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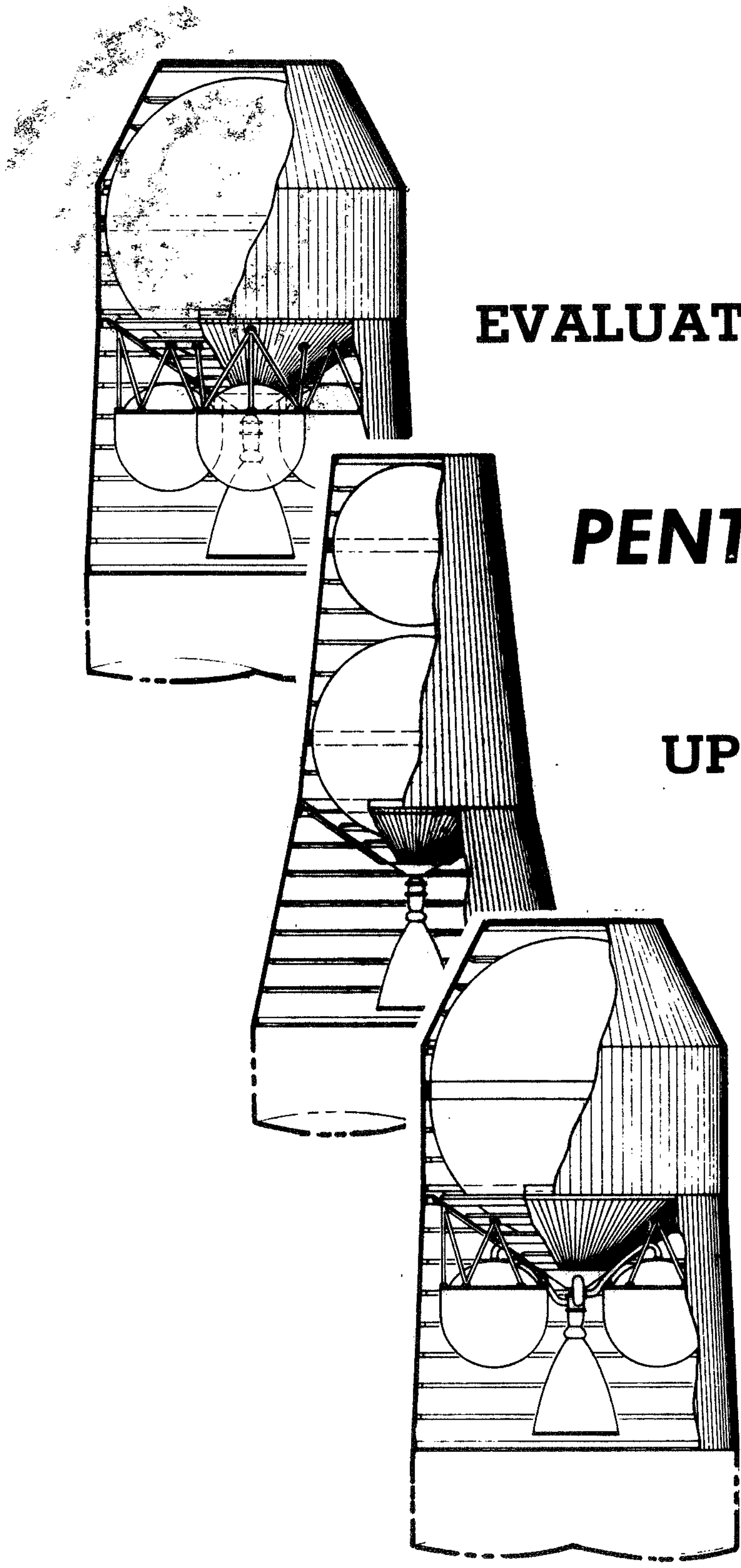

EVALUATION OF A

PENTAPROPELLANT

UPPER STAGE

JUNE 25, 1970

SPACE DIVISION CHRYSLER CORPORATION

TECHNICAL REPORT TR-AE-70-30

EVALUATION OF A PENTAPROPELLANT UPPER STAGE

July 25, 1970

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Prepared for

The National Aeronautics and Space Administration,
Office of Advanced Research and Technology,
Washington, D. C.
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Tripropellant Stage Study

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FOREWORD

This report was prepared by the Chrysler Corporation Space Division, New Orleans, Louisiana, and contains the results of a pentapropellant stage study performed for the National Aeronautics and Space Administration, Office of Advanced Research and Technology, under Supplemental Agreement No. 1 to contract NASw-1965, Tripropellant Stage Study.

The tripropellant stage work conducted under the original contract was documented separately and published as "Evaluation of Hydrogen/Fluorine/Lithium, Hydrogen/Fluorine, and Hydrogen-Lithium/Fluorine Upper Stages", TR-AE-70-29, June 25, 1970.

ACKNOWLEDGEMENTS

The Tripropellant Stage Study was performed under the direction of Dr. Robert S. Levine, NASA Headquarters, telephone (202) 962-1703.

Chrysler Corporation Space Division personnel responsible for major contributions to the study include:

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (continued)

Section 1
INTRODUCTION

1.1 GENERAL

This report describes the results of an exploratory analysis of a pentapropellant (hydrogen/fluorine-oxygen/lithium-beryllium) upper stage conducted under Supplemental Agreement No. 1 to Contract NASw-1965, Tripropellant Stage Study.

The pentapropellant stage effort evolved during the investigation of the tripropellant stage, when it became evident that the tripropellant stage had a relatively poor mass fraction* - low enough to offset the advantage of its very high specific impulse. Chrysler recommended that other attractive propellant combinations also be investigated. As a result of this recommendation, the tripropellant stage study contract was subsequently modified to include evaluation of pentapropellant stage.

The results of the pentapropellant investigation are being documented separately since the tripropellant study schedule did not permit incorporation of these results in the tripropellant stage final report. The results of the tripropellant stage evaluation are presented in Chrysler technical report TR-AE-70-29, "Evaluation of Hydrogen/Fluorine/Lithium, Hydrogen/Fluorine, and Hydrogen-Lithium/Fluorine Upper Stages".

The objective of this study was to determine if a hydrogen/fluorine-oxygen/lithium-beryllium pentapropellant stage would be sufficiently attractive to merit further investigations. Since this objective was the same as that of the tripropellant stage study, the approach and analytical techniques used in both studies were identical; therefore, in the interest of brevity, the tripropellant report (TR-AE-70-29) is referenced frequently in this report to avoid repeating this basic information.

1.2 SUMMARY OF RESULTS

The pentapropellant stage investigated had a hybrid combustion system; (that is, both solid and liquid propellants. The liquid propellants (hydrogen, fluorine and oxygen) were stored in tanks, while the lithium and beryllium were a solid grain in a case similar to a solid rocket motor. The fluorine and oxygen were mixed and stored as FLOX, while the hydrogen was stored separately.

To ensure that reliable conclusions were obtained with respect to the relative attractiveness of the pentapropellant, the pentapropellant stage was sized to achieve

*Mass Fraction = Propellant Weight/Stage Weight maximum payload for various mission requirements and booster vehicles. However, because of an unavailability of engine data, it was not possible to determine the optimum combination of pentapropellant engine characteristics (e.g., mixture ratio, area ratio and chamber pressure) as had been done in the tripropellant effort. The basic engine characteristics assumed in this study are as follows:

Specific Impulse	519 Seconds
Chamber Pressure	1000 psi
Area Ratio	100:1
Percent Hydrogen	27.5

Table 1-1 compares the direct inject payload capability of the pentapropellant stage and the tripropellant (hydrogen/fluorine/lithium), Gel (hydrogen-lithium/fluorine), bipropellant (hydrogen/fluorine) stages evaluated in the tripropellant study. Each payload corresponds to a stage that has been optimized for the particular booster and mission velocity identified. The optimum stage sizes were found to be a function of mission velocity as well as launch vehicle. The results show that the pentapropellant stage does not look as attractive as any of the other three stages.

In addition to the direct injection missions, a long duration mission consisting of a single burn to achieve a velocity increment of 8000 fps after a 205-day coast was also evaluated. The results, which are summarized in table 1-2, show that the pentapropellant stage has a small payload advantage over the tripropellant stage, but has a lower performance than the bipropellant and Gel stages.

Table 1-1. Direct Injection Mission Payload Summary

TOTAL MISSION VELOCITY (FPS)	BOOSTER	PAYLOAD (POUNDS)				
		ATLAS CENTAUR*	ATLAS	TITAN IIID CENTAUR*	TITAN IIID	260-INCH SRM S-IVB
36,140 (EARTH ESCAPE)	PENTAPROPELLANT	4200	3870	**	12400	37200
	TRIPROPELLANT	4400	4260	**	13100	40500
	BIPROPELLANT	4200	4510	**	12700	39500
	GELLED H_2/Li	4350	4520	**	13000	39500
48,500 (0.3 AU PROBE)	PENTAPROPELLANT	820	***	3900	3180	12600
	TRIPROPELLANT	990	***	4110	3600	14500
	BIPROPELLANT	900	300	3900	3680	13800
	GELLED H_2/Li	970	140	4070	3800	13700
54,500 (0.2 AU PROBE)	PENTAPROPELLANT	10	***	1990	930	6030
	TRIPROPELLANT	125	***	2200	1300	7600
	BIPROPELLANT	120	***	2210	1480	7300
	GELLED H_2/Li	150	***	2080	1470	6950

*GROSS WEIGHT ABOVE CENTAUR LIMITED TO 12,000 POUNDS
**KICK STAGE DOES NOT IMPROVE BOOSTER'S PERFORMANCE
***NO CAPABILITY

Table 1-2. Long Duration Mission Payload Summary

Stage	Payload (lb)
Bipropellant	5270
Gelled H_2/Li	5110
Pentapropellant	4990
Tripropellant	4640

Inspection of the detailed results show that the large size and weight of the pentapropellant engine is one reason for low stage performance when compared to the other stages. This could be attributed to the fact that the shape of the combustion chamber, which holds the solid lithium-beryllium propellant, was not optimized during the study.

Also, the optimum engine parameters (mixture ratio, chamber pressure and area ratio) were not determined for the pentapropellant stage. This could be a second reason why the pentapropellant stage compared so poorly.

If both of these facts had been accounted for, it is doubtful that the capability of the pentapropellant stage would have been improved enough to give it a significant payload advantage over any of the other stages investigated in the tripropellant stage evaluation.

Section 2

STUDY APPROACH

The approach taken in evaluating the pentapropellant stage was identical to that used for evaluating the tripropellant stage (see TR-AE-70-29) except that the engine design parameters were not optimized due to the limited engine performance data available. Table 2-1 summarizes the pentapropellant engine parameters considered during this study.

Table 2-1. Pentapropellant Engine Characteristics

Characteristic	Value
Specific Impulse	519 Sec
Area Ratio	100:1
Chamber Pressure	1000 psi
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9

The upper stage sizing program was modified to adapt it to hybrid systems. The modifications enabled the sizes and weights of the combustion chamber, nozzle and pump to be computed internal to the program.

The combustion chamber was sized on the basis of a cylinder length-to-diameter ratio (L/D) of 1.0 and a propellant bore-to-nozzle throat diameter ratio (r_b/r_t) of 1.30. Although the combustion chamber's shape (i.e., L/D and r_b/r_t) was not optimized, it was felt that the assumed values would provide a good shape from the standpoint of grain design. However, during the study it was found that combustion chamber size could have a large impact on overall system considerations, particularly on the interstage size and weight. The nozzle length was computed on the basis of a 17.5 degree nozzle half angle.

An Aerojet-General[1] method was used to compute the weights for a maraging steel (170 ksi yield strength) combustion chamber and a fixed nozzle. Figures 2-1 and 2-2 show typical motor weights and dimensions, respectively, computed for various propellant loads.

The liquid propellant pump weights were based on those found in Rocketdyne's Tripropellant Engine Study[2]. Although these were for a tripropellant engine, it was felt that they would be representative since the hydrogen pump consumes most of the pump power and the pentapropellant and tripropellant stages have approximately the same percentage of hydrogen by weight. Typical pump weights are depicted in figure 2-3.

The sizing program was further modified so that several multiple tank configurations could be considered in addition to the tandem tank versions normally considered for two liquid propellants, in this case hydrogen and FLOX. The tandem tank versions are illustrated in figure 2-4; they are identical to those considered for the bipropellant and Gel stages in the tripropellant stage evaluation (TR-AE-70-29). These geometries were generally found to be best for both the direct injection missions and the long duration mission.

The three multiple tank configurations are similar to those considered for the tripropellant stage. Each has a single (spherical or cylindrical) hydrogen tank and two FLOX tanks diametrically opposed and located on the perimeter of the hydrogen tank. Sketches of the three multiple tank versions are presented in figure 2-5. The first two versions (a and b) have spherical FLOX tanks and, depending upon whether or not the combustion chamber can be submerged between the two FLOX tanks, have either a thrust cone or spider beam type thrust structure. The last multiple tank version (c) has two cylindrical FLOX tanks. The radii of these tanks are the largest possible without violating the specified geometric constraints. The cylindrical lengths are computed to give the necessary tank volumes. There is no thrust cone version of this tankage arrangement.

The modified version of the computer program has the same geometric constraints on stage configuration geometry as did the one used in the tripropellant study. These are covered in detail in TR-AE-70-29.

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(1) Threewit, T.R., "The Integrated Design Computer Program and the ACP-1103 Interior Ballistics Computer Program," STM-180, Aerojet-General Corporation, Sacramento, California, December 1, 1964.

(2) Huntsinger, J.P., "Tripropellant Engine System Study, Final Report," Report R-7877, Rocketdyne Division, North American Rockwell Corporation, Canoga Park, California, November 3, 1969.

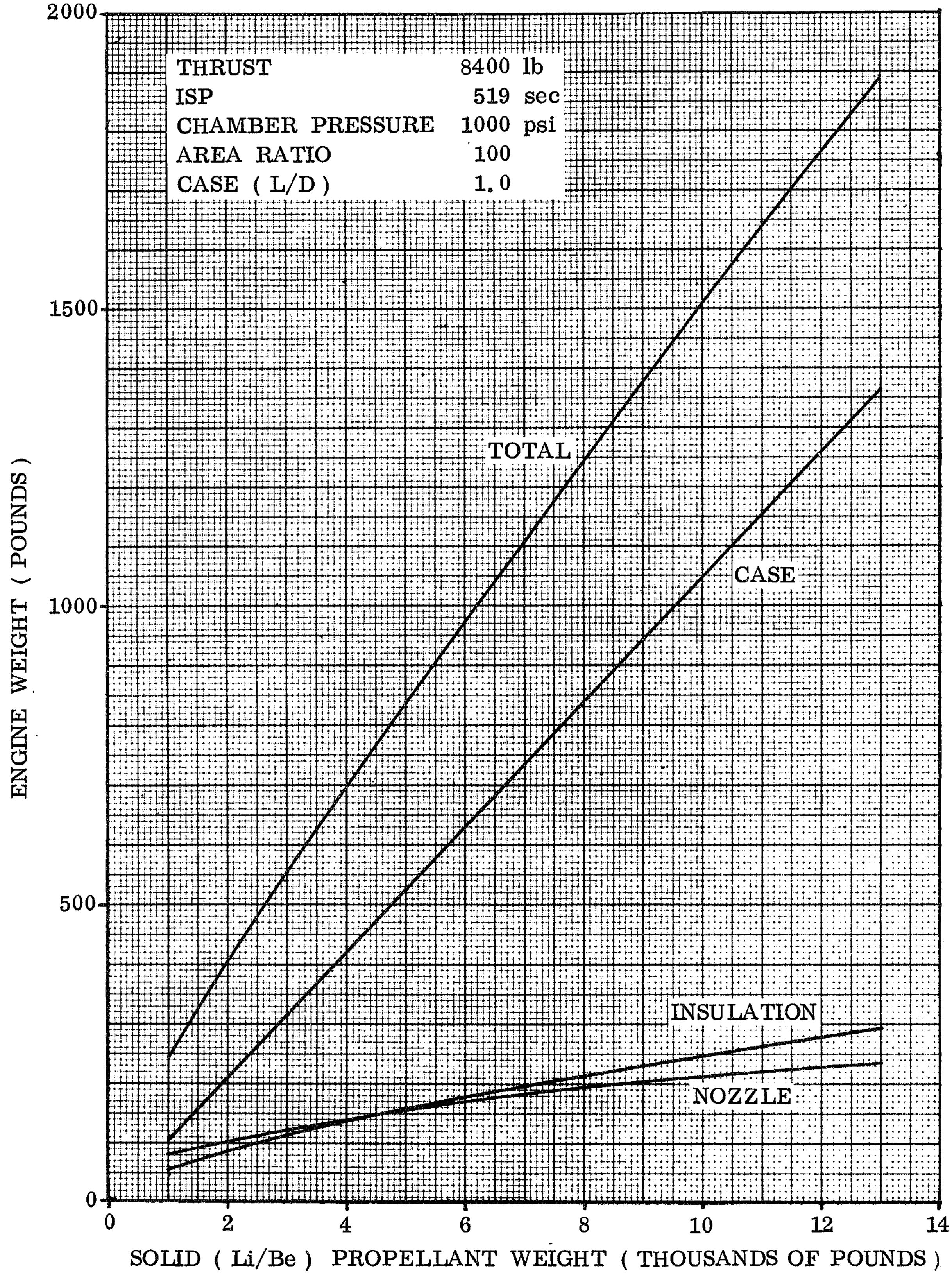

Figure 2-1. Typical Hybrid Engine Weights

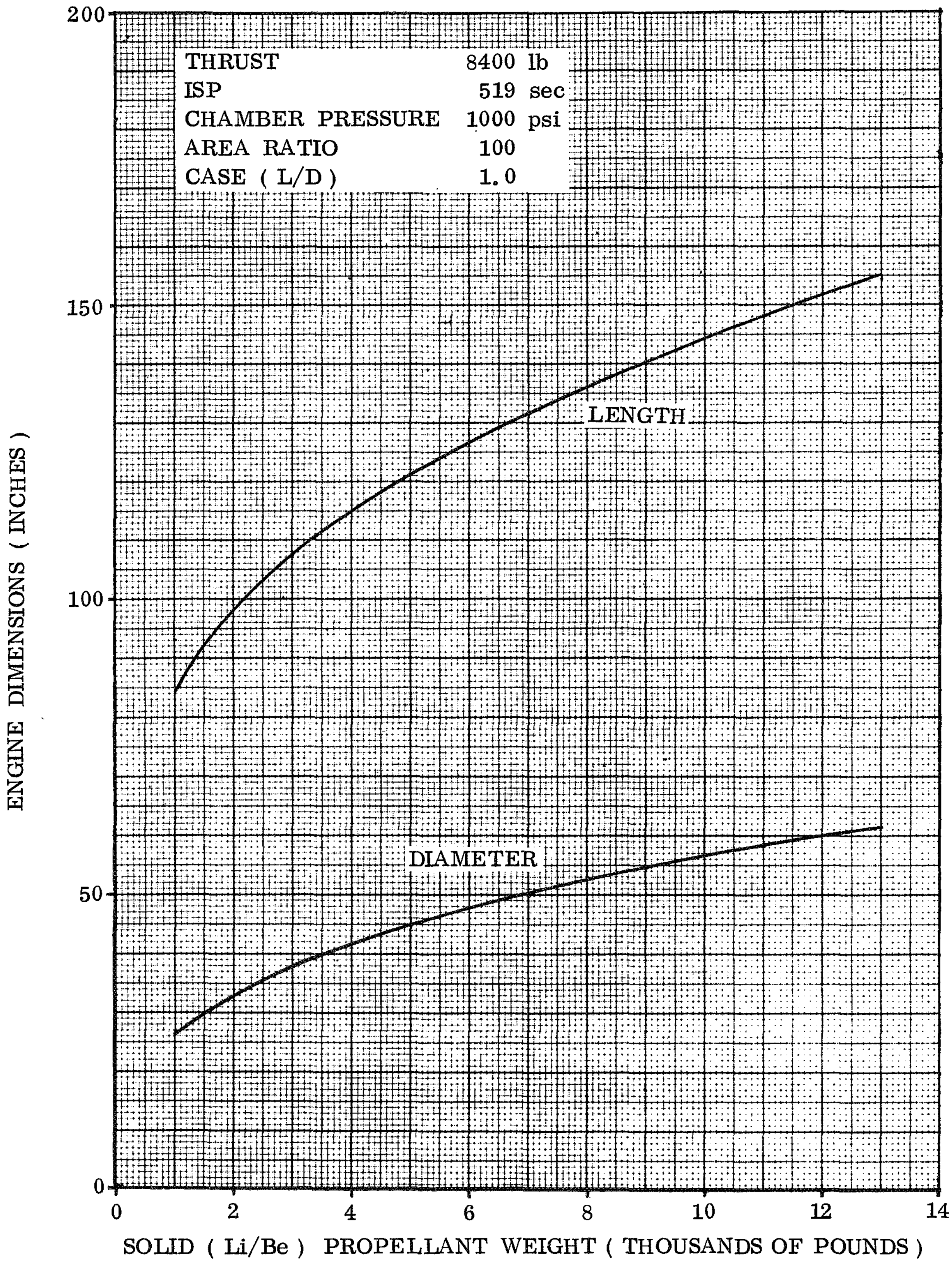

Figure 2-2. Typical Hybrid Engine Sizes

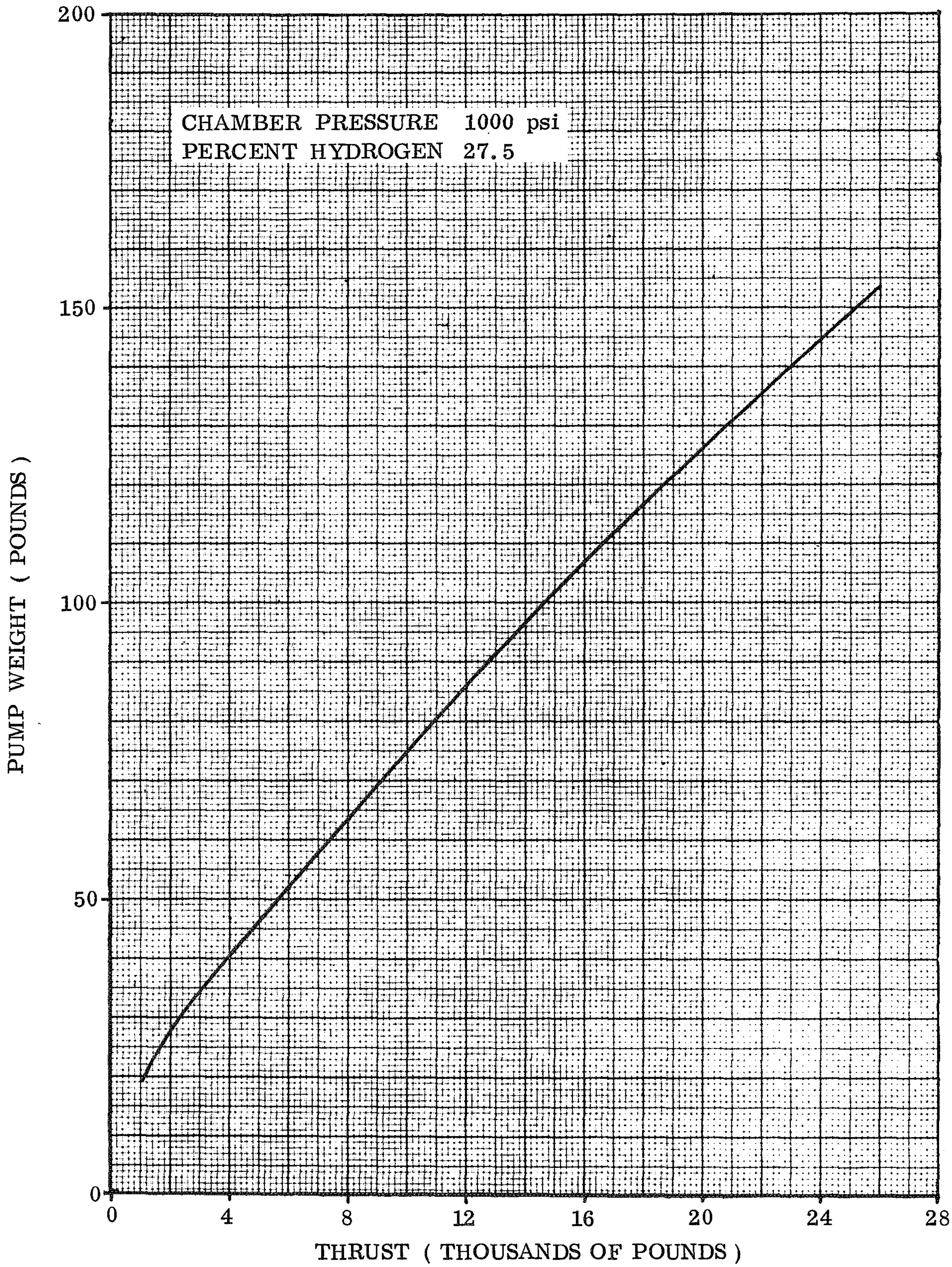

Figure 2-3. Typical Liquid Propellant Pump Weights

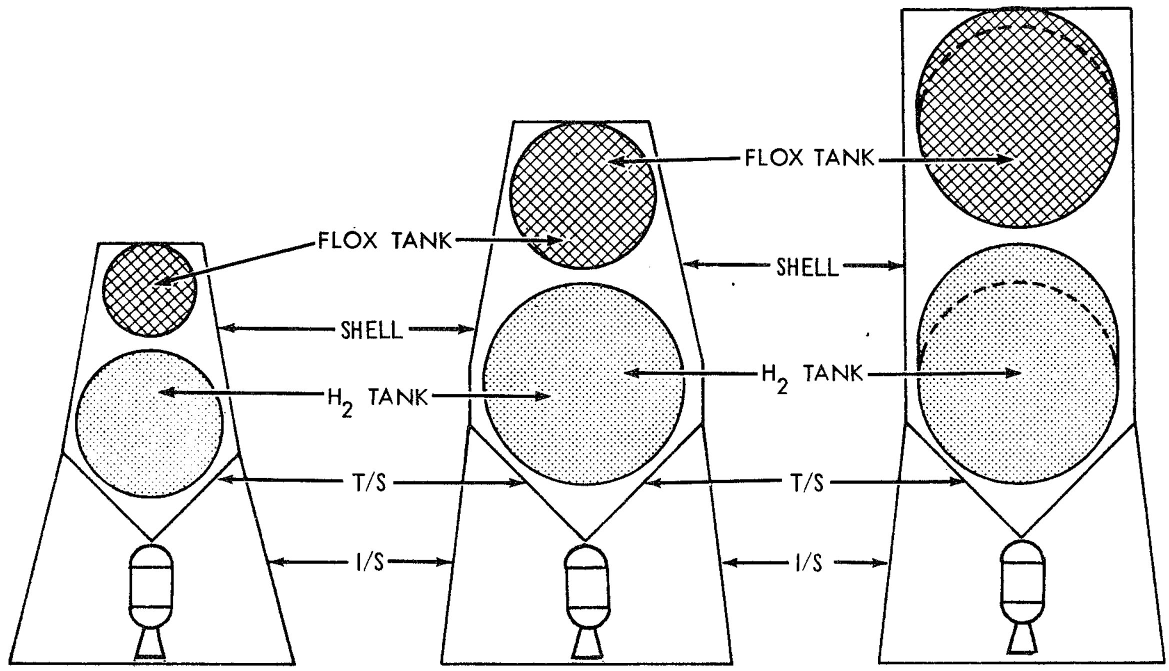

Figure 2-4. Tandem Tank Pentapropellant Stage Configurations

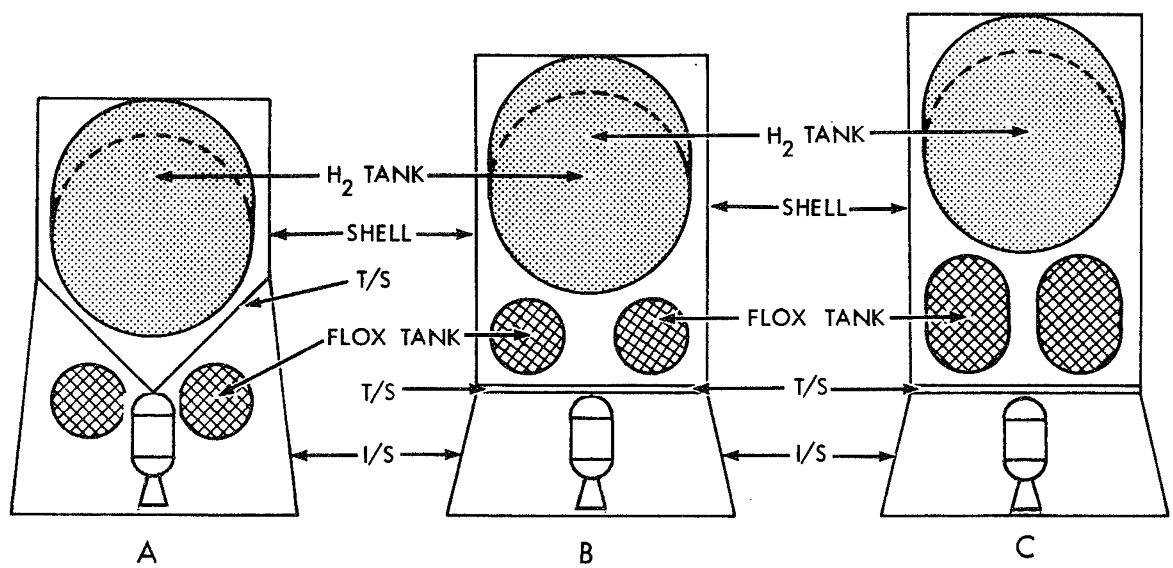

Figure 2-5. Multiple Tank Pentapropellant Stage Configurations

Section 3
STUDY RESULTS

3.1 GENERAL

The same two general classes of missions analyzed during tripropellant stage investigation were considered during the pentapropellant stage evaluation. The two types of missions were: 1) direct injection, and 2) long duration. The basic difference between these is that the direct injection missions have a very short coast prior to the single burn of the upper stage; whereas the long duration mission has a coast period of several months before the upper stage burn.

The results of the direct injection missions and the long duration mission are presented in paragraphs 3.3 and 3.4, respectively.

3.2 DATA AND ASSUMPTIONS

The constraints, guidelines, and pertinent design data used for both the pentapropellant stage direct injection and long duration missions were identical to those used in evaluating the tripropellant stage. In the interest of brevity, these will not be repeated in this report. The reader is referenced to sections 3.2.1 and 3.4.1 of TR-AE-70-29.

3.3 DIRECT INJECTION MISSION

The basic direct inject mission profile consisted of a booster delivering the pentapropellant stage and payload to a velocity increment corresponding to the gross weight above the booster. After burnout, the booster is jettisoned and, after a short coast, the upper stage is ignited to supply the remaining velocity increment necessary to fulfill mission requirements. Direct injection missions were investigated for total mission velocities ranging from earth escape to velocities corresponding to zero payload for each particular booster/gross weight combination. The five boosters investigated for the direct injection missions were 1) Atlas/Centaur, 2) Atlas, 3) Titan IIID/Centaur, 4) Titan IIID, and 5) 260-Inch SRM/S-IVB. The results of the direct injection mission analyses are presented in the remaining paragraphs of this section.

3.3.1 ATLAS/CENTAUR BOOSTER RESULTS

The payload of the pentapropellant stage is shown in figure 3-1 for several of the total mission velocities investigated. Although the figure shows that various payloads

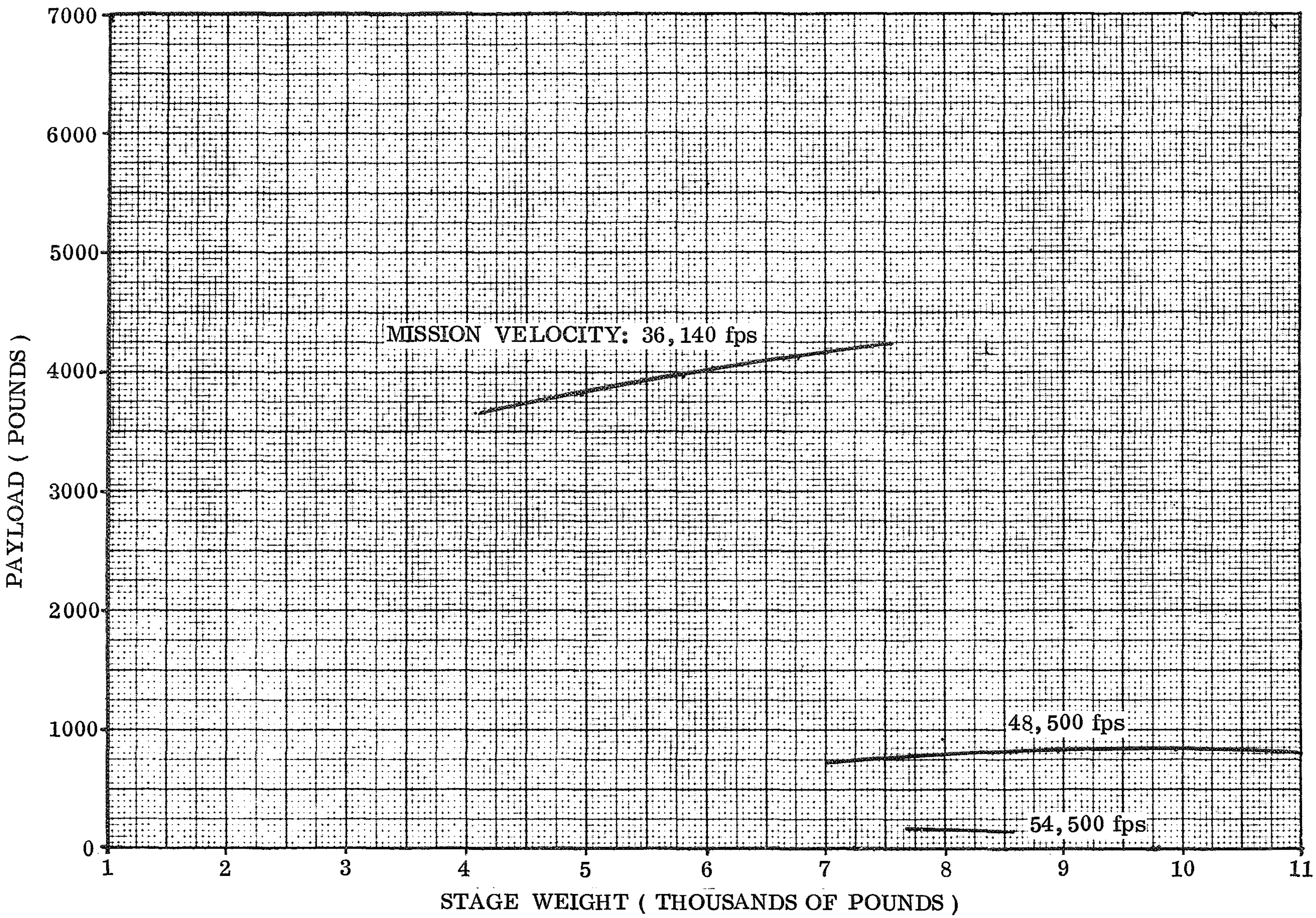

Figure 3-1. Payload Variation with Stage Weight (Direct Injection Mission, Atlas)

are obtainable at a single stage weight, the booster-upper stage velocity split is different for each mission velocity, and hence do not correspond to identically configured stages.

A summary of the major stage characteristics, engine parameters, and major stage design characteristics are given in tables 3-1, 3-2, and 3-3, respectively. These data correspond to a 12,000 pound gross weight stage (payload, stage and interstage) sized to achieve an earth escape velocity (36,140 fps). Data given in these tables are strictly applicable to the specified mission and gross weight; however, in general, these data are representative of the stages designed for other missions and gross weights. This mission and weight combination was selected so that comparison could readily be made with the tripropellant, Gel, and bipropellant stages presented in reference 1.

Figure 3-2 shows an external profile of the pentapropellant stage designed to interface with the Atlas/Centaur for the described mission.

For the missions and gross weights investigated, the pentapropellant stage performance does not exceed that of the best stage considered in the tripropellant stage evaluation. The reasons for this can be seen in a weight comparison of the four stages, (See table 3-4.) The largest penalty, in this instance approximately 250 pounds, is found in the engine. The pentapropellant stage combustion chamber and nozzle are longer than the equivalent liquid engine, hence the interstage on the pentapropellant stage is larger and weighs more than those on the other stages. These penalties might have been reduced and performance of the pentapropellant stage improved, had the combustion chamber shape (L/D and r_b/r_t) been optimized during this study.

3.3.2 ATLAS BOOSTER RESULTS

Figure 3-3 presents the payload as a function of stage weight for the pentapropellant stage atop the Atlas booster. The single mission velocity (36,140 fps) shown was the only velocity investigated for this launch vehicle which produced finite payloads. At this mission velocity the pentapropellant stage performance was inferior to the stages evaluated during the tripropellant investigation.

As was the case with the Atlas/Centaur booster, the pentapropellant stage performance is degraded because of the weight and size of the engine. When used with the Atlas booster, the engine size and weight have a more serious degrading effect on stage performance. A weight comparison of the pentapropellant stage with the tripropellant, bipropellant, and gelled configurations is depicted in table 3-5. The data presented in this chart are for a 30,000 pound gross weight stage and an earth escape mission (36,140 fps).

Figure 3-4 depicts the external profile of this pentapropellant stage. Tables 3-6 through 3-8 summarize the major stage and engine characteristics, and pertinent design data for the pentapropellant stage.

Table 3-1. Engine Data Summary (Direct Injection Mission, Atlas/Centaur)

Total Mission Velocity:	36140	fps
Stage Velocity Increment - First Burn:	11390	fps
Stage Velocity Increment - Second Burn:	0	fps
First Coast Time:	0.5	hrs
Second Coast Time:	0	hrs
Gross Weight:	12000	lb

Stage	Pentapropellant
Payload (lb)	4217
Specific Impulse (sec)	519
Thrust (lb)	8240
Interstage Weight (lb)	227
Total Stage Weight (lb)	7556
Inert Stage Weight (lb)	1648
Total Propellant Weight (lb)	5908
Propellant Consumed	
First Burn (lb)	5817
Second Burn (lb)	0
Residual Propellant Weight (lb)	59
Stage Mass Ratio	1.988
Stage Payload Fraction	0.351
Stage Structural Ratio	0.225
Stage Velocity Ratio	0.687
Stage Thrust to Weight Ratio	0.7:1

Table 3-2. Engine Data Summary (Direct Injection Mission, Atlas/Centaur)

Parameters	Value
Thrust (lb)	8240
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	378
Length (in.)	90.6
Exit Diameter (in.)	22.1

Table 3-3. Design Data Summary (Direct Injection Mission, Atlas/Centaur)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	1600	2804	1414
Residual (lb)	16	28	14
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	9	15	8
Total Load (lb)	1625	2847	1436
Tankage			Motor Case
Number of Tanks	1	1	N/A
Volume (ft^3)	391.7	38.3	N/A
Radius (In.)	54.00	25.10	N/A
Cylinder Length (In.)	1.92	0	N/A
Dome Thickness (In.)	0.0250	0.0250	N/A
Cylinder Thickness (In.)	0.0345	N/A	N/A
Design Pressure (psi)	29.1	25.4	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	38	159	N/A
Insulation Thickness (In.)	0.18	0.11	N/A

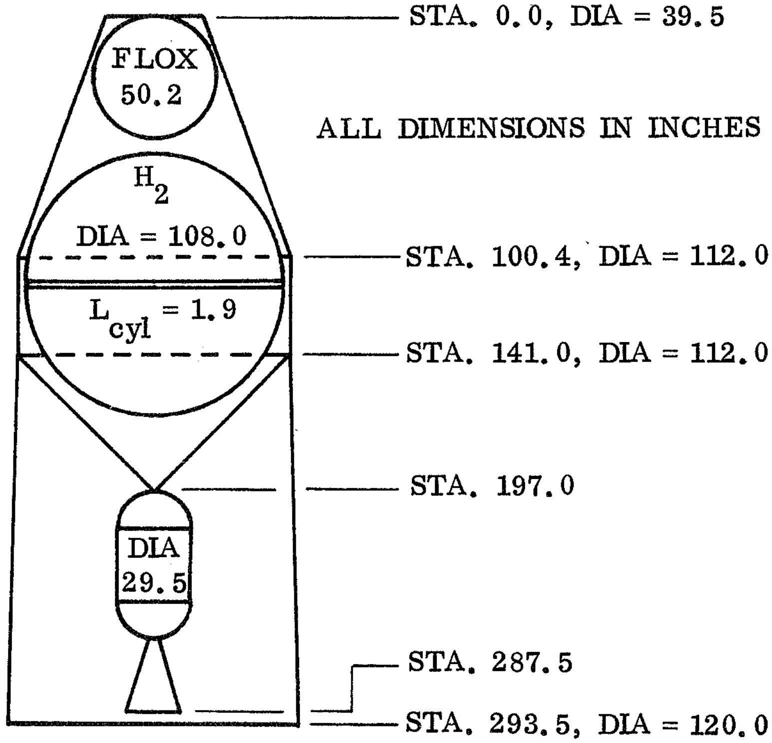

Figure 3-2. Pentapropellant Stage (Direct Injection Mission, Atlas/Centaur)

Table 3-4. Weight Statement Comparison (Direct Injection Mission, Atlas)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		597		589		582		417
SHELL	124		96		127		84	
THRUST STRUCTURE	44		44		44		23	
TANKAGE	132		198		146		90	
Hydrogen	(109)		(120)		(123)		(57)	
Fluorine or FLOX	(23)		(28)		(23)		(33)	
Lithium	(--)		(50)		(--)		(--)	
INTERSTAGE	227		169		172		122	
TANK SUPPORTS	70		82		93		98	
PROPULSION		499		309		267		230
ENGINE	378		139		139		116	
PRESS. SYSTEM	38		59		54		53	
FEED SYSTEM	70		98		61		48	
RCS	13		13		13		13	
THERMAL CONTROL		14		39		34		15
INSULATION	14		39		34		15	
Hydrogen	(12)		(23)		(31)		(11)	
Fluorine or FLOX	(2)		(4)		(3)		(4)	
Lithium	(--)		(12)		(--)		(--)	
Li TANK HEATERS, ETC.	---		0		---		---	
METEOROID SHIELD		0		0		0		0
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		115		106		102		89
TOTAL INERT (INCL. I/S*)		1875		1693		1635		1401
PROPELLANT		5908		5920		6015		6402
USEABLE	5817		5829		5922		6302	
RESIDUAL	59		59		60		64	
BOILOFF	0		0		0		0	
START/SHUTDOWN	32		32		33		36	
TOTAL STAGE (INCL. I/S*)		7783		7613		7650		7803
PAYLOAD		4217		4387		4350		4197
GROSS WEIGHT ABOVE BOOSTER		12000		12000		12000		12000

* INTERSTAGE

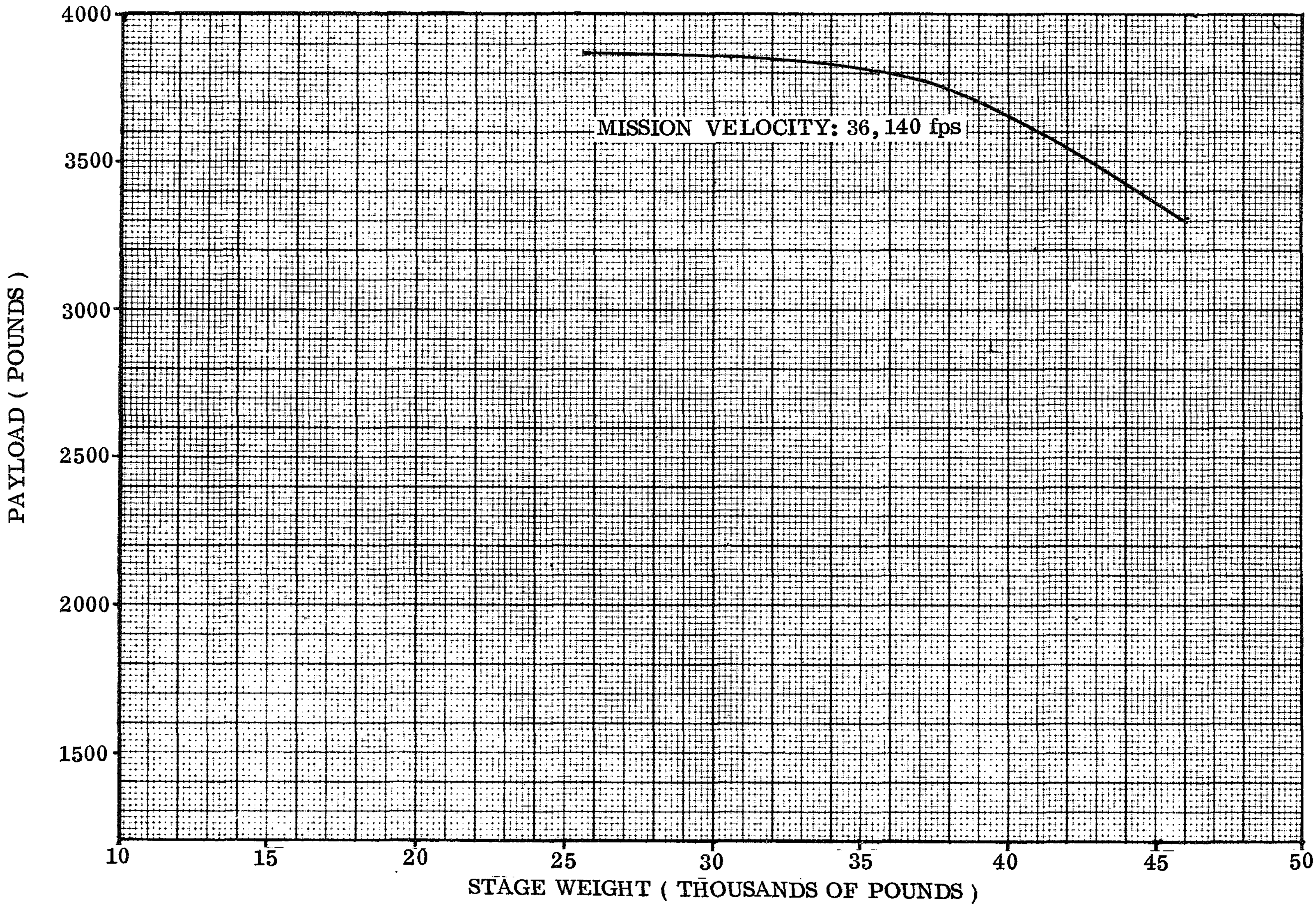

Figure 3-3. Payload Variation with Stage Weight (Direct Injection Mission, Atlas)

Table 3-5. Weight Statement Comparison (Direct Injection Mission, Atlas)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		1891		1994		1841		1236
SHELL	570		699		558		294	
THRUST STRUCTURE	62		130		62		62	
TANKAGE	513		633		517		213	
Hydrogen	(458)		(418)		(463)		(135)	
Fluorine or FLOX	(55)		(77)		(54)		(78)	
Lithium	(--)		(138)		(--)		(--)	
INTERSTAGE	489		228		362		318	
TANK SUPPORTS	257		304		342		349	
PROPULSION		1347		717		618		552
ENGINE	1116		367		366		298	
PRESS. SYSTEM	106		161		142		135	
FEED SYSTEM	112		176		97		106	
RCS	13		13		13		13	
THERMAL CONTROL		74		124		102		37
INSULATION	74		124		102		37	
Hydrogen	(71)		(81)		(97)		(29)	
Fluorine or FLOX	(3)		(11)		(5)		(8)	
Lithium	(--)		(32)		(--)		(--)	
Li TANK HEATERS, ETC.	---		0		---		---	
METEOROID SHIELD		0		0		0		0
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		261		244		214		162
TOTAL INERT (INCL. I/S*)		4423		3729		3425		2637
PROPELLANT		21910		22053		22200		23082
USEABLE	21602		21753		21897		22763	
RESIDUAL	219		220		221		231	
BOILOFF	0		0		0		0	
START/SHUTDOWN	79		80		82		89	
TOTAL STAGE (INCL. I/S*)		26133		25782		25625		25719
PAYLOAD		3867		4218		4375		4281
GROSS WEIGHT ABOVE BOOSTER		30000		30000		30000		30000

* INTERSTAGE

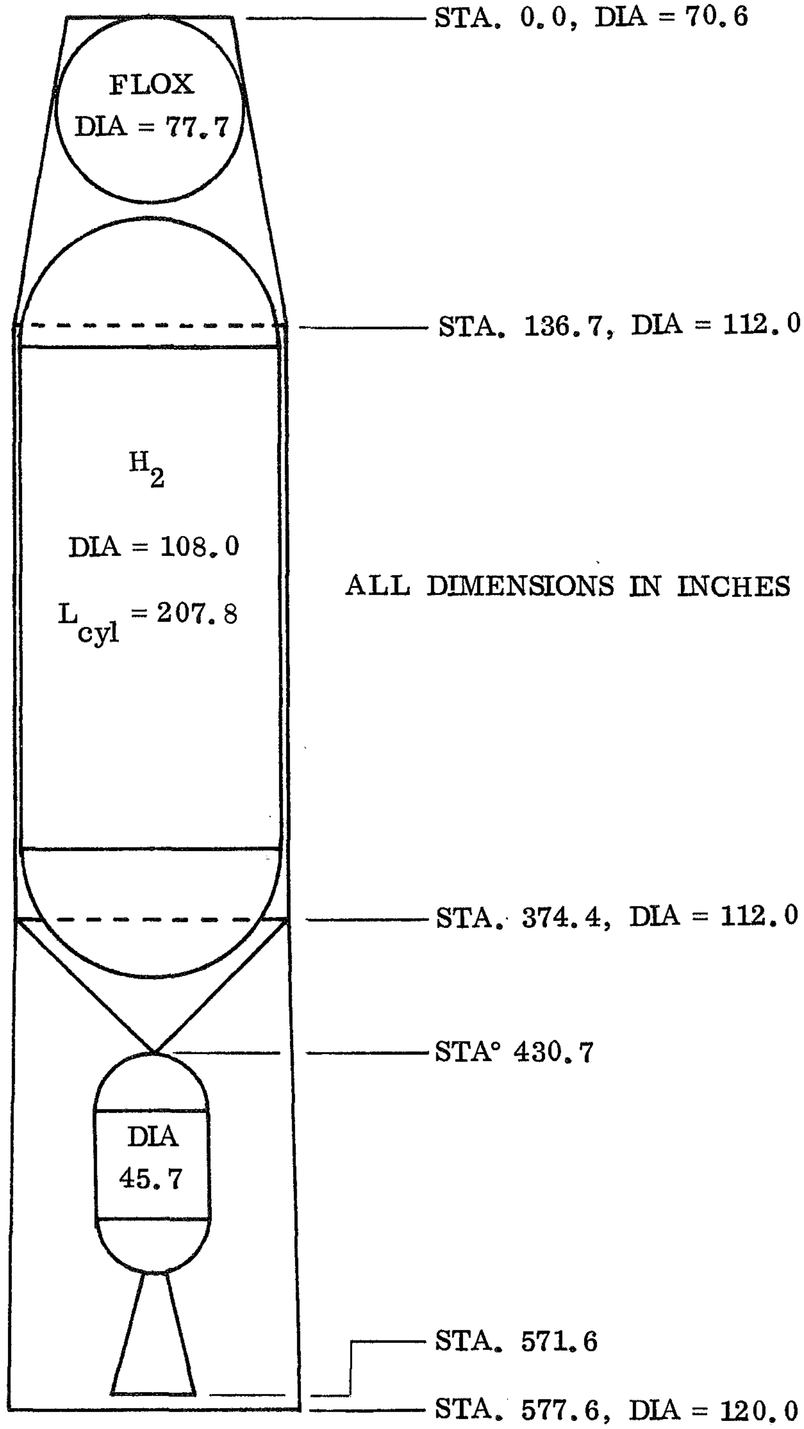

Figure 3-4. Pentapropellant Stage (Direct Injection Mission, Atlas)

Table 3-6. Major Stage Characteristics Summary (Direct Injection Mission, Atlas)

Total Mission Velocity:	36140	fps
Stage Velocity Increment - First Burn:	22040	fps
Stage Velocity Increment - Second Burn:	0	fps
First Coast Time:	0.5	hrs
Second Coast Time:	0	hrs
Gross Weight:	30000	lb

Stage	Pentapropellant
Payload (lb)	3867
Specific Impulse (sec)	519
Thrust (lb)	20657
Interstage Weight (lb)	489
Total Stage Weight (lb)	25644
Inert Stage Weight (lb)	3734
Total Propellant Weight (lb)	21910
Propellant Consumed	
First Burn (lb)	21611
Second Burn (lb)	0
Residual Propellant Weight (lb)	46
Stage Mass Ratio	3.775
Stage Payload Fraction	0.129
Stage Structural Ratio	0.154
Stage Velocity Ratio	1.329
Stage Thrust to Weight Ratio	0.7:1

Table 3-7. Engine Data Summary (Direct Injection Mission, Atlas)

Parameters	Value
Thrust (lb)	20657
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	1116
Length (in.)	141.2
Exit Diameter (in.)	34.9

Table 3-8. Design Data Summary (Direct Injection Mission, Atlas)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	5943	10416	5252
Residual (lb)	60	106	53
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	22	38	19
Total Load (lb)	6025	10560	5324
Tankage			Motor Case
Number of Tanks	1	1	N/A
Volume (ft^3)	1483.6	142.2	N/A
Radius (In.)	54.00	38.85	N/A
Cylinder Length (In.)	207.84	0.0	N/A
Dome Thickness (In.)	0.0250	0.0250	N/A
Cylinder Thickness (In.)	0.0428	N/A	N/A
Design Pressure (psi)	36.0	25.4	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	40	159	N/A
Insulation Thickness (In.)	0.36	0.07	N/A

3.3.3 TITAN IIID/CENTAUR BOOSTER RESULTS

The performance of a Titan IIID/Centaur/Pentapropellant stage launch vehicle is presented in figure 3-5, as a function of stage weight and mission velocity.

Tables 3-9 through 3-11 provide summaries of the major stage characteristics, engine parameters and computed design data for a 12,000 pound gross weight pentapropellant stage used to perform a 48,500 fps mission. The stage shown does not have the maximum payload which could have been obtained. This is because it was assumed that the maximum weight that could be interfaced with the Centaur stage was 12,000 pounds. Therefore, the results were constrainted to stages where the gross weight (payload, stage and interstage) did not exceed 12,000 pounds.

Figure 3-6 is a sketch of the pentapropellant stage for this mission and gross weight, and table 3-12 is a comparative weight statement for the pentapropellant, tripropellant, Gel and bipropellant stages. Examination of the weight statement reveals that the pentapropellant stage again suffers from the longer and heavier engine.

3.3.4 TITAN IIID BOOSTER RESULTS

The performance of the pentapropellant stage when mated to the Titan IIID booster is presented in figure 3-7 for various mission velocities. Although the figure shows the payload of this launch vehicle combination to be rising at the low mission velocity (36,140 fps), it is doubtful that much higher performance could be expected because of the greater length to diameter ratio this stage would have at larger gross weights.

As with the Atlas booster results, a gross weight of 30,000 pounds and a mission velocity of 36,140 fps (earth escape) have been selected for comparative purposes. Again, this particular size stage is not optimum.

Tables 3-13 through 3-15 depict the major stage characteristics, engine parameters and major design data, respectively, of this 30,000 pound stage. A sketch of the pentapropellant stage is shown in figure 3-8, and a weight statement illustrating the differences between the pentapropellant stage and the other stages is given in table 3-16. Again, the large engine size on the pentapropellant stage accounts for its poor performance relative to the other stages.

3.3.5 260-INCH SRM/S-IVB BOOSTER RESULTS

The largest booster investigated was the 260-inch Solid Rocket Motor (SRM)/ S-IVB. The results, shown in figure 3-9, indicate that at lower velocities the optimum stage sizes would have exceeded gross weights greater than 70,000 pounds, which was the highest gross weight investigated. This was the largest tripropellant stage evaluated due to the lack of tripropellant engine data over 50,000 pounds thrust. The 70,000 pound gross weight was selected as a convenient size for the 48,500 fps mission.

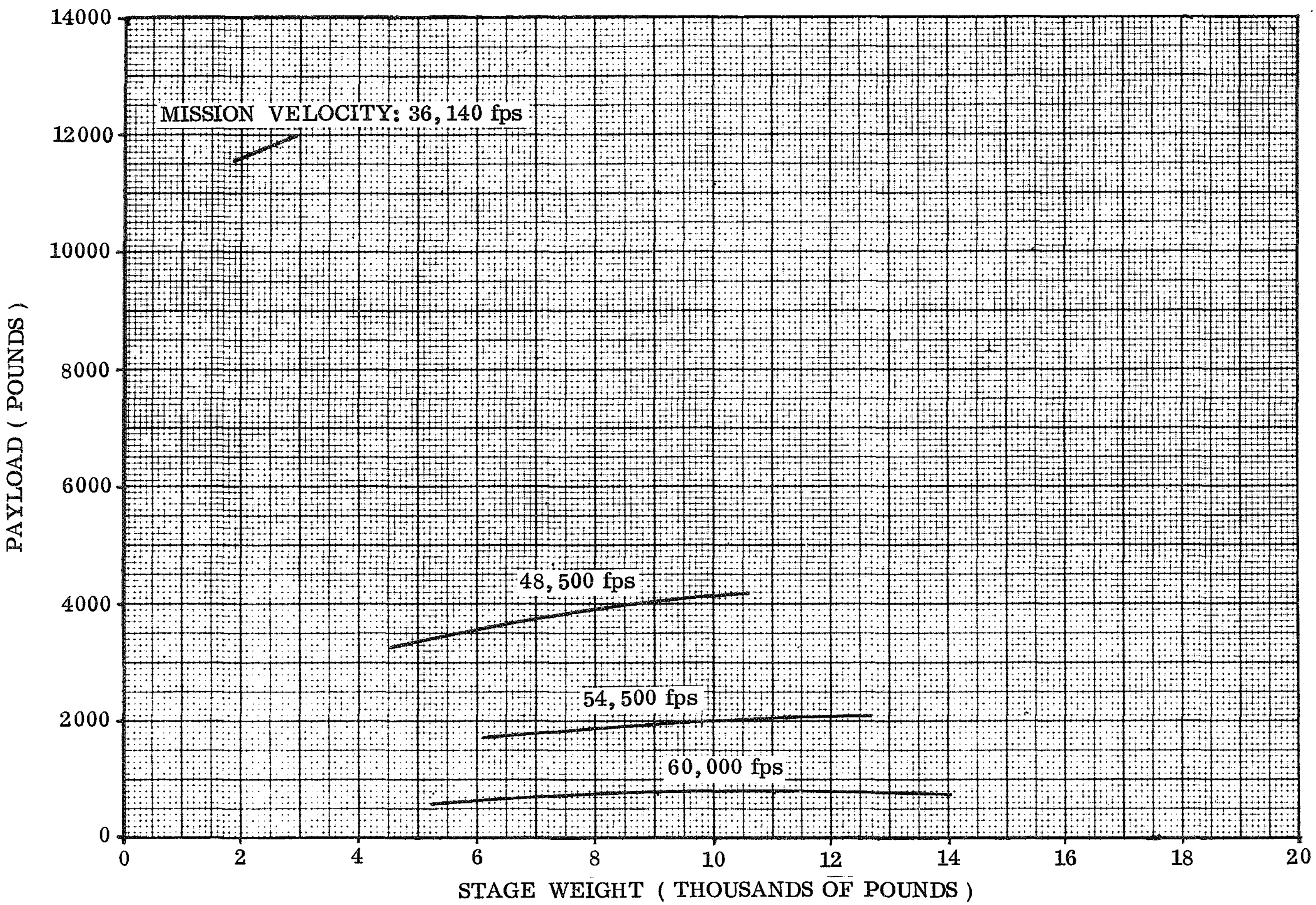

Figure 3-5. Payload Variation with Stage Weight (Direct Injection Mission, Titan IIID/Centaur)

Table 3-9. Major Stage Characteristics (Direct Injection Mission, Titan IIID/Centaur)

Total Mission Velocity:	48500	fps
Stage Velocity Increment - First Burn:	12200	fps
Stage Velocity Increment - Second Burn:	0	fps
First Coast Time:	0.5	hrs
Second Coast Time:	0	hrs
Gross Weight:	12000	lb

Stage	Pentapropellant
Payload (lb)	3895
Specific Impulse (sec)	519
Thrust (lb)	8256
Interstage Weight (lb)	204
Total Stage Weight (lb)	7900
Inert Stage Weight (lb)	1696
Total Propellant Weight (lb)	6204
Propellant Consumed	
First Burn (lb)	6110
Second Burn (lb)	0
Residual Propellant Weight (lb)	62
Stage Mass Ratio	2.087
Stage Payload Fraction	0.325
Stage Structural Ratio	0.222
Stage Velocity Ratio	0.736
Stage Thrust to Weight Ratio	0.7:1

Table 3-10. Engine Data Summary (Direct Injection Mission, Titan IIID/Centaur)

Parameters	Value
Thrust (lb)	8256
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	390
Length (in.)	91.6
Exit Diameter (in.)	22.1

Table 3-11. Design Data Summary (Direct Injection Mission, Titan IIID/Centaur)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	1680	2945	1485
Residual (lb)	17	30	15
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	9	15	8
Total Load (lb)	1706	2990	1508
Tankage			Motor Case
Number of Tanks	1	1	N/A
Volume (ft^3)	429.34	40.25	N/A
Radius (In.)	54.00	25.51	N/A
Cylinder Length (In.)	9.00	0	N/A
Dome Thickness (In.)	0.0258	0.0250	N/A
Cylinder Thickness (In.)	0.0516	N/A	N/A
Design Pressure (psi)	43.4	25.4	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	42	159	N/A
Insulation Thickness (In.)	0.30	0.11	N/A

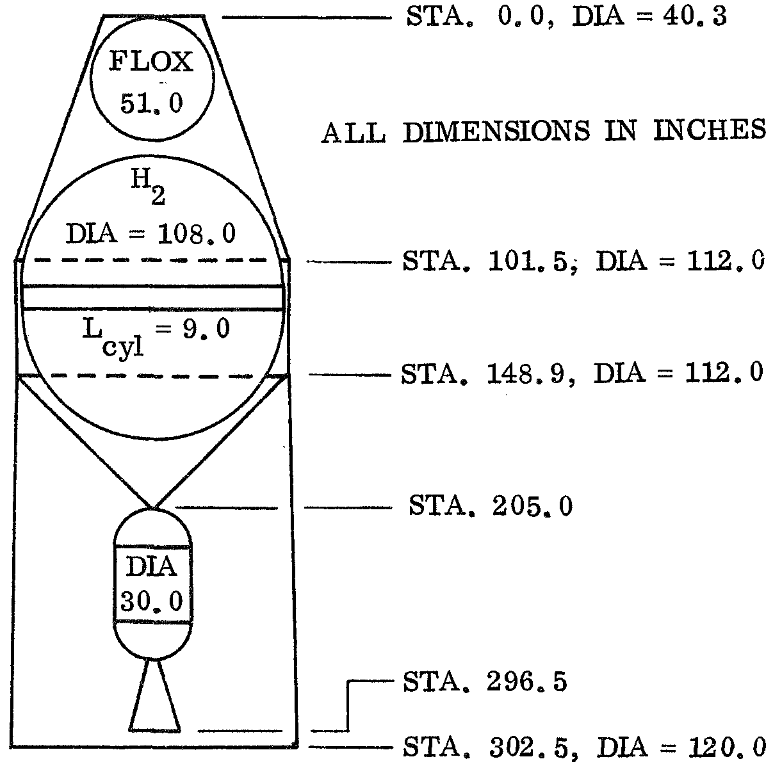

Figure 3-6. Pentapropellant Stage (Direct Injection Mission, Titan IIID/Centaur)

Table 3-12. Weight Statement Comparison (Direct Injection Mission, Titan IIID/Centaur)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		591		559		569		406
SHELL	118		86		118		77	
THRUST STRUCTURE	44		44		44		24	
TANKAGE	152		194		154		94	
Hydrogen	(128)		(114)		(131)		(60)	
Fluorine or FLOX	(24)		(29)		(23)		(34)	
Lithium	(--)		(51)		(--)		(--)	
INTERSTAGE	204		150		155		110	
TANK SUPPORTS	73		85		98		101	
PROPULSION		518		312		269		233
ENGINE	390		139		139		115	
PRESS. SYSTEM	44		61		56		55	
FEED SYSTEM	71		99		61		50	
RCS	13		13		13		13	
THERMAL CONTROL		24		44		34		16
INSULATION	24		44		34		16	
Hydrogen	(22)		(28)		(31)		(12)	
Fluorine or FLOX	(2)		(4)		(3)		(4)	
Lithium	(--)		(12)		(--)		(--)	
Li TANK HEATERS, ETC.	---		0		---		---	
METEOROID SHIELD		0		0		0		0
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		118		108		103		90
TOTAL INERT (INCL. I/S*)		1901		1673		1625		1395
PROPELLANT		6204		6215		6312		6703
USEABLE	6110		6121		6217		6600	
RESIDUAL	62		62		62		67	
BOILOFF	0		0		0		0	
START/SHUTDOWN	32		32		33		36	
TOTAL STAGE (INCL. I/S*)		8105		7888		7937		8098
PAYLOAD		3895		4112		4063		3902
GROSS WEIGHT ABOVE BOOSTER		12000		12000		12000		12000

* INTERSTAGE

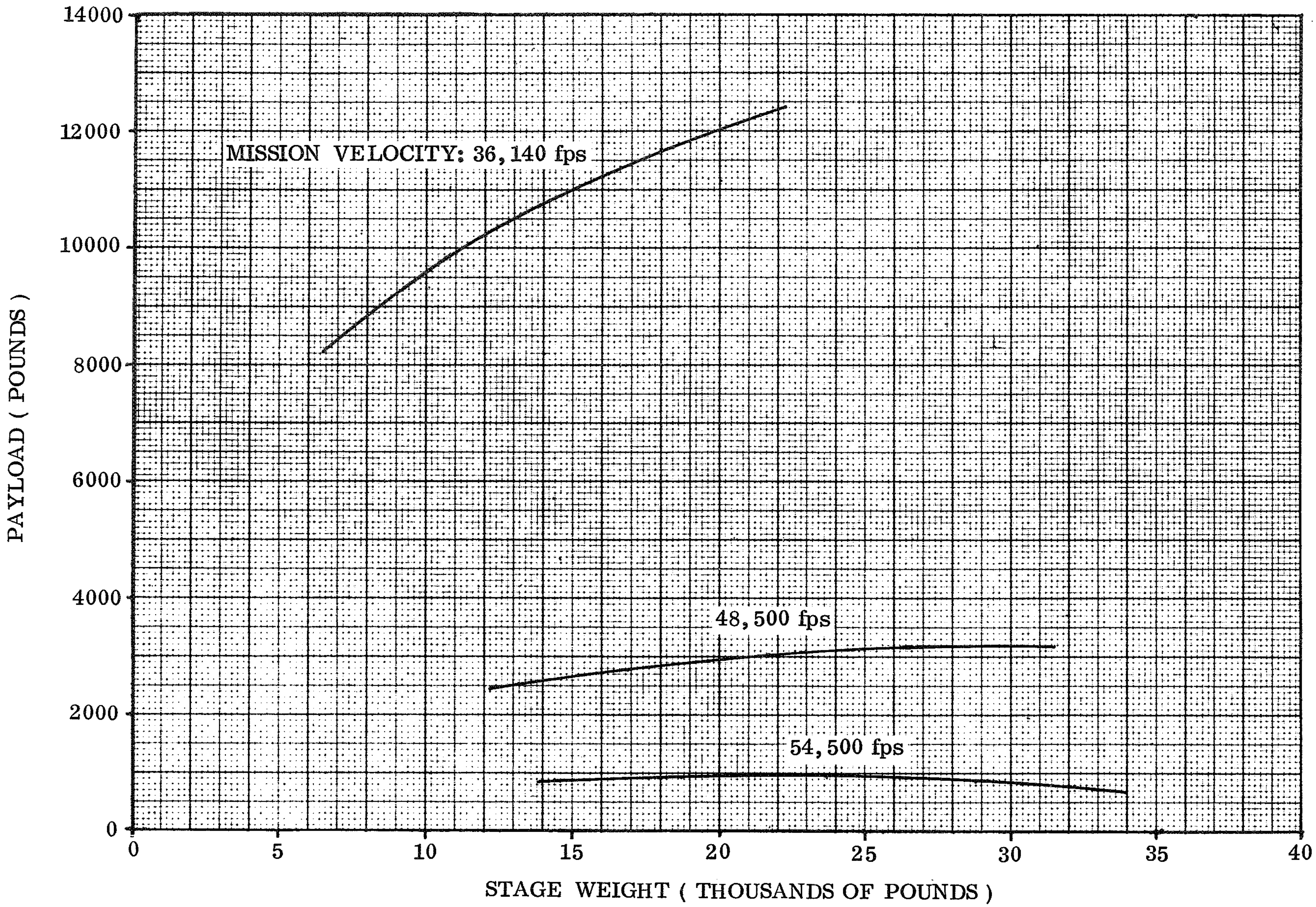

Figure 3-7. Payload Variation with Stage Weight (Direct Injection Mission, Titan IIID)

Table 3-13. Major Stage Characteristics (Direct Injection Mission, Titan IIID)

Total Mission Velocity:	48500	fps
Stage Velocity Increment - First Burn:	24000	fps
Stage Velocity Increment - Second Burn:	0	fps
First Coast Time:	0.5	hrs
Second Coast Time:	0	hrs
Gross Weight:	30000	lb

Stage	Pentapropellant
Payload (lb)	3168
Specific Impulse (sec)	519
Thrust (lb)	20787
Interstage Weight (lb)	304
Total Stage Weight (lb)	26528
Inert Stage Weight (lb)	3593
Total Propellant Weight (lb)	22934
Propellant Consumed	
First Burn (lb)	22625
Second Burn (lb)	0
Residual Propellant Weight (lb)	229
Stage Mass Ratio	4.250
Stage Payload Fraction	0.106
Stage Structural Ratio	0.144
Stage Velocity Ratio	1.447
Stage Thrust to Weight Ratio	0.7:1

Table 3-14. Engine Data Summary (Direct Injection Mission, Titan IIID)

Parameters	Value
Thrust (lb)	20787
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	1156
Length (in.)	142.8
Exit Diameter (in.)	35.1

Table 3-15. Design Data Summary (Direct Injection Mission, Titan IIID)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	6222	10905	5498
Residual (lb)	63	111	56
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	22	39	19
Total Load (lb)	6307	11055	5573
Tankage			Motor Case
Number of Tanks	1	1	N/A
Volume (ft^3)	1552.9	148.8	N/A
Radius (In.)	54.00	39.45	N/A
Cylinder Length (In.)	220.92	0	N/A
Dome Thickness (In.)	0.0250	0.0250	N/A
Cylinder Thickness (In.)	0.0428	N/A	N/A
Design Pressure (psi)	36.0	25.4	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	40	159	N/A
Insulation Thickness (In.)	0.36	0.07	N/A

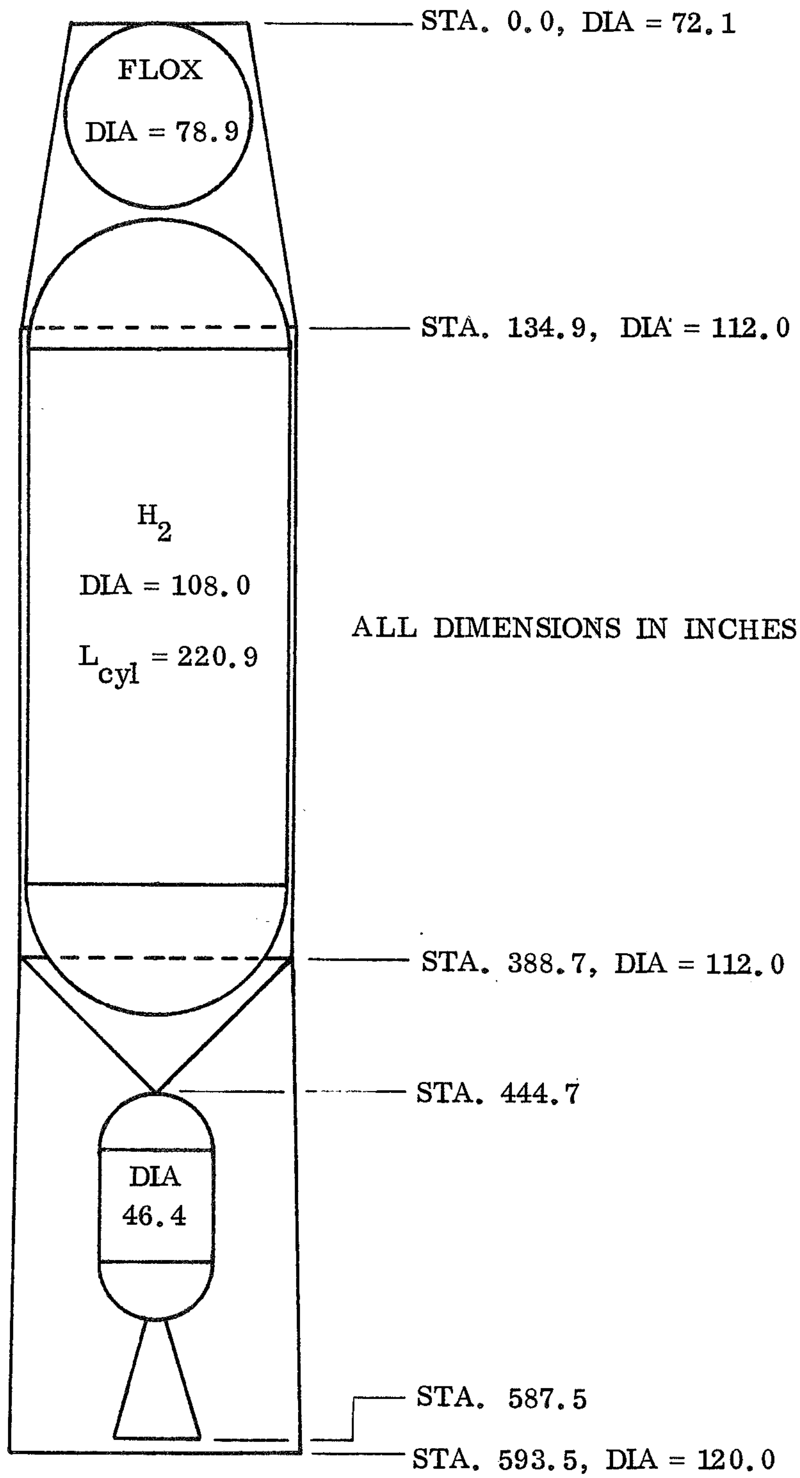

Figure 3-8. Pentapropellant Stage (Direct Injection Mission, Titan IIID)

Table 3-16. Weight Statement Comparison (Direct Injection Mission, Titan IIID)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		1528		1697		1533		1024
SHELL	356		434		349		182	
THRUST STRUCTURE	62		146		62		62	
TANKAGE	537		660		541		222	
Hydrogen	(480)		(437)		(485)		(142)	
Fluorine or FLOX	(57)		(80)		(56)		(80)	
Lithium	(--)		(143)		(--)		(--)	
INTERSTAGE	304		140		224		194	
TANK SUPPORTS	269		317		357		364	
PROPULSION		1392		730		625		558
ENGINE	1156		369		368		299	
PRESS. SYSTEM	111		167		147		140	
FEED SYSTEM	112		181		97		106	
RCS	13		13		13		13	
THERMAL CONTROL		77		128		105		37
INSULATION	77		128		105		37	
Hydrogen	(74)		(84)		(100)		(29)	
Fluorine or FLOX	(3)		(11)		(5)		(8)	
Lithium	(--)		(33)		(--)		(--)	
Li TANK HEATERS, ETC.	---		0		---		---	
METEOROID SHIELD		0		0		0		0
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		251		230		202		156
TOTAL INERT (INCL. I S*)		3898		3435		3115		2425
PROPELLANT		22934		23011		23186		24029
USEABLE	22625		22701		22873		23700	
RESIDUAL	229		229		231		240	
BOILOFF	0		0		0		0	
START/SHUTDOWN	80		81		82		89	
TOTAL STAGE (INCL. I S*)		26832		26446		26301		26454
PAYLOAD		3168		3554		3699		3546
GROSS WEIGHT ABOVE BOOSTER		30000		30000		30000		330000

* INTERSTAGE

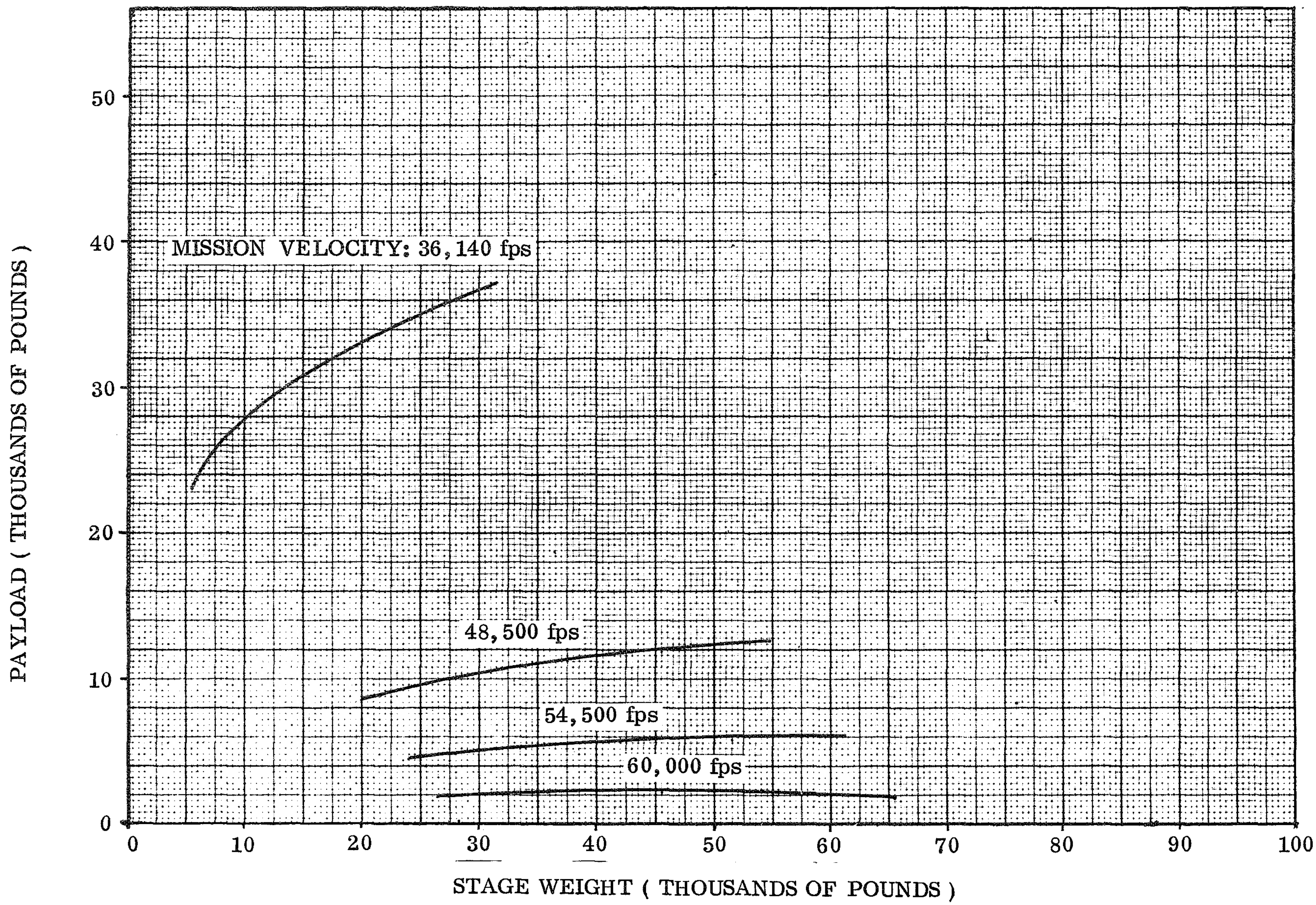

Figure 3-9. Payload Variation with Stage Weight (Direct Injection Mission, 260-Inch SRM/S-IVB)

Tables 3-17 through 3-19 summarize the major stage characteristics, engine parameters, and major design data for this size pentapropellant stage. Figure 3-10 depicts an external profile of the stage, and table 3-20 gives a weight statement for the comparable pentapropellant, tripropellant, Gel, and bipropellant stages.

As with the pentapropellant stages investigated for the other boosters, the engine size detracts from the pentapropellant stages capability.

Table 3-17. Major Stage Characteristics (Direct Injection Mission, 260-Inch SRM/S-IVB)

Total Mission Velocity:	48500 fps
Stage Velocity Increment - First Burn:	20200 fps
Stage Velocity Increment - Second Burn:	0 fps
First Coast Time:	0.5 hrs
Second Coast Time:	0 hrs
Gross Weight:	70000 lb
Stage	**Pentapropellant**
Payload (lb)	12622
Specific Impulse (sec)	519
Thrust (lb)	47166
Interstage Weight (lb)	2608
Total Stage Weight (lb)	54770
Inert Stage Weight (lb)	6859
Total Propellant Weight (lb)	47910
Propellant Consumed	
First Burn (lb)	47249
Second Burn (lb)	0
Residual Propellant Weight (lb)	182
Stage Mass Ratio	3.377
Stage Payload Fraction	0.180
Stage Structural Ratio	0.134
Stage Velocity Ratio	1.217
Stage Thrust to Weight Ratio	0.7:1

Table 3-18. Engine Data Summary (Direct Injection Mission, 260-Inch SRM/S-IVB)

Parameters	Value
Thrust (lb)	47166
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	2337
Length (in.)	194.3
Exit Diameter (in.)	52.8

Table 3-19. Design Data Summary (Direct Injection Mission, 260-Inch SRM/S-IVB)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	12993	22774	11482
Residual (lb)	132	231	116
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	50	88	44
Total Load (lb)	13175	23093	11642
Tankage			Motor Case
Number of Tanks	1	1	N/A
Volume (ft^3)	3211.7	310.8	N/A
Radius (In.)	109.84	50.43	N/A
Cylinder Length (In.)	0	0	N/A
Dome Thickness (In.)	0.0395	0.0250	N/A
Cylinder Thickness (In.)	N/A	N/A	N/A
Design Pressure (psi)	32.7	25.4	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	39	159	N/A
Insulation Thickness (In.)	0.31	0.06	N/A

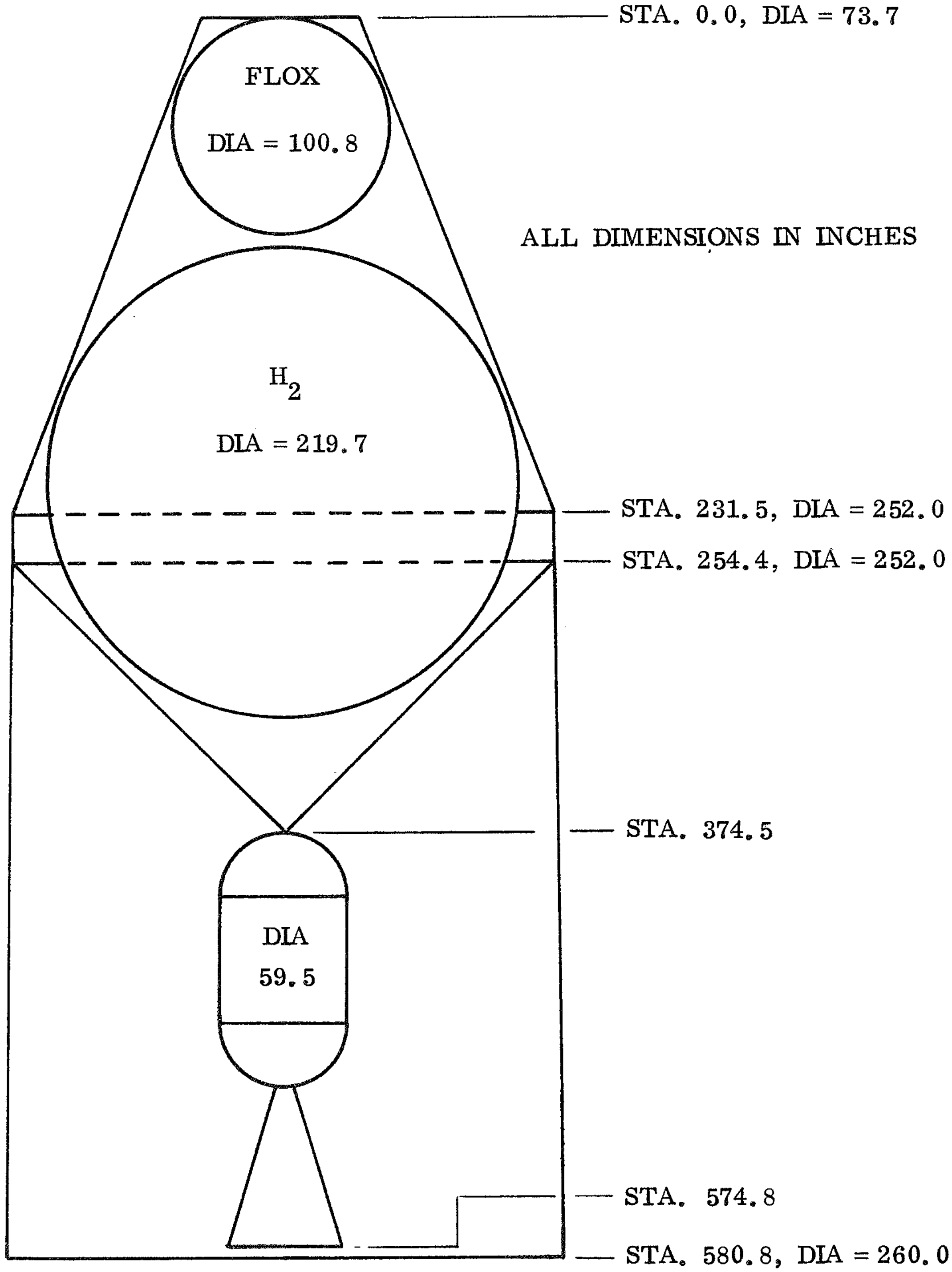

Figure 3-10. Pentapropellant Stage (Direct Injection Mission, 260-Inch SRM/S-IVB)

Table 3-20. Weight Statement Comparison (Direct Injection Mission, 260-Inch SRM/S-IVB)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		5372		4560		4803		2973
SHELL	1009		778		917		662	
THRUST STRUCTURE	524		378		498		187	
TANKAGE	790		953		687		365	
Hydrogen	(697)		(639)		(591)		(232)	
Fluorine or FLOX	(93)		(114)		(96)		(133)	
Lithium	(--)		(200)		(--)		(--)	
INTERSTAGE	2608		1793		1951		1221	
TANK SUPPORTS	441		658		750		538	
PROPULSION		2875		1704		1469		1254
ENGINE	2237		921		918		763	
PRESS. SYSTEM	204		324		273		265	
FEED SYSTEM	321		446		265		213	
RCS	13		13		13		13	
THERMAL CONTROL		92		162		125		65
INSULATION	92		162		125		65	
Hydrogen	(88)		(105)		(116)		(55)	
Fluorine or FLOX	(4)		(11)		(9)		(10)	
Lithium	(--)		(46)		(--)		(--)	
Li TANK HEATERS, ETC.	---		0		---		---	
METEOROID SHIELD		0		0		0		0
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		479		396		382		279
TOTAL INERT (INCL. I/S*)		9468		7472		7429		5221
PROPELLANT		47910		48357		49226		51297
USEABLE	47249		47690		48544		50580	
RESIDUAL	479		484		493		513	
BOILOFF	0		0		0		0	
START/SHUTDOWN	182		183		189		204	
TOTAL STAGE (INCL. I/S*)		57378		55819		56655		56518
PAYLOAD		12622		14171		13345		13482
GROSS WEIGHT ABOVE BOOSTER		70000		70000		70000		70000

* INTERSTAGE

3.4 LONG DURATION MISSION

Only one long duration mission was investigated during this study. Basically, this mission profile consisted of a booster placing the upper stage and payload on a Mars trajectory. After separating from the booster, the upper stage and payload coasted 205 days with a full propellant load to the vicinity of Mars, where a single 8000-fps retro burn placed the upper stage and payload into a low circular orbit around Mars. A gross weight of 12,000 pounds, including payload and interstage, was used for this analysis since it is intermediate to the optimum size stages for use with the Titan IIID/Centaur and 260-Inch SRM/S-IVB boosters, which are 10,000 and 14,000 pounds, respectively. Therefore, the conclusions pertinent to a 12,000 pound stage may be applied to either the Titan IIID/Centaur or the 260-Inch SRM/S-IVB.

Table 3-21 summarizes the weights of the pentapropellant stage and those stages investigated during the evaluation of the tripropellant stage. As depicted, the pentapropellant stage, though it has a larger and heavier engine, out-performs the tripropellant stage. This can be attributed to the added weight of the thermal control system for the lithium tank on the tripropellant stage. The bipropellant and Gel stages, however, have payloads greater than the pentapropellant stage.

Tables 3-22 through 3-24 summarize the major stage characteristics, the engine parameters and the design data of the pentapropellant stage selected for comparison. An external profile of this stage is shown in figure 3-11.

Table 3-21. Weight Statement Comparison (Interplanetary Mission, 120-Inch Booster)

STAGE	PENTAPROPELLANT		TRIPROPELLANT		GELLED H_2/Li		BIPROPELLANT	
STRUCTURE		672		653		624		420
SHELL	117		175		106		76	
THRUST STRUCTURE	44		56		44		26	
TANKAGE	254		267		248		123	
Hydrogen	(234)		(209)		(227)		(94)	
Fluorine or FLOX	(20)		(25)		(21)		(29)	
Lithium	(--)		(33)		(--)		(--)	
INTERSTAGE	197		79		147		115	
TANK SUPPORTS	60		76		79		80	
PROPULSION		531		365		346		293
ENGINE	326		140		138		115	
PRESS. SYSTEM	56		69		76		63	
FEED SYSTEM	66		83		57		47	
RCS	83		73		75		68	
THERMAL CONTROL		287		712		281		186
INSULATION	287		510		281		186	
Hydrogen	(270)		(262)		(258)		(159)	
Fluorine or FLOX	(17)		(32)		(23)		(27)	
Lithium	(--)		(216)		(--)		(--)	
Li TANK HEATERS, ETC.	---		202		---		---	
METEOROID SHIELD		145		193		133		88
MISCELLANEOUS SYSTEMS		650		650		650		650
CONTINGENCY (7.5%)		156		187		142		114
TOTAL INERT (INCL. I/S*)		2441		2760		2176		1751
PROPELLANT		4567		4598		4712		4983
USEABLE	4489		4520		4632		4898	
RESIDUAL	46		46		47		50	
BOILOFF	0		0		0		0	
START/SHUTDOWN	32		32		33		35	
TOTAL STAGE (INCL. I/S*)		7008		7358		6888		6734
PAYLOAD		4992		4642		5112		5266
GROSS WEIGHT ABOVE BOOSTER		12000		12000		12000		12000

* INTERSTAGE

Table 3-22. Major Stage Characteristics (Interplanetary Mission, 120-Inch Booster)

Total Mission Velocity:	8000	fps
Stage Velocity Increment - First Burn:	8000	fps
Stage Velocity Increment - Second Burn:	0	fps
First Coast Time:	4920	hrs
Second Coast Time:	0	hrs
Gross Weight:	12000	lb

Stage	Pentapropellant
Payload (lb)	4992
Specific Impulse (sec)	519
Thrust (lb)	8262
Interstage Weight (lb)	197
Total Stage Weight (lb)	6811
Inert Stage Weight (lb)	2244
Total Propellant Weight (lb)	4567
Propellant Consumed	
First Burn (lb)	4489
Second Burn (lb)	0
Residual Propellant Weight (lb)	46
Stage Mass Ratio	1.624
Stage Payload Fraction	0.416
Stage Structural Ratio	0.333
Stage Velocity Ratio	0.485
Stage Thrust to Weight Ratio	0.7:1

Table 3-23. Engine Data Summary (Interplanetary Mission, 120-Inch Booster)

Parameters	Value
Thrust (lb)	8262
Specific Impulse (sec)	519.0
Expansion Ratio	100:1
Chamber Pressure (psi)	1000
Percent Hydrogen	27.5
Percent Fluorine	14.6
Percent Oxygen	33.6
Percent Lithium	5.4
Percent Beryllium	18.9
Weight (lb)	325
Length (in.)	85.8
Exit Diameter (in.)	22.1

Table 3-24. Design Data Summary (Interplanetary Mission, 120-Inch Booster)

Propellant Tank	Hydrogen	FLOX	Li-Be Solid
Propellant Weights			
Usable (lb)	1235	2164	1091
Residual (lb)	12	22	11
Boiloff (lb)	0	0	0
Startup/Shutdown (lb)	9	15	8
Total Load (lb)	1256	2201	1110
Tankage			Motor Case
Number of Tanks	1	2	N/A
Volume (ft^3)	357.3	30.9	N/A
Radius (In.)	50.00	23.38	N/A
Cylinder Length (In.)	12.00	0	N/A
Dome Thickness (In.)	0.0517	0.0250	N/A
Cylinder Thickness (In.)	0.1034	N/A	N/A
Design Pressure (psi)	94.0	45.5	N/A
Thermal			Motor Case
Initial Temperature (°R)	36	150	N/A
Vent Temperature (°R)	50	176	N/A
Insulation Thickness (In.)	2.94	0.94	N/A

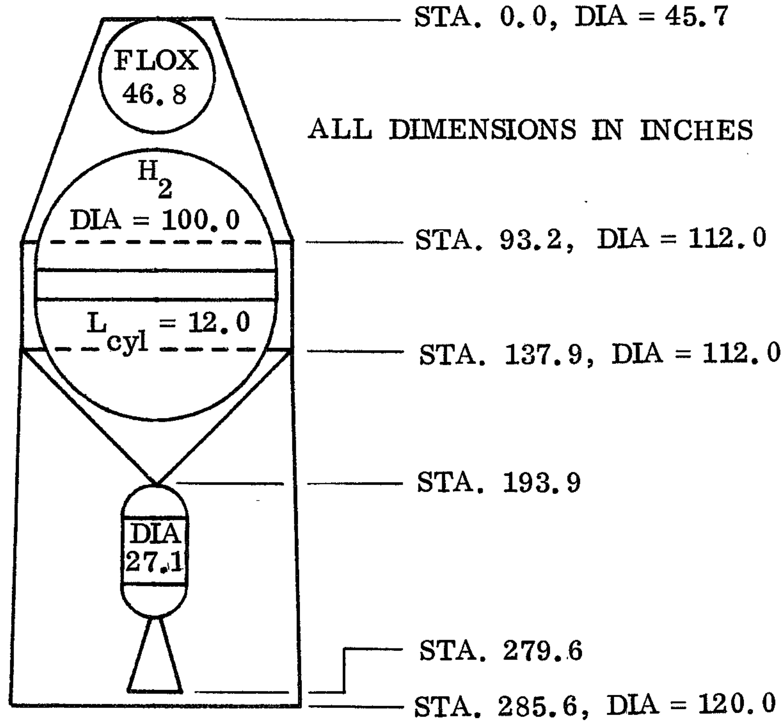

Figure 3-11. Pentapropellant Stage (Interplanetary Mission, 120-Inch Booster)

Section 4

CONCLUSIONS AND RECOMMENDATIONS

The result of this exploratory analysis of the pentapropellant (hydrogen/fluorine-oxygen/lithium-beryllium) stage indicates that a hydrogen-fluorine bipropellant stage is superior to the pentapropellant stage. The large size and weight of the pentapropellant engine is the reason for its low performance relative to the bipropellant stage. Even though the pentapropellant stage engine parameters (mixture ratio, chamber pressure, and area ratio) and combustion chamber shape (length to diameter ratio) were not optimized during the study, it is doubtful that the capability of the pentapropellant stage could be improved sufficiently by optimizing these parameters to give it a significant payload advantage over the bipropellant stage. Therefore, it is Chrysler's recommendation that further studies of this pentapropellant combination not be undertaken.

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