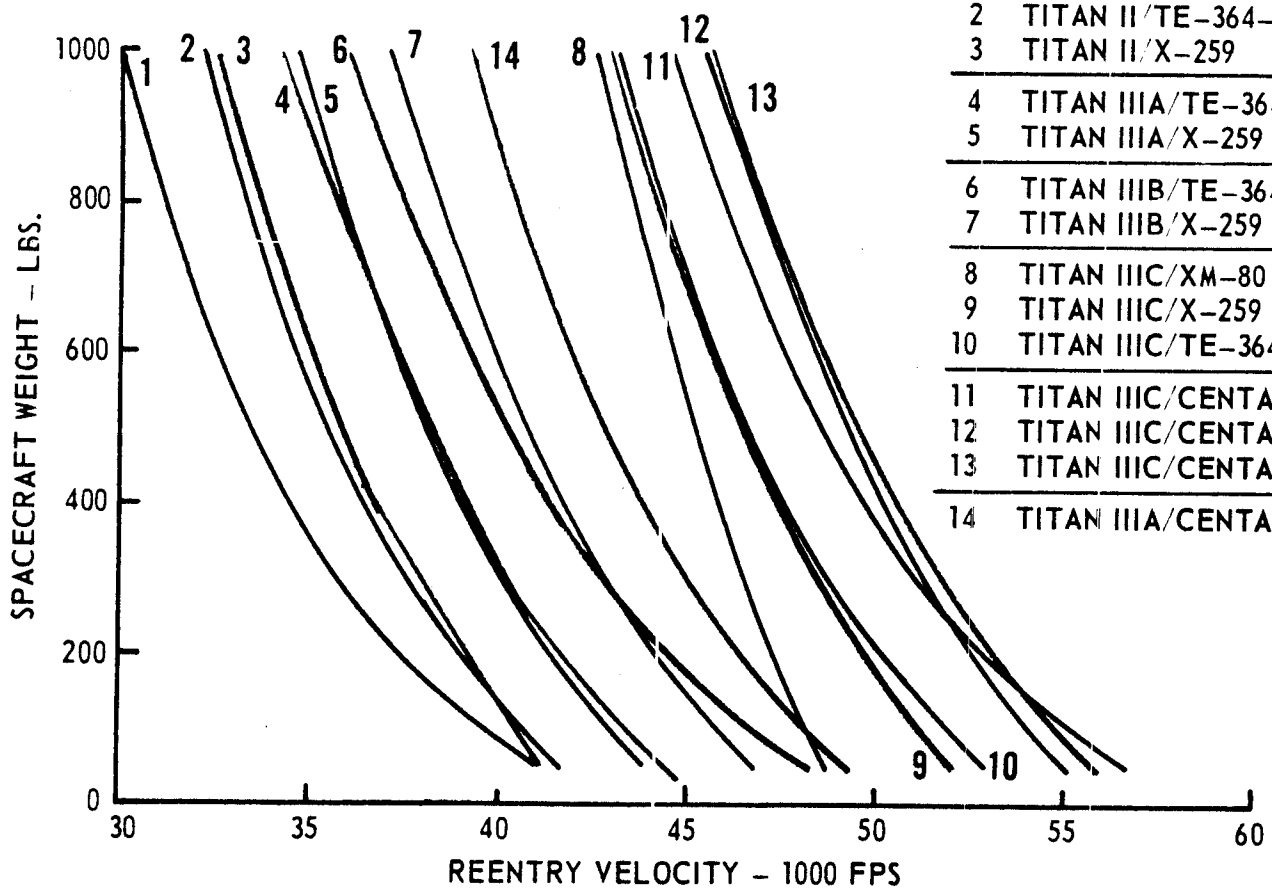


FIGURE 5-37

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE TITAN BOOSTER FAMILY SINGLE STAGE VELOCITY PACKAGES



1	TITAN II/TE-364-2	GLV
2	TITAN II/TE-364-4	
3	TITAN II/X-259	
4	TITAN IIIA/TE-364-4	SLV-5A
5	TITAN IIIA/X-259	
6	TITAN IIIB/TE-364-2	SLV-5B
7	TITAN IIIB/X-259	
8	TITAN IIIC/XM-80	SLV-5C
9	TITAN IIIC/X-259	
10	TITAN IIIC/TE-364-4	
11	TITAN IIIC/CENTAUR/TE-364-2	SLV-5C/CENTAUR (LESS TRANSTAGE)
12	TITAN IIIC/CENTAUR/X-259	
13	TITAN IIIC/CENTAUR/TE-364-4	
14	TITAN IIIA/CENTAUR/TE-364-4	SLV-5A/CENTAUR (LESS TRANSTAGE)

FIGURE 5-38

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE SATURN BOOSTER FAMILY SINGLE STAGE VELOCITY PACKAGES

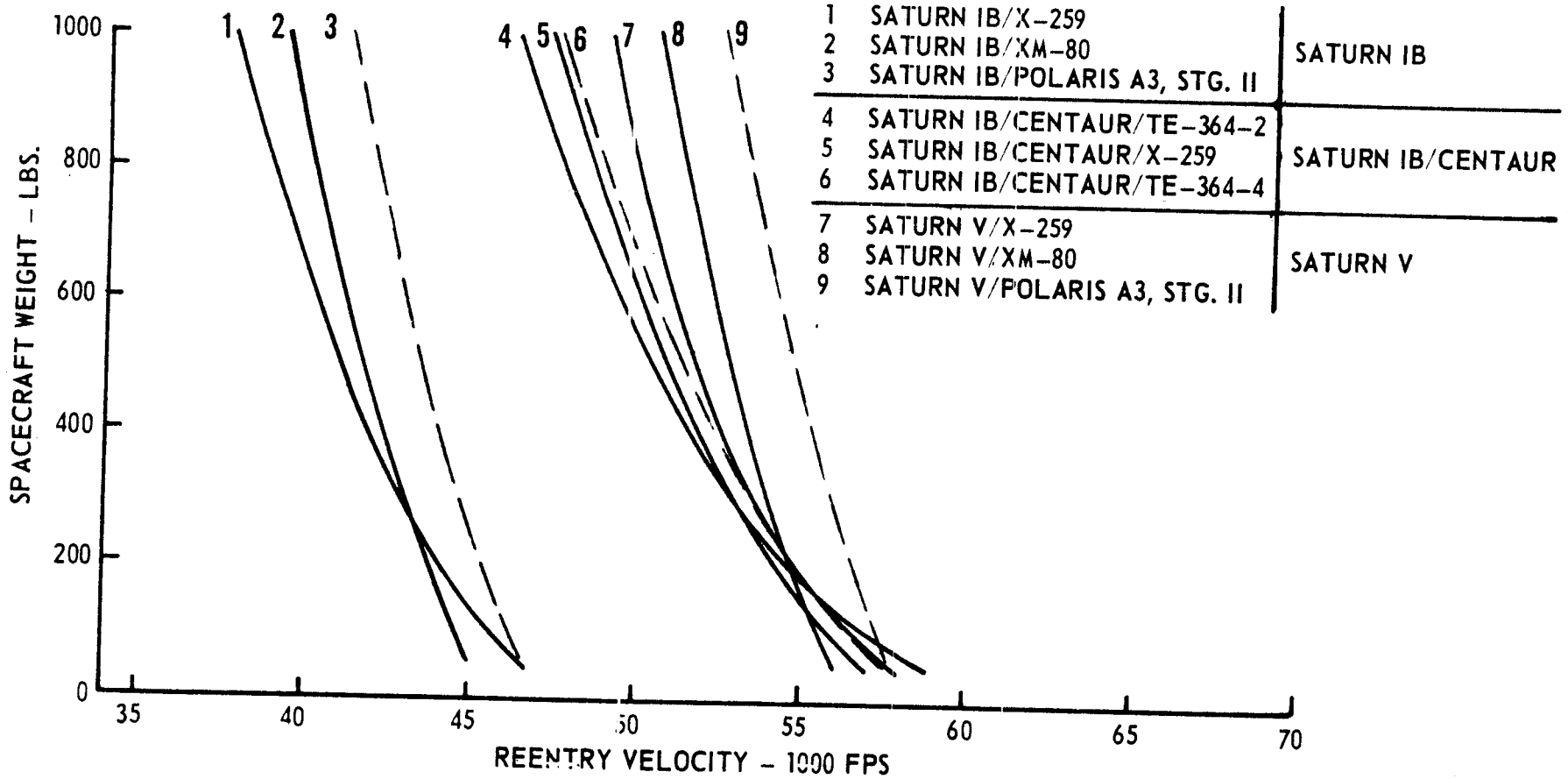


FIGURE 5-39

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE THOR BOOSTER FAMILY

TWO STAGE VELOCITY PACKAGES

1	DSV-2K/AGENA/TE-364-4/MG-18	THOR/AGENA
2	DSV-2L/IMP. DELTA/TE-364-4/MG-18	TAD/IMP. DELTA
3	DSV-2L/AGENA/X-259/FW-4	TAT/AGENA
4	DSV-2L/AGENA/TE-364-4/MG-18	

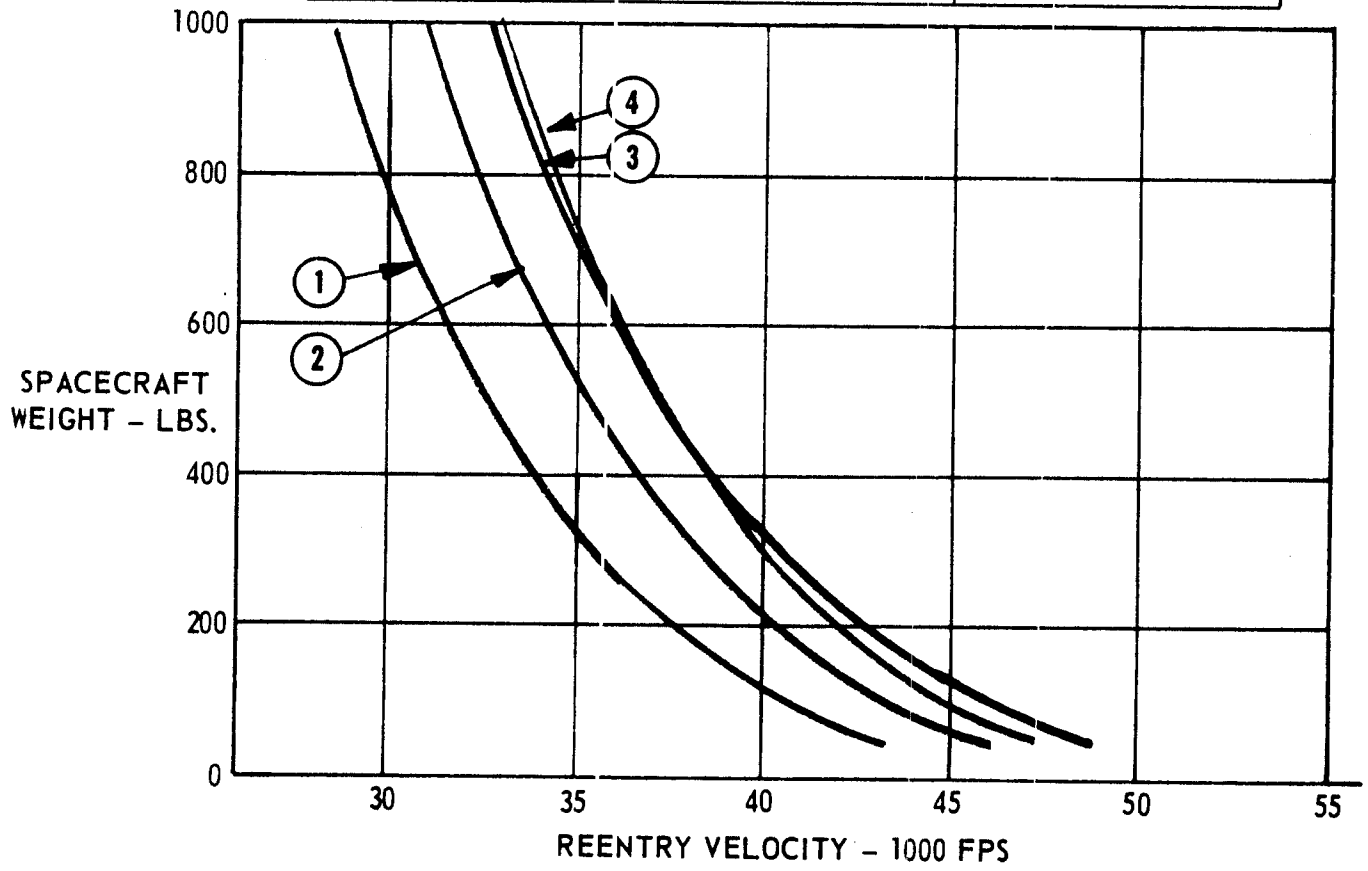


FIGURE 5-40

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE ATLAS BOOSTER FAMILY TWO STAGE VELOCITY PACKAGES

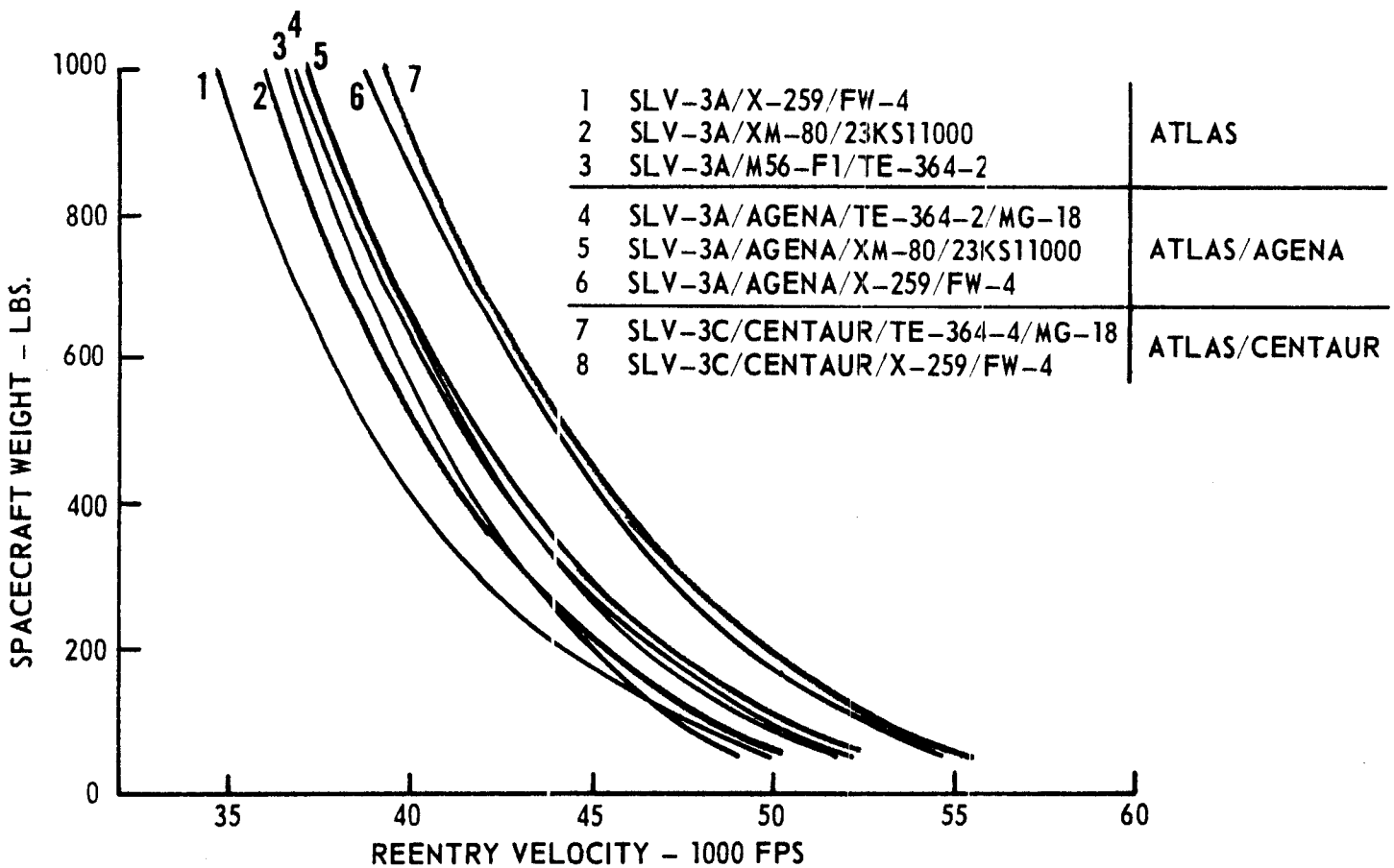
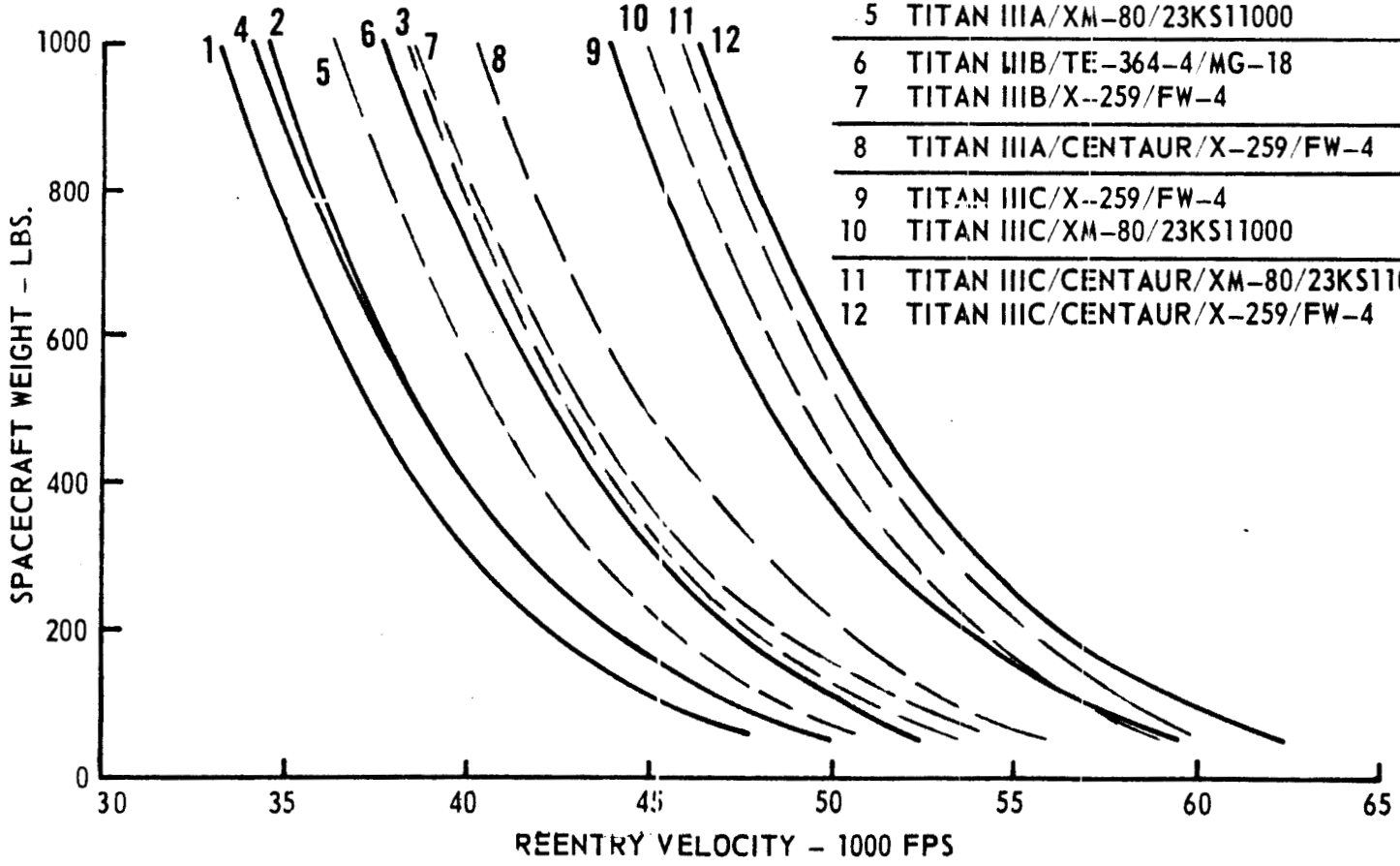


FIGURE 5-41

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE TITAN BOOSTER FAMILY

TWO STAGE VELOCITY PACKAGES



1	TITAN II/TE–364–2/MG–18	GLV
2	TITAN II/X–259/FW–4	
3	TITAN II/XM–80/23KS11000	
4	TITAN IIIA/X–259/FW–4	SLV–5A
5	TITAN IIIA/XM–80/23KS11000	
6	TITAN IIIB/TE–364–4/MG–18	SLV–5B
7	TITAN IIIB/X–259/FW–4	
8	TITAN IIIA/CENTAUR/X–259/FW–4	SLV–5A/CENTAUR
9	TITAN IIIC/X–259/FW–4	SLV–5C
10	TITAN IIIC/XM–80/23KS11000	
11	TITAN IIIC/CENTAUR/XM–80/23KS11000	SLV–5C/CENTAUR
12	TITAN IIIC/CENTAUR/X–259/FW–4	

FIGURE 5–42

PERFORMANCE CAPABILITIES FOR RESEARCH LAUNCH VEHICLES OF THE SATURN BOOSTER FAMILY TWO STAGE VELOCITY PACKAGES

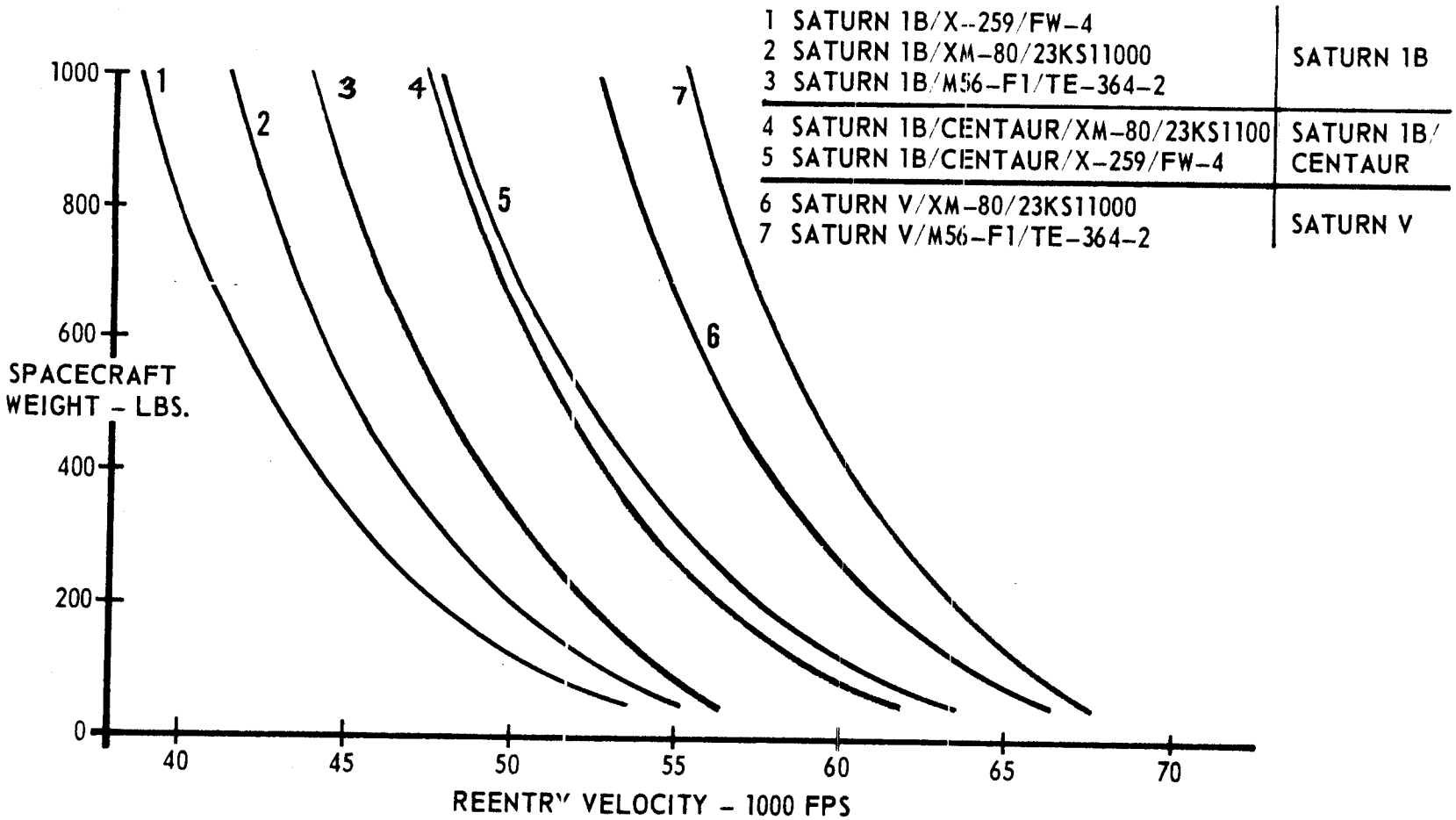


FIG 5-43

PERFORMANCE IMPROVEMENTS USING OPTIMIZED 1970 SOLID MOTORS

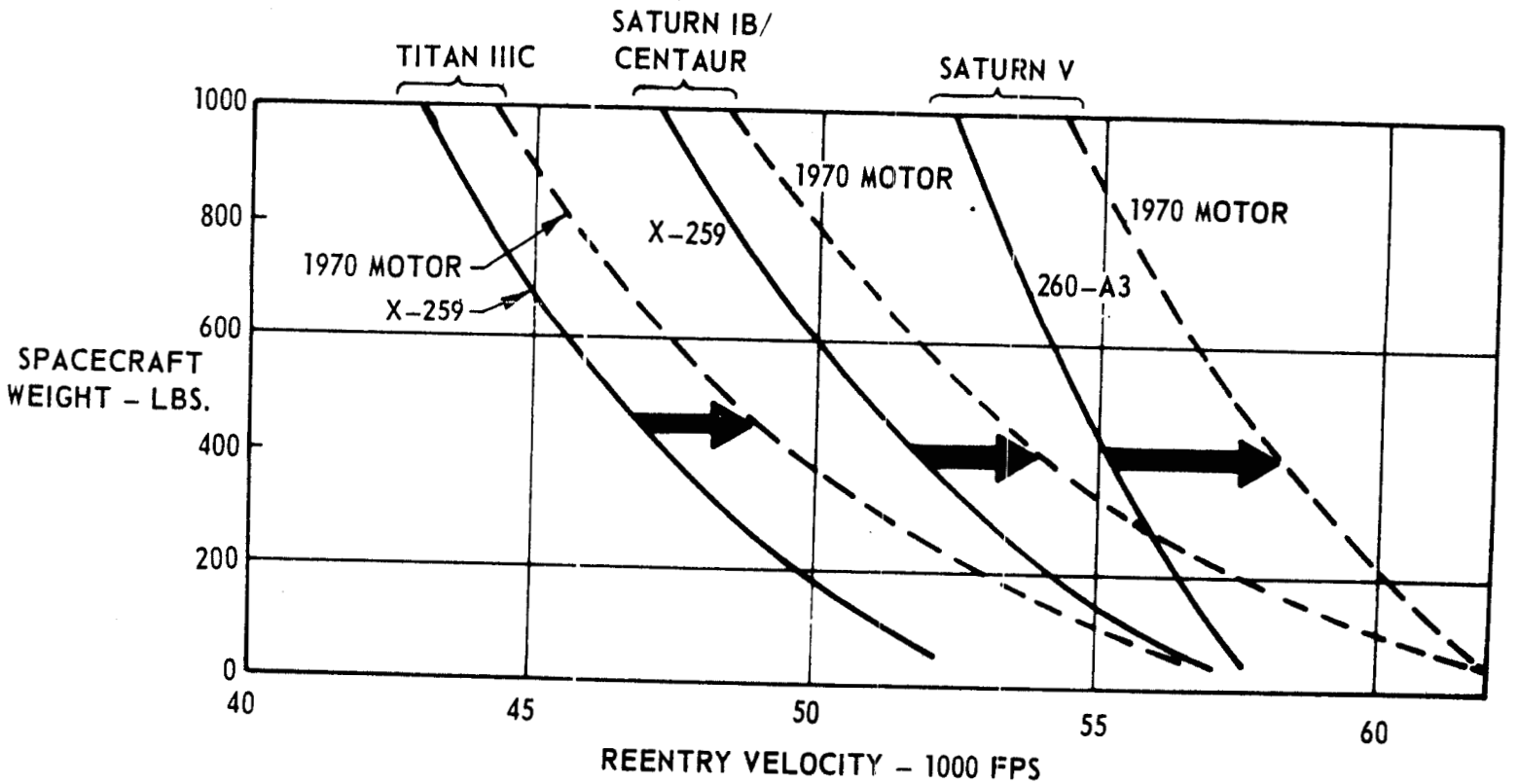


FIGURE 5–44

PERFORMANCE TRADE-OFF AS A FUNCTION OF NUMBER OF VELOCITY PACKAGE STAGES

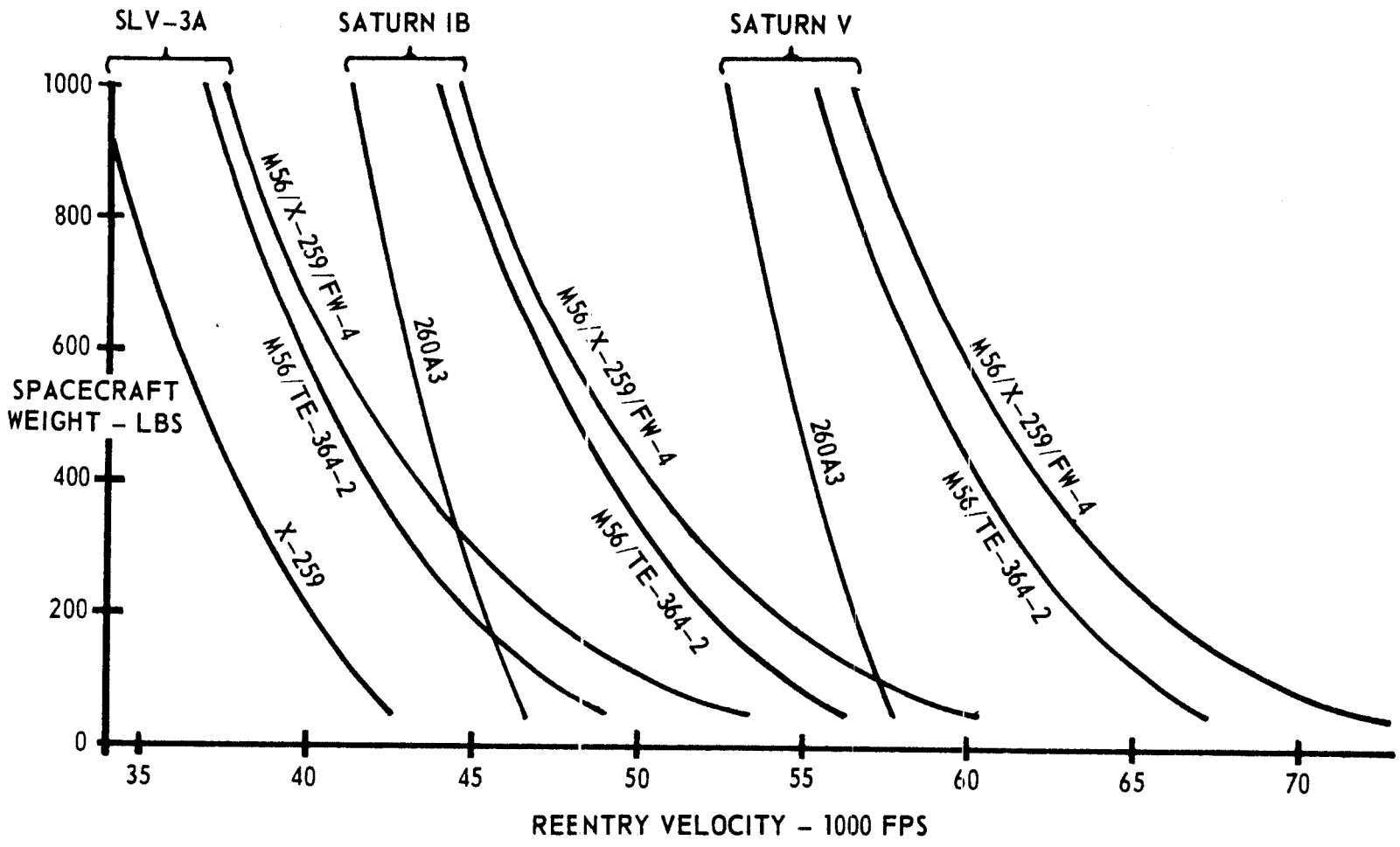


FIGURE 5-45

PERFORMANCE COMPARISON OF EXISTING SOLID PROPELLANT VELOCITY PACKAGES (TITAN IIIC BOOSTER)

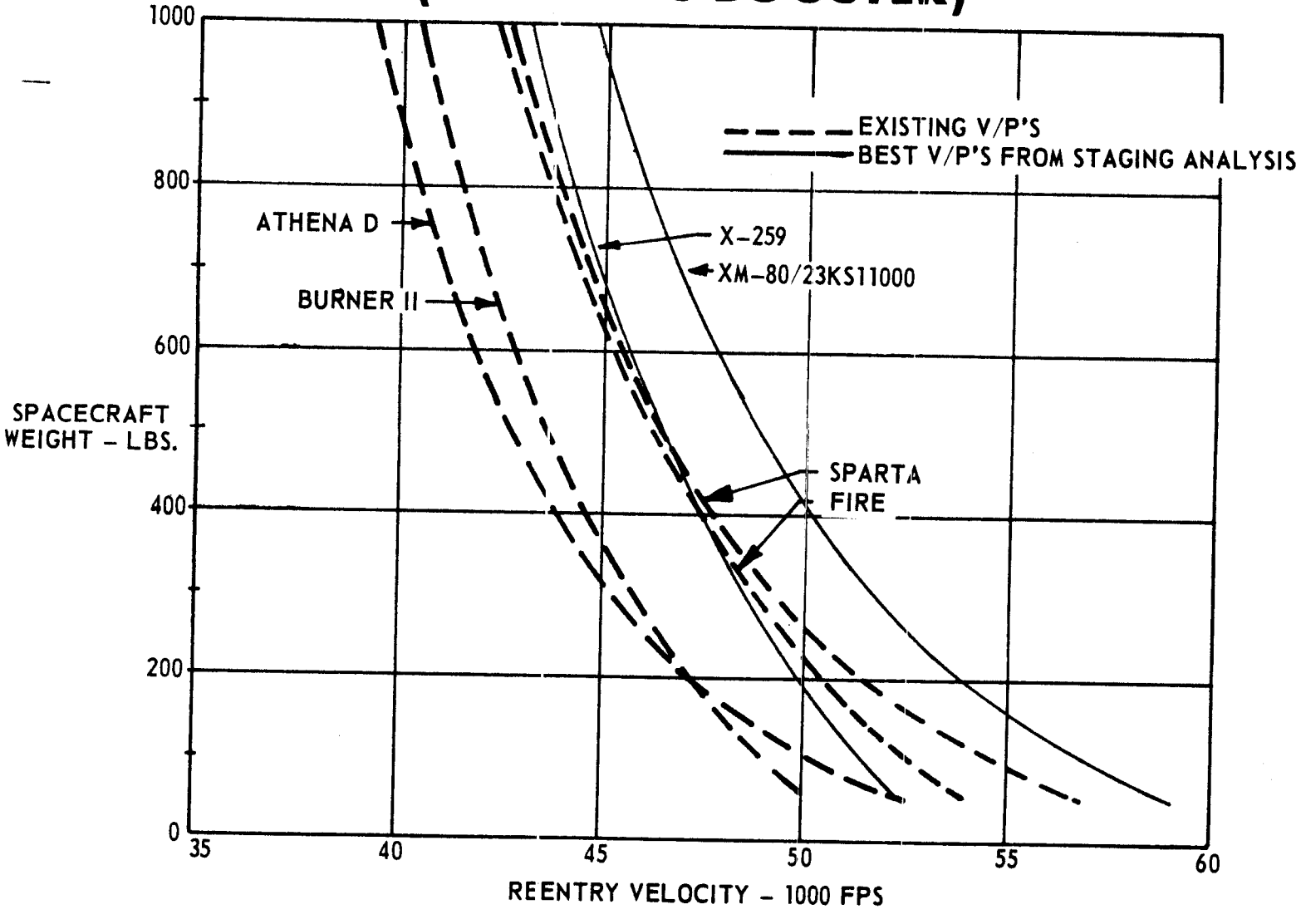


FIGURE 5-46

PERFORMANCE COMPARISON OF EXISTING LIQUID PROPELLANT VELOCITY PACKAGES

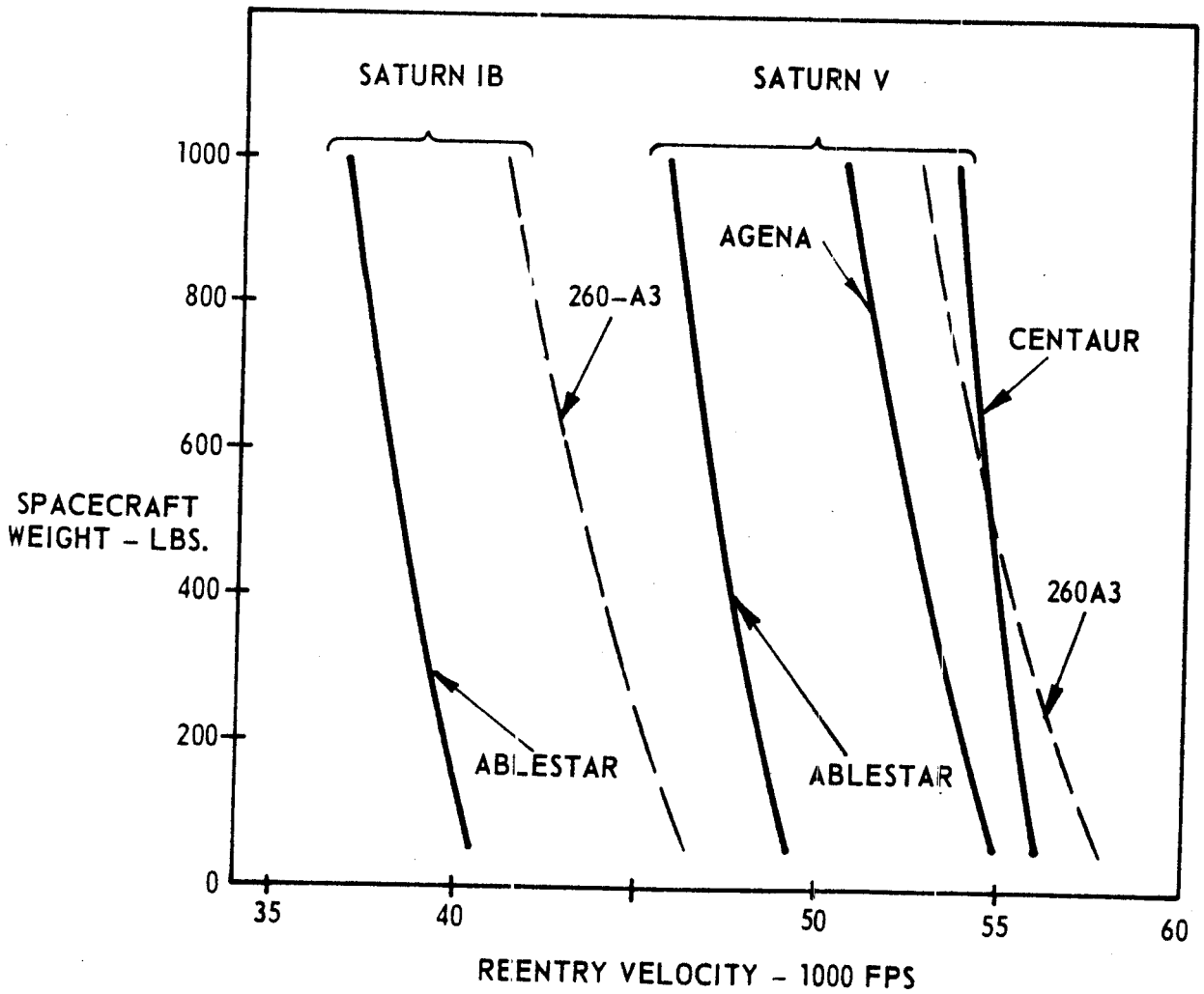


FIGURE 5–47

PERFORMANCE TRADE BETWEEN GUIDED & SPIN-STABILIZED VELOCITY PACKAGES

RESEARCH LAUNCH VEHICLE: TITAN IIIC/X-259

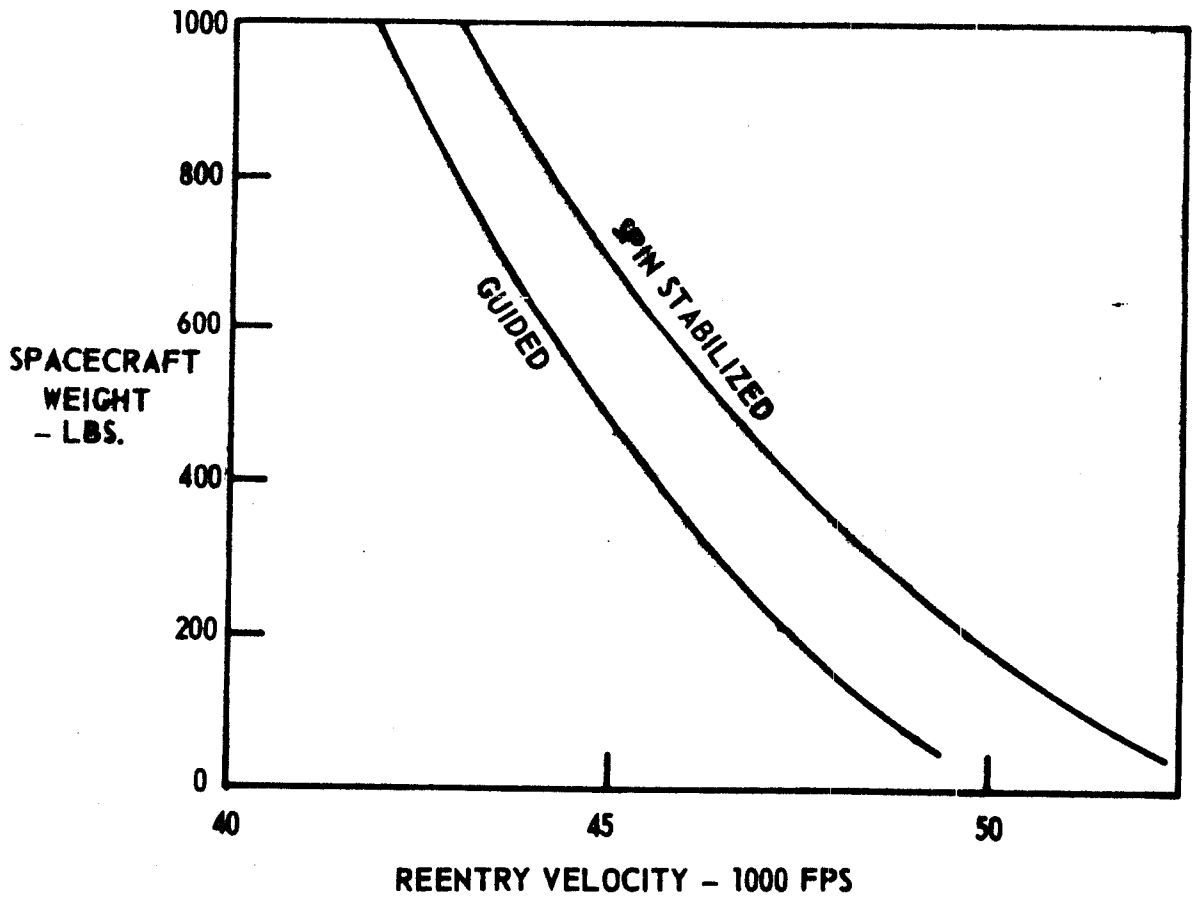


FIGURE 5-48

APPROACH

5.1 BOOSTER DEFINITION DATA

5.2 COMPILE VELOCITY PACKAGE PROPULSION DATA

5.3 OBTAIN PARAMETRIC WEIGHT DATA AS A FUNCTION OF VELOCITY PACKAGE SIZE

5.4 EVALUATE VELOCITY PACKAGE GUIDANCE AND CONTROL CONCEPTS

5.5 CONDUCT VELOCITY PACKAGE STAGING ANALYSIS

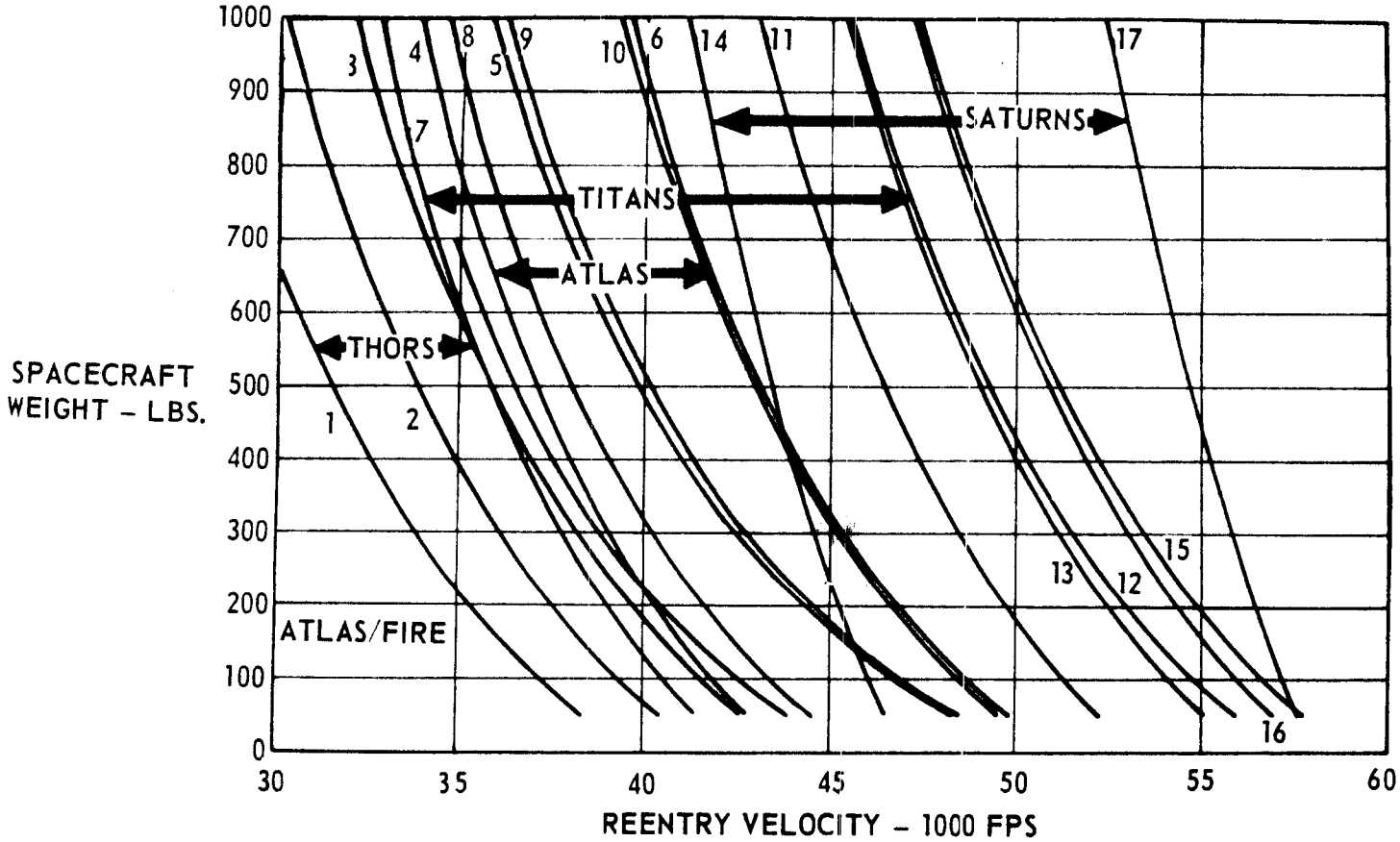
5.6 PERFORMANCE ANALYSIS AND TRADE STUDIES

5.7 CANDIDATE RESEARCH LAUNCH VEHICLE SELECTION

- 5.7.1 BEST ONE AND TWO-STAGE VELOCITY PACKAGES
- 5.7.2 SELECTION AND ELIMINATION PROCEDURES
- 5.7.3 RECOMMENDED CONFIGURATIONS

FIGURE 5–49

CANDIDATE SINGLE STAGE VELOCITY PACKAGES

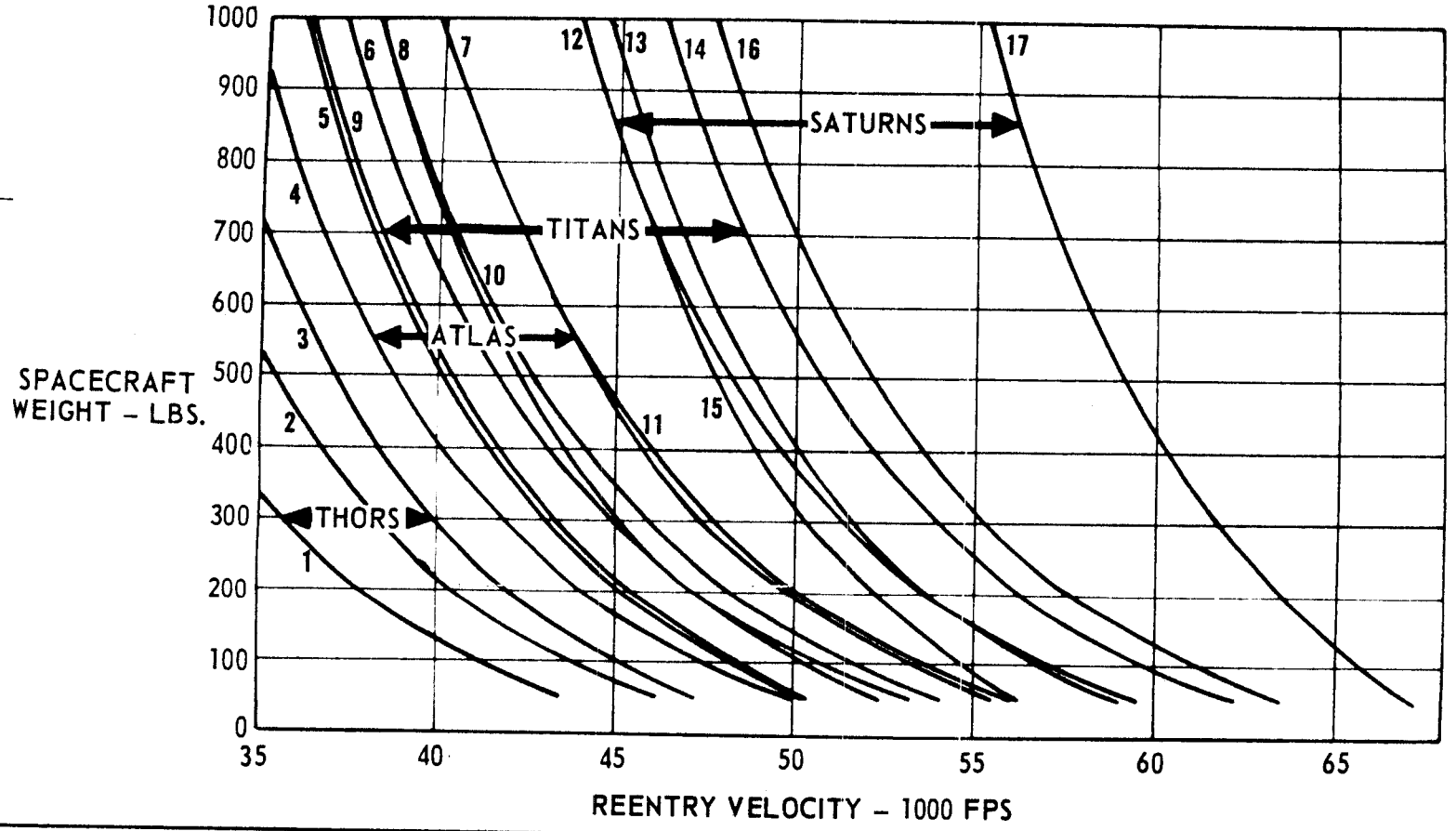


1	DSV-2K/AGENA/TE-364-2	THORS
2	DSV-2L/IMP. DELTA/TE-364-2	
3	DSV-2L/AGENA/TE-364-4	
4	SLV-3A/X-259	ATLAS
5	SLV-3A/AGENA/TE-364-2	
6	SLV-3C/CENTAUR/TE-364-4	

7	TITAN II/X-259	TITANS
8	TITAN IIIA/TE-364-4	
9	TITAN IIIB/TE-364-2	
10	TITAN IIIA/CENTAUR/TE-364-4	
11	TITAN IIIC/X-259	
12	TITAN IIIC/CENTAUR/TE-364-4	
13	TITAN IIIC/CENTAUR/X-259	
14	SATURN IB/260-A3	SATURNS
15	SATURN IB/CENTAUR/TE-364-4	
16	SATURN IB/CENTAUR/X-259	
17	SATURN V/260-A3	

FIGURE 5-50

CANDIDATE TWO STAGE VELOCITY PACKAGES



1	DSV-2K/AGENA/TE-364-4/MG-18	THORS
2	DSV-2L/IMP. DELTA/TE-364-4/MG-18	
3	DSV-2L/AGENA/TE-364-4/MG-18	
4	SLV-3A/X-259/FW-4	ATLAS
5	SLV-3A/XM-80/23KS11000	
6	SLV-3A/AGENA/X-259/FW-4	
7	SLV-3C/CENTAUR/X-259/FW-4	
8	TITAN II/XM-80/23KS11000	TITANS
9	TITAN IIIA/XM-80/23KS11000	
10	TITAN IIIB/X-259/FW-4	
11	TITAN IIIA/CENTAUR/X-259/FW-4	
12	TITAN IIIC/X-259/FW-4	
13	TITAN IIIC/XM-80/23KS1100	
14	TITAN IIIC/CENTAUR/X-259/FW-4	
15	SATURN IB/M56/TE-364-2	SATURNS
16	SATURN IB/CENTAUR/X-249/FW-4	
17	SATURN V/M-56/TE-364-2	

FIGURE 5-51

VEHICLE SELECTION PROCEDURE
STEP 1

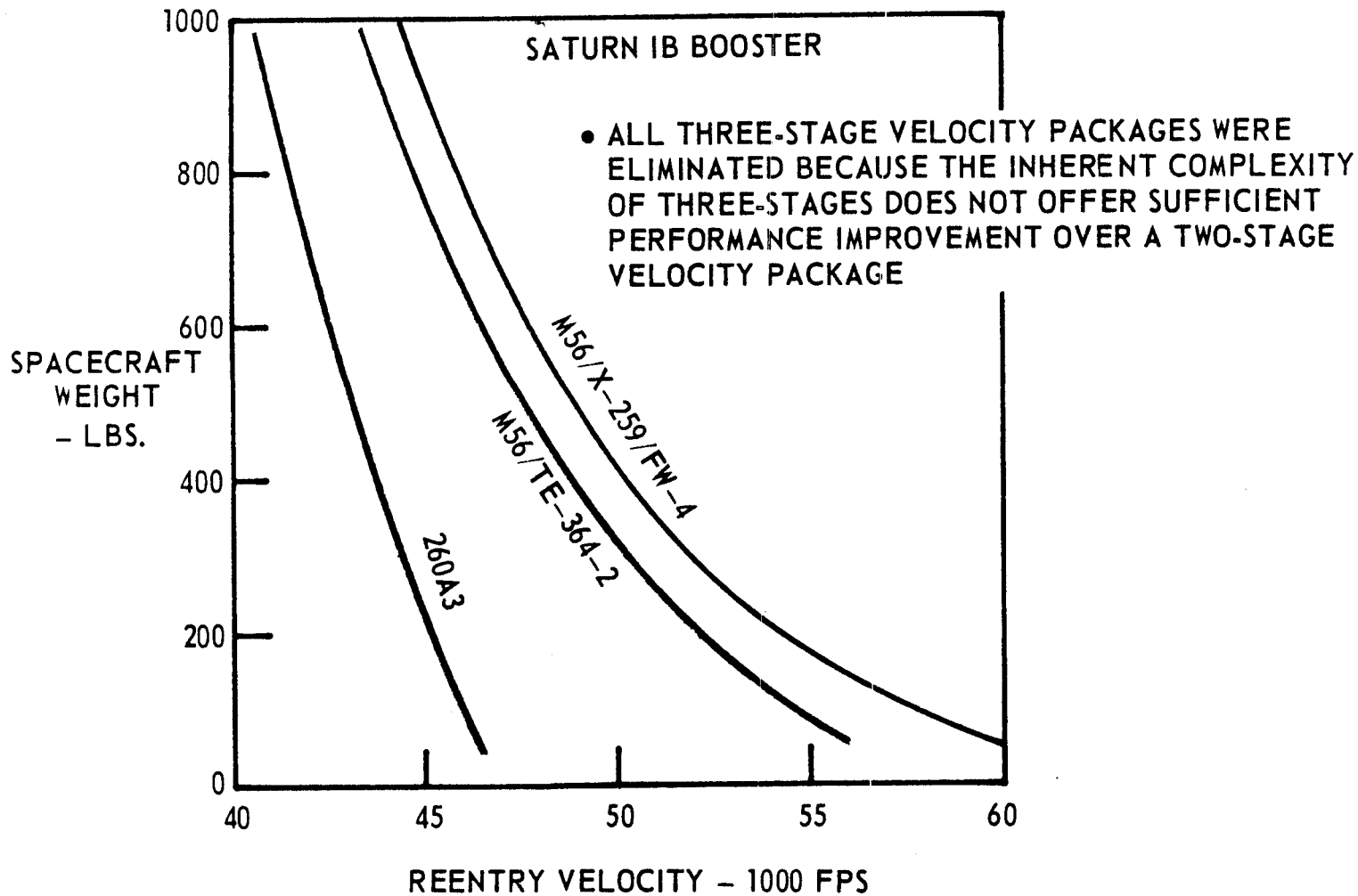
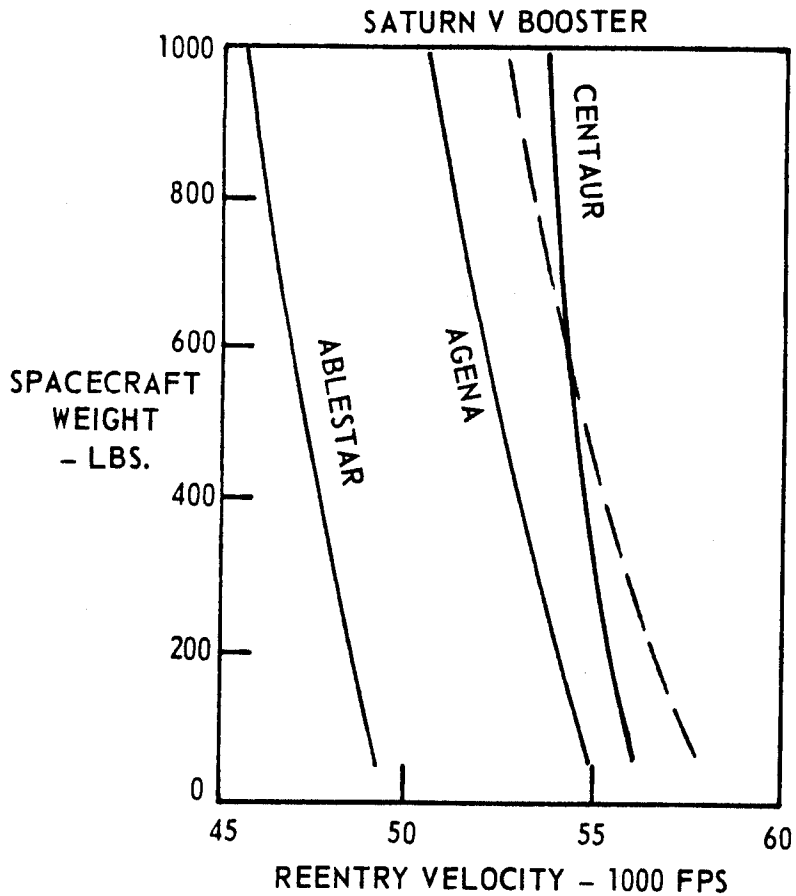


FIGURE 5-52

VEHICLE SELECTION PROCEDURE
STEP 2



- ALL LIQUID VELOCITY PACKAGES USED AS A FINAL STAGE OF A RESEARCH LAUNCH VEHICLE WERE ELIMINATED SINCE EQUAL OR BETTER PERFORMANCE CAN BE OBTAINED WITH A ONE-STAGE SOLID PROPELLANT VELOCITY PACKAGE

FIGURE 5–53

VEHICLE SELECTION PROCEDURE STEP 3

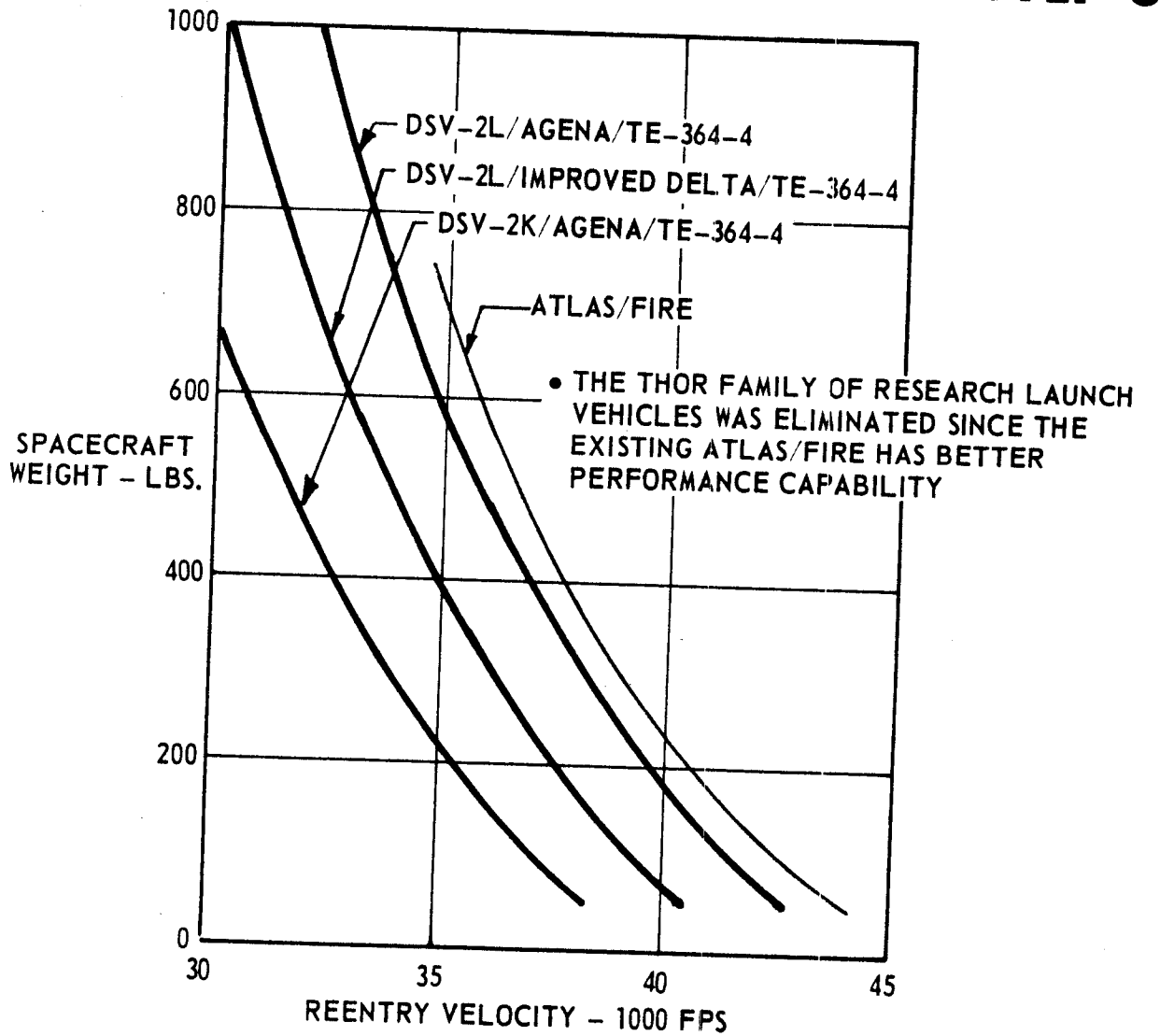
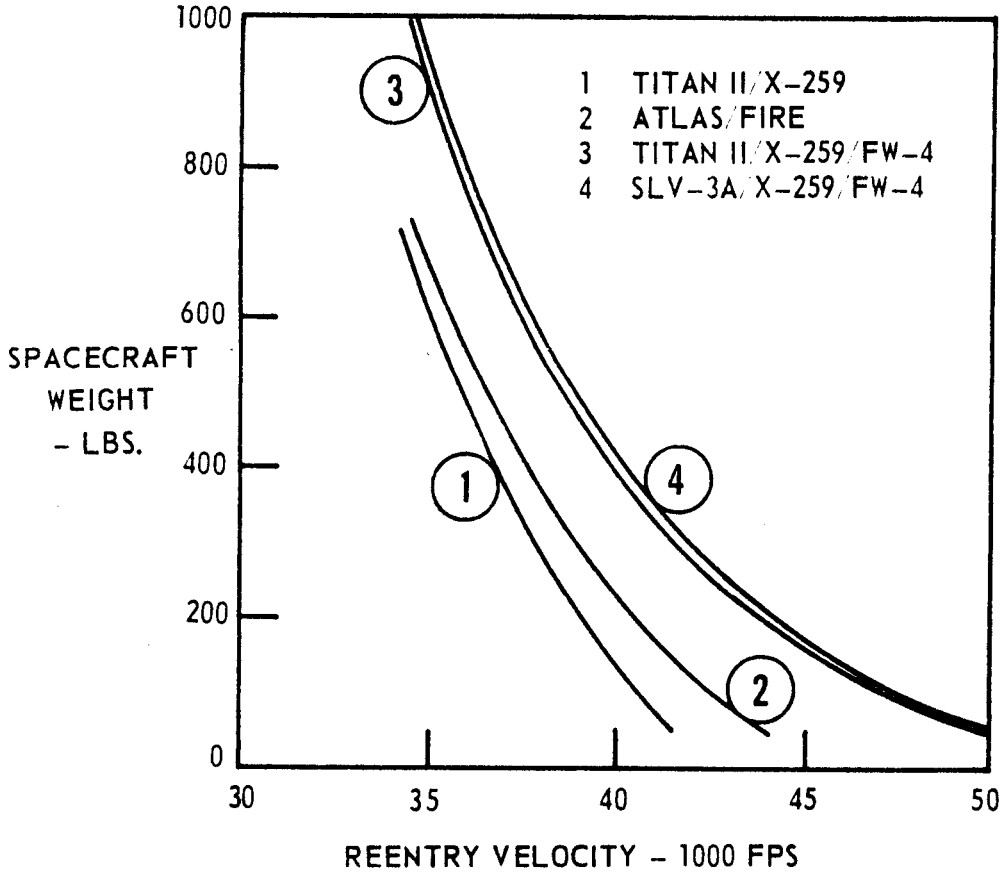


FIGURE 5-54

VEHICLE SELECTION PROCEDURE
STEP 4



- THE TITAN II BOOSTER WAS ELIMINATED BECAUSE THE EXISTING ATLAS/FIRE SHOWS BETTER PERFORMANCE THAN THE TITAN II/X-259 AND AN SLV-3A/X-259/FW-4 SHOWS BETTER PERFORMANCE THAN A TITAN II/X-259/FW-4

FIGURE 5-55

VEHICLE SELECTION PROCEDURE
STEP 5

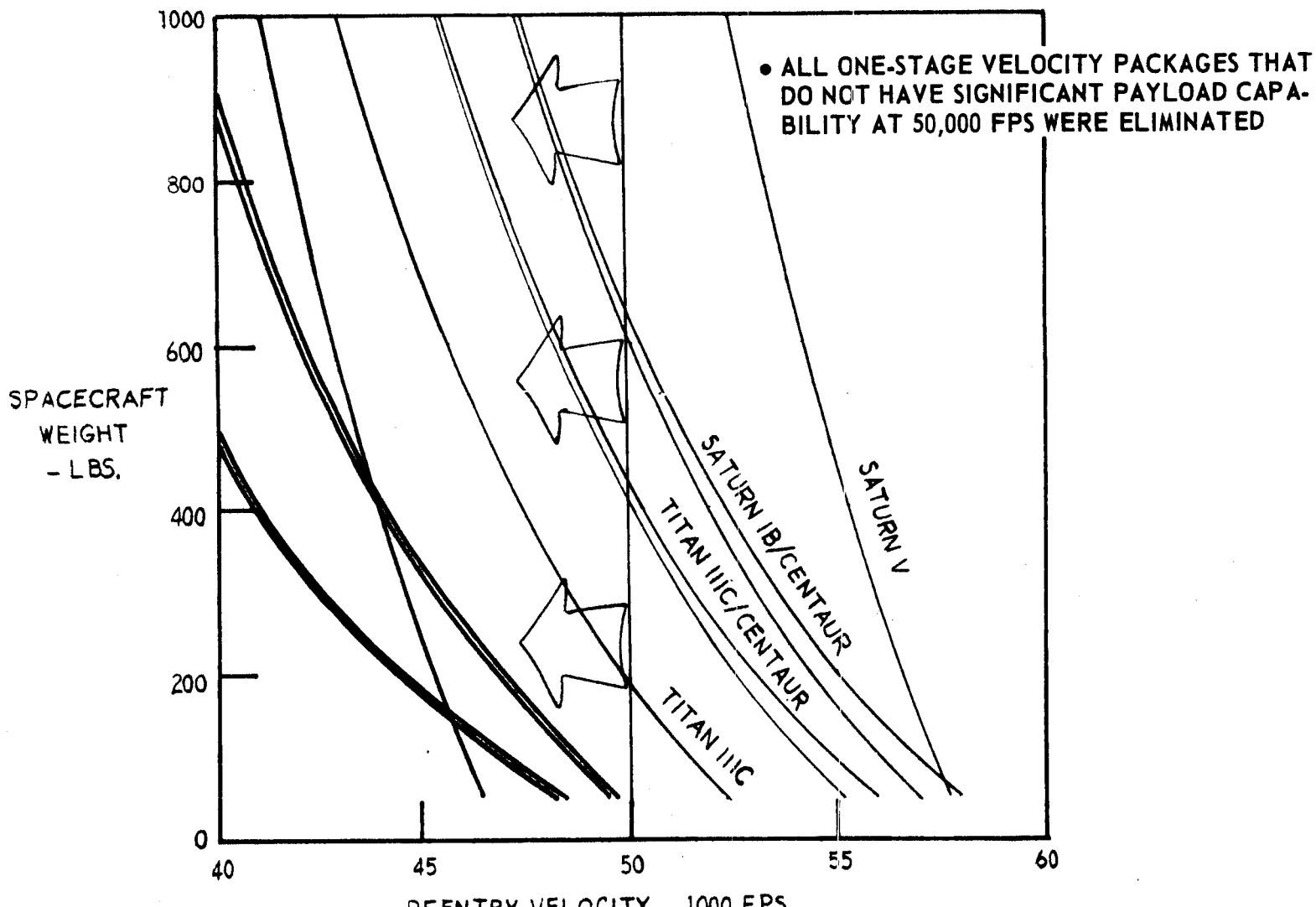
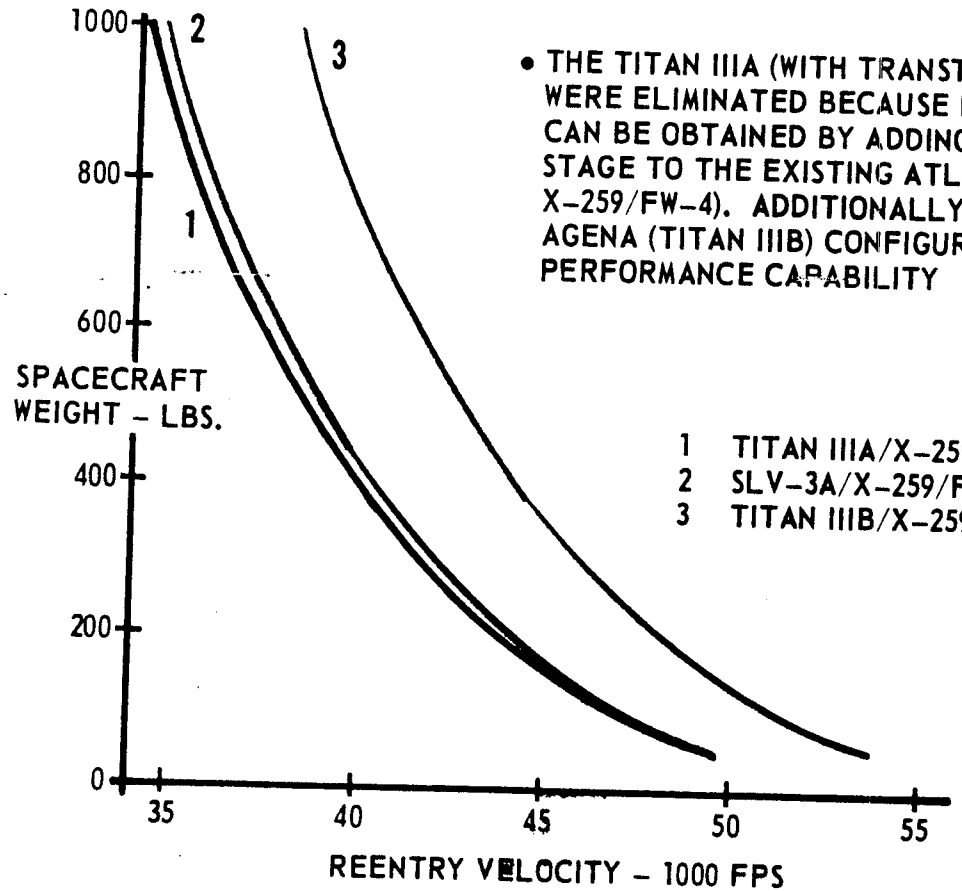


FIGURE 5-56

VEHICLE SELECTION PROCEDURE
STEP 6

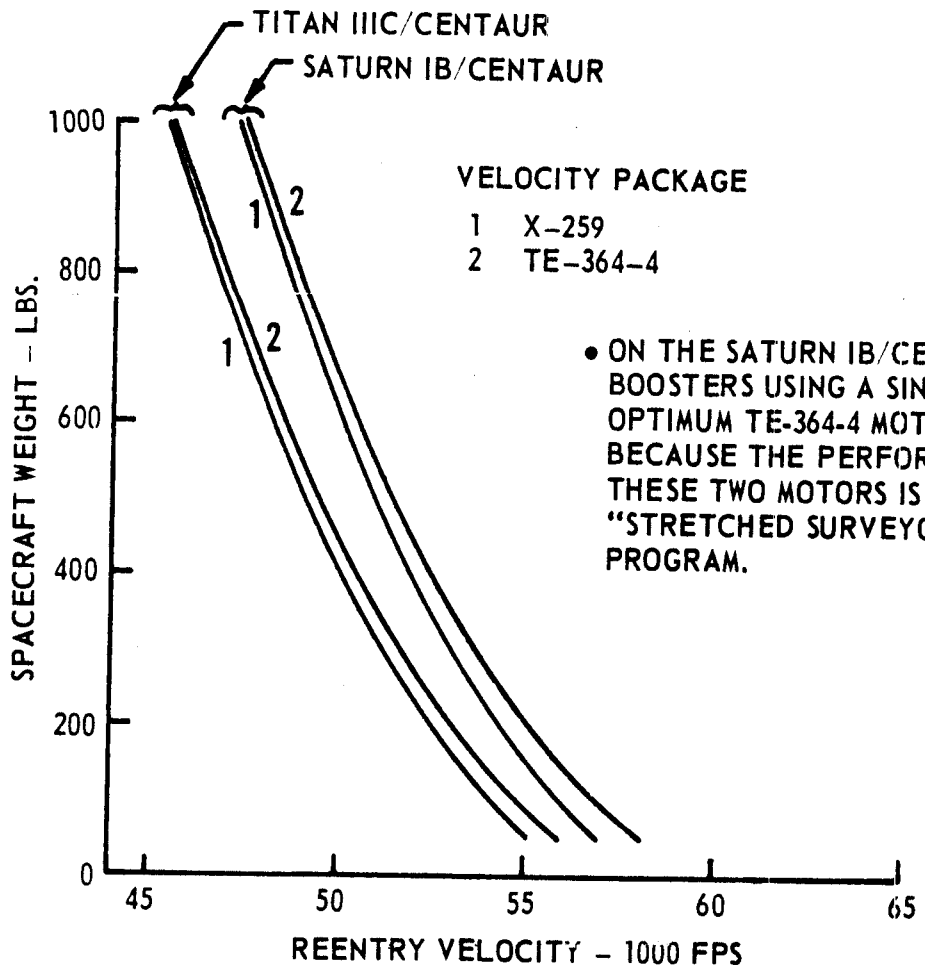


- THE TITAN IIIA (WITH TRANSTAGE) CONFIGURATIONS WERE ELIMINATED BECAUSE BETTER PERFORMANCE CAN BE OBTAINED BY ADDING AN ADDITIONAL V/P STAGE TO THE EXISTING ATLAS/FIRE VEHICLE (SLV-3A/X-259/FW-4). ADDITIONALLY, THE SMALLER TITAN/AGENA (TITAN IIIB) CONFIGURATION SHOWS GREATER PERFORMANCE CAPABILITY

1 TITAN IIIA/X-259/FW-4
2 SLV-3A/X-259/FW-4
3 TITAN IIIB/X-259/FW-4

FIGURE 5-57

VEHICLE SELECTION PROCEDURE
STEP 7



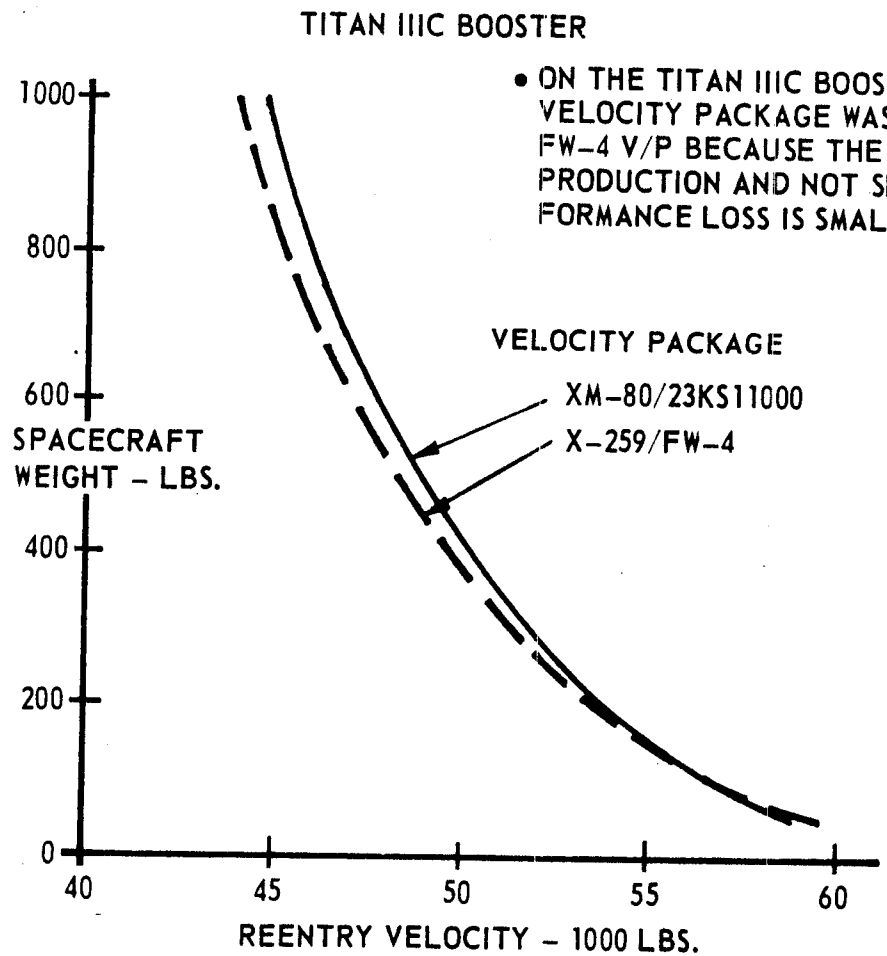
VELOCITY PACKAGE

1 X–259
2 TE–364–4

- ON THE SATURN IB/CENTAUR AND TITAN IIIC/CENTAUR BOOSTERS USING A SINGLE-STAGE V/P, THE NEAR-OPTIMUM TE-364-4 MOTOR WAS REPLACED BY THE X–259 BECAUSE THE PERFORMANCE DIFFERENCE BETWEEN THESE TWO MOTORS IS SMALL AND THE TE–364–4, "STRETCHED SURVEYOR", IS AN UNFUNDED MOTOR PROGRAM.

FIGURE 5–58

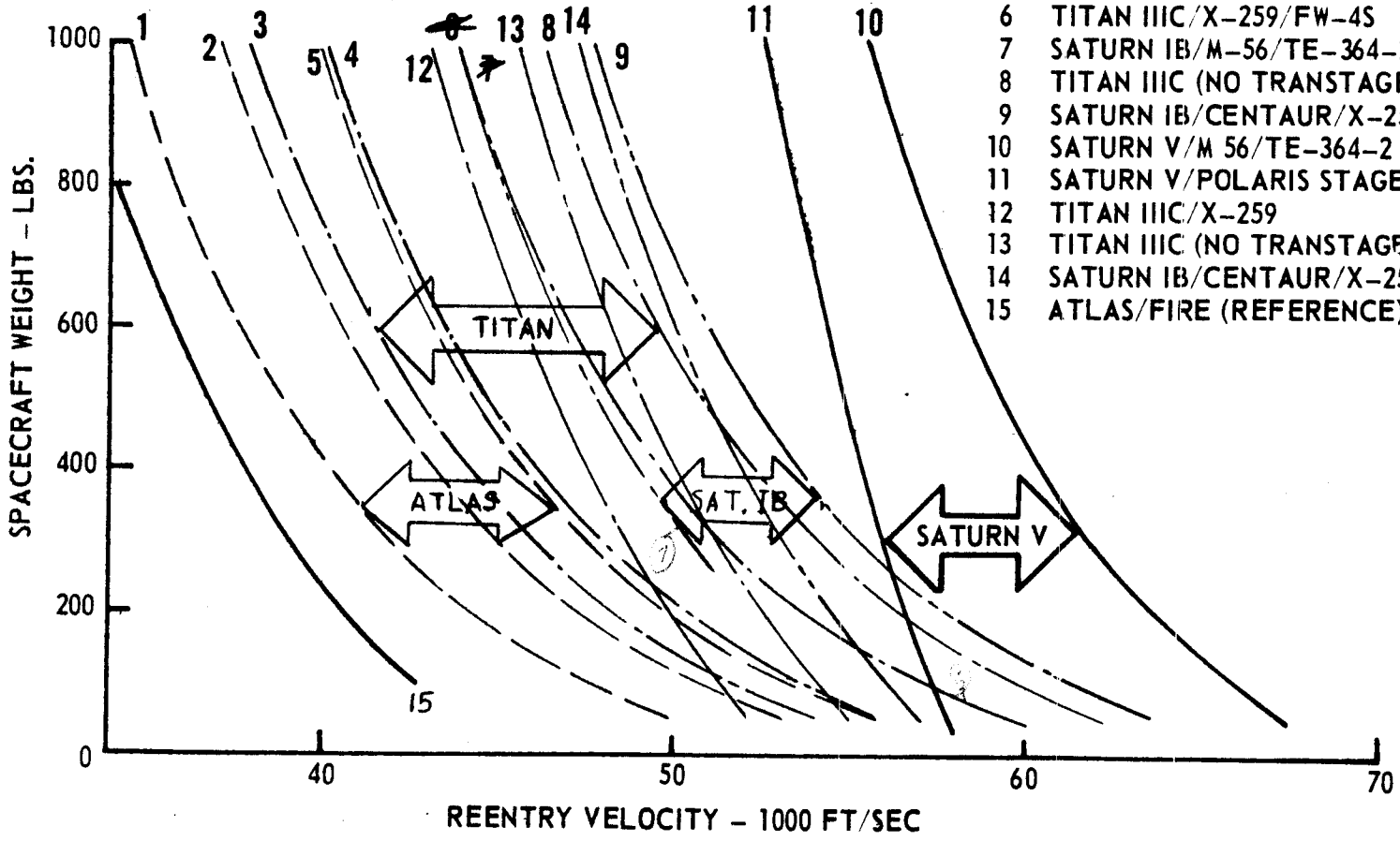
VEHICLE SELECTION PROCEDURE
STEP 8



- ON THE TITAN IIIC BOOSTER THE XM80/23KS11000 VELOCITY PACKAGE WAS REPLACED BY THE X-259/FW–4 V/P BECAUSE THE XM–80 MOTOR IS OUT OF PRODUCTION AND NOT SPIN QUALIFIED. THE PERFORMANCE LOSS IS SMALL.

FIGURE 5–59

REENTRY PERFORMANCE CAPABILITIES FOR SELECTED RESEARCH LAUNCH VEHICLES



1 SLV–3A/X–259/FW–4S
2 SLV–3A/AGENA D/X–259/FW–4S
3 TITAN IIIB/X–259/FW–4S
4 TITAN IIIA (NO TRANSTAGE)/CENTAUR/X–259/FW–4S
5 SLV–3C/CENTAUR/X–259/FW–4S
6 TITAN IIIC/X–259/FW–4S
7 SATURN IB/M–56/TE–364–2
8 TITAN IIIC (NO TRANSTAGE)/CENTAUR/X–259/FW–4S
9 SATURN IB/CENTAUR/X–259/FW–4S
10 SATURN V/M 56/TE–364–2
11 SATURN V/POLARIS STAGE II.
12 TITAN IIIC/X–259
13 TITAN IIIC (NO TRANSTAGE)/CENTAUR/X–259
14 SATURN IB/CENTAUR/X–259
15 ATLAS/FIRE (REFERENCE)

FIGURE 5–60

CONCLUSIONS

- THE NUMBER OF VELOCITY PACKAGES REQUIRED IS SMALL AND DO NOT EXCEED TWO-STAGES
- EXISTING SOLID PROPELLANT MOTORS ARE ADEQUATE FOR V/P PROPULSION
- COMPLEX GUIDANCE OF THE VELOCITY PACKAGE IS NOT REQUIRED
- CONVENTIONAL BALLISTIC TRAJECTORY FLIGHT MODES ARE SUPERIOR TO UNCONVENTIAL PARKING ORBIT FLIGHT MODES
- EXISTING RANGE COMPLEXES CAN BE USED

FIGURE 5-61