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SPACE SHUTTLE PHASE B"
FINAL REPORT
Volume II. Technical Summary
ADDENDUM "A"

Booster

Contract NAS9-10960
DRL T-751, DRL Line Item 6
DRD SE-420T
SD 72-SH-0012-2
15 March 1971

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(MSC-03332)

15 March 1972

SPACE SHUTTLE PHASE B''
FINAL REPORT
VOLUME II TECHNICAL SUMMARY

Addendum "A" Booster

Approved by

H. F. Rogers
Program Director
Space Shuttle Program
Convair Division of General Dynamics

Contract NAS9-10960
DRL T-751, DRL Item 6
DRD SE-420T

Space Division • North American Rockwell 12214 LAKEWOOD BOULEVARD • DOWNEY, CALIFORNIA 90241

FOREWORD

This addendum is comprised of characteristics and performance data for the booster vehicles studied and evaluated by Convair Aerospace Division of General Dynamics Corporation under a Phase B contract extension with the Space Division of North American-Rockwell Corporation, Downey, California. These studies also included Convair Aerospace Division of General Dynamics Corporation sponsored activities covering Advanced Technology effort related to reusable Space Transportation Systems and concurrent bidding and proposal activit ies.

The studies and evaluations were accomplished with assistance from IBM. American Airlines, the Aerospace Division of Honeywell, Inc., Chyrsler Corporation Space Division, and North American-Rockwell Division.

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1.0 INTRODUCTION

1.0 INTRODUCTION

The Phase B′ study concluded with a definition of a space transportation system that could be designed, developed, and operated with significantly lower RDT&E program costs and reduced peak annual funding than had been defined for the fully reusable flyback LO_2/LH_2 system during the initial Phase B studies. The baseline recommended was a series pressure fed/LO_2 Propane, single-stage booster vehicle.

The costs for this vehicle, however, exceeded both the acceptable RDT&E costs and the peak annual rates; thus, studies were continued into Phase B″ to explore alternatives leading to lower costs. The Phase B″ extension covered a period from 1 November 1971 through 15 March 1972. Studies during this period encompassed both solid- and liquid-propelled booster vehicles with both 14- by 45-foot and 15- by 60-foot payload orbiters; however, the major emphasis was on the pressure-fed booster.

The program reviews were presented by a series of briefing meetings.

1. Washington, D.C., 15 December 1971

   This program review was a discussion of the external tank orbiter for both pressure-fed and flyback boosters, a summary of the pressure-fed system versus F-1 flyback system, and alternate configurations of the pressure-fed booster.

   This presentation was published in three documents, SV 71-59, Vol. 1, Executive Summary Report; Vol. II, Presentation; and Vol. III, Supporting Data.

2. MSFC - Huntsville, Alabama, 3 February 1972

   This presentation consisted principally of subsystem splinter meetings and covered the various booster configurations under study and included the vehicle performance characteristics, operations, checkout, ground handling, attrition, and cost comparisons. The presentation was documented with briefing charts of the subject material.

3. Huntsville, Alabama, 15 February 1972

   This program review covered the series pressure-fed and series F-1 liquid-rocket-motor boosters, and the parallel burn 120- and

and 156-inch solid-rocket-motor propelled boosters. A review of the subsystem basic issues included flight control evaluation, separation, abort, and structures, propulsion, recovery, avionics, and test and operations.

The review was documented with briefing charts of the subject material.

4. Houston, Texas, 16 February 1972

This presentation covered series versus parallel burn, and liquid versus solid-rocket motors. The technical discriminators, technical and cost drivers, and program and cost evaluation material was the primary content of this review. Convair provided booster support data for this North American-Rockwell presentation.

5. Washington, D.C., 22 February 1972

This presentation covered the performance characteristics and assessment of the series pressure-fed, series pump-fed (F-1), and 156-inch solid-rocket-motor boosters.

The presentation was documented with briefing charts of the subject material.

2.0 CONCLUSIONS

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2.1 FLYBACK VS PFB

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2.0 CONCLUSIONS

2.1 FLYBACK BOOSTER VERSUS PRESSURE-FED BOOSTER STUDIES

The flyback booster was evaluated with the pressure-fed booster to determine differences and effects on program funding. The conclusions of this evaluation are:

1. The single pressure-fed booster offered the lowest program cost per flight of the pressure-fed booster arrangements studied.

2. The flyback booster (F-1) required the highest peak annual funding and highest program cost.

It was recommended that the pressure-fed booster, series burn with LO_2/propane, be continued for further study. The flyback booster study was discontinued. These conclusions and recommendations were presented at the 15 December 1971 Program Review briefings at NASA Headquarters in Washington, D.C.

2.2 PFB, F-1, SRM (156 IN.)

2.2 PFB, F-1, SRM (156 IN.)

2.2 PRESSURE-FED, PUMP-FED, AND SOLID ROCKET MOTORS (156-INCH) BOOSTER STUDIES

The pressure-fed, pump-fed, and solid-rocket-motor were evaluated to determine differences and effects on program funding. The conclusions of this evaluation are:

1. The pressure-fed booster meets all program goals. Table 2-1 provides the details of vehicle capabilities and cost. This configuration provides the lowest cost per flight of all candidate vehicles.

2. The pump-fed (F-1) booster offers one potential approach to a recoverable booster. Table 2-2 provides comparison details with identification of related risk, capabilities, and cost. This configuration is sensitive to recovery concept but offers cost per flight comparable to the pressure-fed booster.

3. The solid-rocket-motor booster offers a program compromise. Table 2-3 defines the development risk, cost, and areas of concern These configurations provide potential of lowest DDT&E cost but high cost per flight.

These conclusions were presented 22 February 1972 at the Program Review briefings at NASA Headquarters in Washington, D.C.

Table 2-1. Pressure-Fed Booster Capability and Cost

Pressure-Fed Booster Meets All Program Goals
• DESIGNED FOR REUSABILITY & TURNAROUND
• A FEASIBLE CONCEPT WITH ACCEPTABLE RISK
✓ EARLY PFE DEMONSTRATION
✓ SIMPLE RECOVERY MODE
✓ DESIGNED FOR HIGH IMPACT LOADS & RETRIEVAL CONDITION
• ACCEPTABLE BOOSTER DDT&E COSTS ($1.34B)
• LOWEST BOOSTER COST/FLIGHT ($2.3M WITHOUT ATTRITION)

Table 2-2. Pump-Fed Booster Comparison

Pump-Fed (F-1) Booster Offers Potential Compromise Approach to Recoverable Booster

- REDUCED DEVELOPMENT RISK
- LIGHTER WEIGHT SYSTEM
- COMPROMISE IN REUSABILITY & TURNAROUND
- VERY SENSITIVE TO RECOVERY CONCEPT
- REDUCED BOOSTER DDT&E COSTS ($0.98 B)
- COMPARABLE BOOSTER COST/FLIGHT ($2.5 M)

Table 2-3. Solid-Rocket-Motor Booster Details

SRM Boosters Offer A Further Program Compromise

- LOWEST DEVELOPMENT RISK & DDT&E COST ($0.46 B)
- NO RECOVERY SYSTEM
- PROVEN SRM EXPENDABLE MOTORS

HIGH BOOSTER COST/FLIGHT ($8.1 M)

- SEPARATION/ABORT OF PARALLEL SYSTEM PRIMARY CONCERN
- THRUST TERMINATION MAJOR DEVELOPMENT ITEM

3.0 SUPPORTING DATA

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3.1.1 PFB SERIES BURN

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3.0 SUPPORTING DATA

3.1 PRIMARY STUDIES

Primary booster studies have been prepared for the following:

1. Pressure-fed booster - series burn.

2. Solid-rocket-motor (156 in.) booster - parallel burn.

3. Pump-fed booster - series burn.

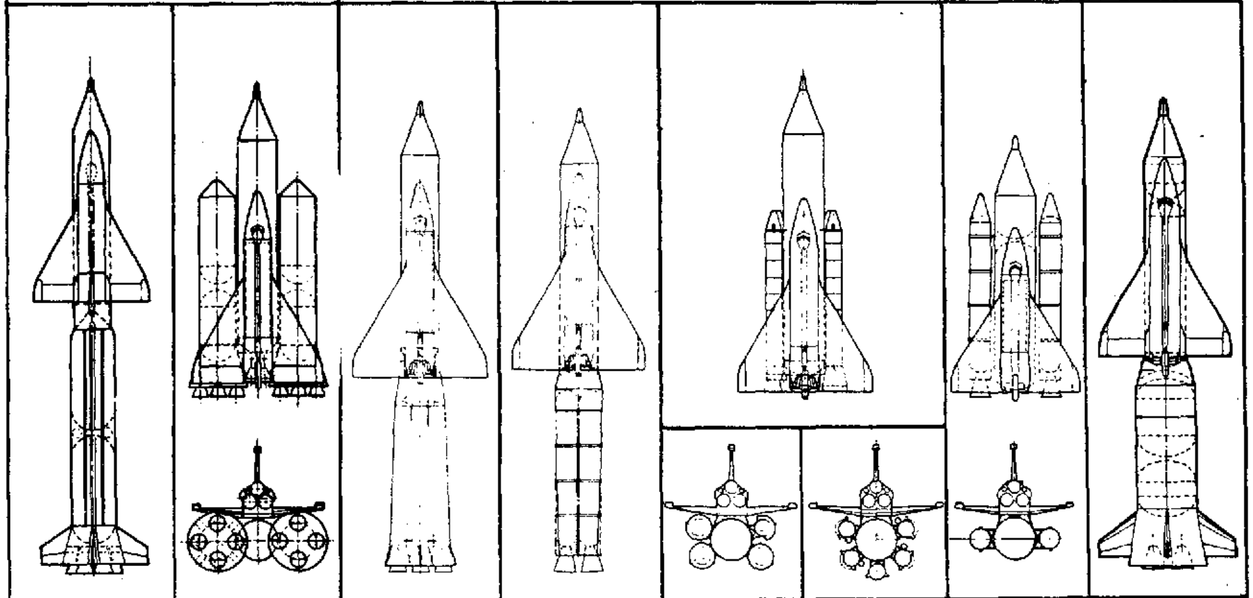
Subsystem details have been presented to the NASA centers and headquarters during Program Reviews defined in Section 1. The study emphasis was directed per NASA study directive of 4 February 1972. See Figure 3-1 for illustration of the study effort.

3.1.1 Booster Description - Series Pressure-Fed

The pressure-fed booster is a reusable vehicle configured in a tandem arrangement with the orbiter and its external oxygen/hydrogen tank. The vehicle system is a series-burn type featuring a booster liftoff weight of 4,446,000 pounds, a staging velocity of 4800 fps and a subsonicaly deployed parachute recovery system for controlling the impact to 150 fps with a recovery weight of 655,000 pounds,

The booster arrangement consists of a nose element, a forward LO_2 tank of 718 inconel; interstage, aft RP-1 fuel tank, and thrust structure of 6Al-4V titanium. Four fins are provided with 718 inconel leading edges and flaps, and titanium main box structure. Recovery parachutes are provided and stowed in the fin. The material chosen is compatible with the recovery retrieval concept.

The main propulsion system uses seven pressure-fed engines. Each is rated at 1,035,000 pounds thrust (sea level) with an LITVC system (liquid oxygen, five-degree effective angle maximum). The propulsion pressurization uses LN_2/N_2 H_4 pressurants to transfer propellants from the tanks to engines. The propellants are LO_2/RP. Figures 3-2 and 3-3 illustrate the configuration. Table 3-1 defines the system summary. Table 3-2 defines the system weights. Figures 3-4 through 3-34 illustrate system details.

	PRESSURE-FED BOOSTERS (PFB)		SOLID ROCKET MOTOR BOOSTERS (SRM)								PUMP-FED BOOSTER
CONFIGURATION CONCEPT											
CORPORATE STUDY EMPHASIS	GDCA									MC DAC	TBC
*NASA STUDY EMPHASIS	1	3				3	1	1	1	1	2
P/L BAY SIZE (FT.)	15x60	15x60	14x45	15x60	14x45	15x60	14x45	15x60	14x45	15x60	15x60
ENGINE SIZE	—	—	120 IN.		156 IN.		120 IN.		156 IN.		—
BURN SEQUENCE	SERIES	PARALLEL	SERIES				PARALLEL				SERIES

*NASA STUDY DIRECTIVE 2/4/72

1 ~ PRIMARY
2 ~ SECONDARY
3 ~ OTHER

Figure 3-1. Configuration Study Matrix

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

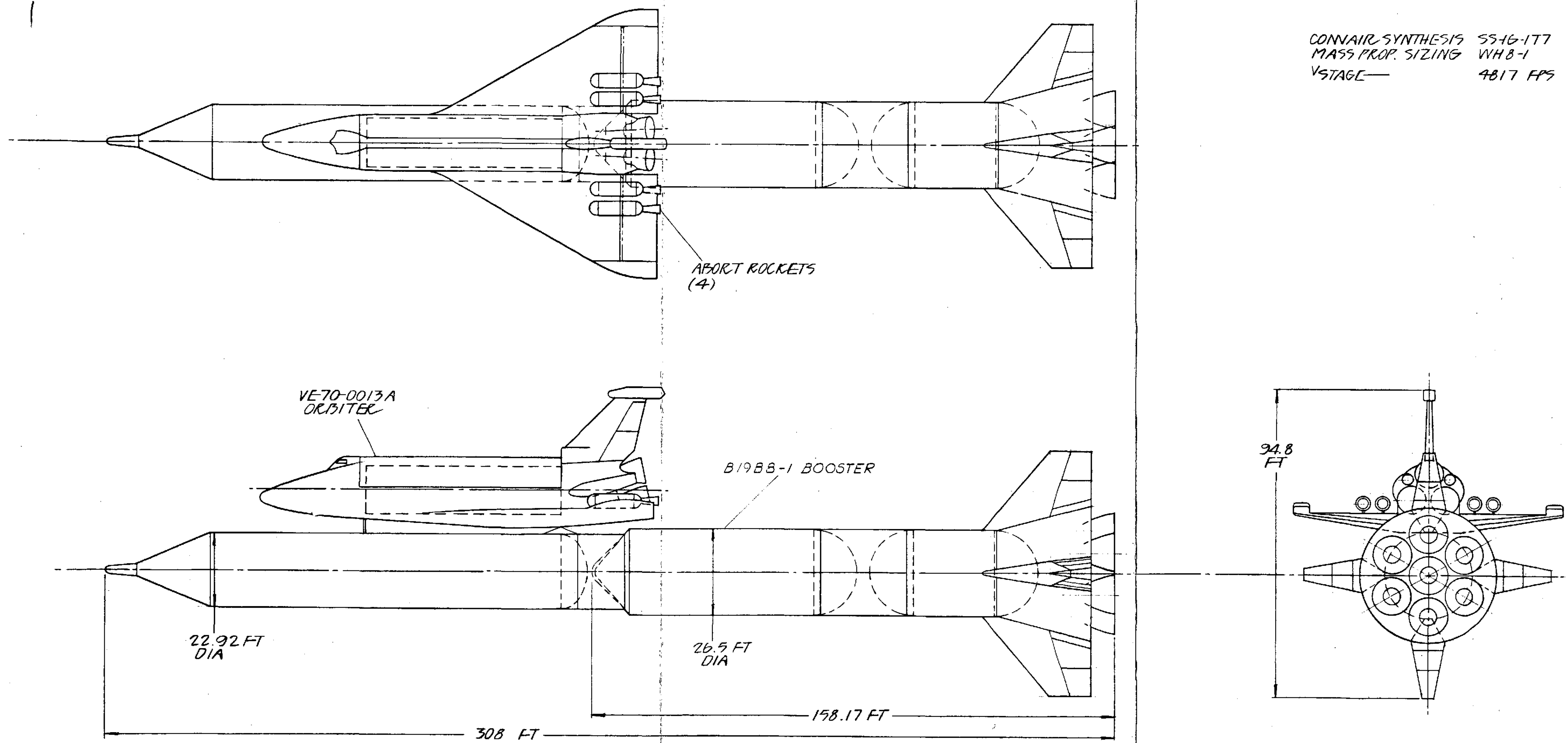


Figure 3-2. B19B8-1 Single Pressure Fed LO_2/RP Booster-Series Burn

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Table 3-1. System Summary

System	Pressure Fed Booster Series Burn (LO_2/RP)	Payload Weight 40k lb Polar Payload Bay Size 15 ft diameter by 60 ft
Item	**Units**	**Design Point**
Gross Liftoff Weight	M lb	5.791
Booster Gross Weight	M lb	4.446
Booster Ascent Propellant	M lb	3.735
Orbiter Gross Weight**	M lb	1.345
Orbiter Weight at Staging	M lb	1.345
Orbiter Ascent Propellant	M lb	0.975
Orbiter Spacecraft Weight	k lb	176
Orbiter Tank Weight (Burnout)	k lb	64.1
Relative Staging Velocity	fps	4817
Staging Flight Path Angle	deg	22.6
Staging Dynamic Pressure	psf	73
Staging Altitude	k ft	136.8
Maximum Dynamic Pressure	psf	646
SL Thrust/Booster Engine	M lb	1.035
Vac Thrust/Orbiter Engine	k lb	470
No. Engines Booster	-	7
No. Engines Orbiter	-	3
T/W at Liftoff	-	1.25
T/W Orbiter at Staging*	-	1.49 (1.05 w/o abort rockets)
Booster Burn Time	sec	137.2
Center Engine Cutoff (To limit maximum q)	sec	32.5

*Includes abort rocket thrust
**Includes abort rocket weight

Remarks: has approximately 8% extra growth capability in orbiter spacecraft and booster dry weights.

Synthesis Ref: SS-16-1T7

Three-view drawing 76Z0873, inboard drawing 76Z0865

Table 3-2. Pressure-Fed Booster, LO_2/RP Weight Summary

	Weight (lb)
Fins, Flaps, Mechanisms	46,040
Flap Actuation (hydraulics) (dry)	3,140
Impact and Retrieval	4,925
Fuel Tank, (including LO_2 line)	82,924
LO_2 Tank	152,250
Intertank Structure	31,800
Base Heat Protection	9,220
Thrust Structure, Skirt	74,636
Interstage Attach, Separation	500
Fairings	3,800
Parachute System	19,429
Main Engines (including LITVC)	78,982
Pressurant System (dry)	19,690
Engine Installation	1,797
Feed Systems	5,506
PU System	750
Avionics, Electrical	3,402
ECS	334
Growth	53,913
Dry Weight	593,038
Pressurants	64,570
Residual Fuel	27,615
Residual Oxidizer	18,188
Hydraulic Fluid, Ice/Frost	1,176
Burnout Weight (entry)	704,587
Ascent Propellants	(3,735,503)
Main Impulse	3,675,909
Thrust Decay	779
TVC Oxidizer	58,815
Liftoff Weight, Booster	4,440,090
Weight at Parachute Deployment	660,000
Weight at Water Impact	655,000
Adapter and Fin (including contingency)	6,000
Orbiter and Tanks	1,345,004
Gross Liftoff Weight	5,791,094

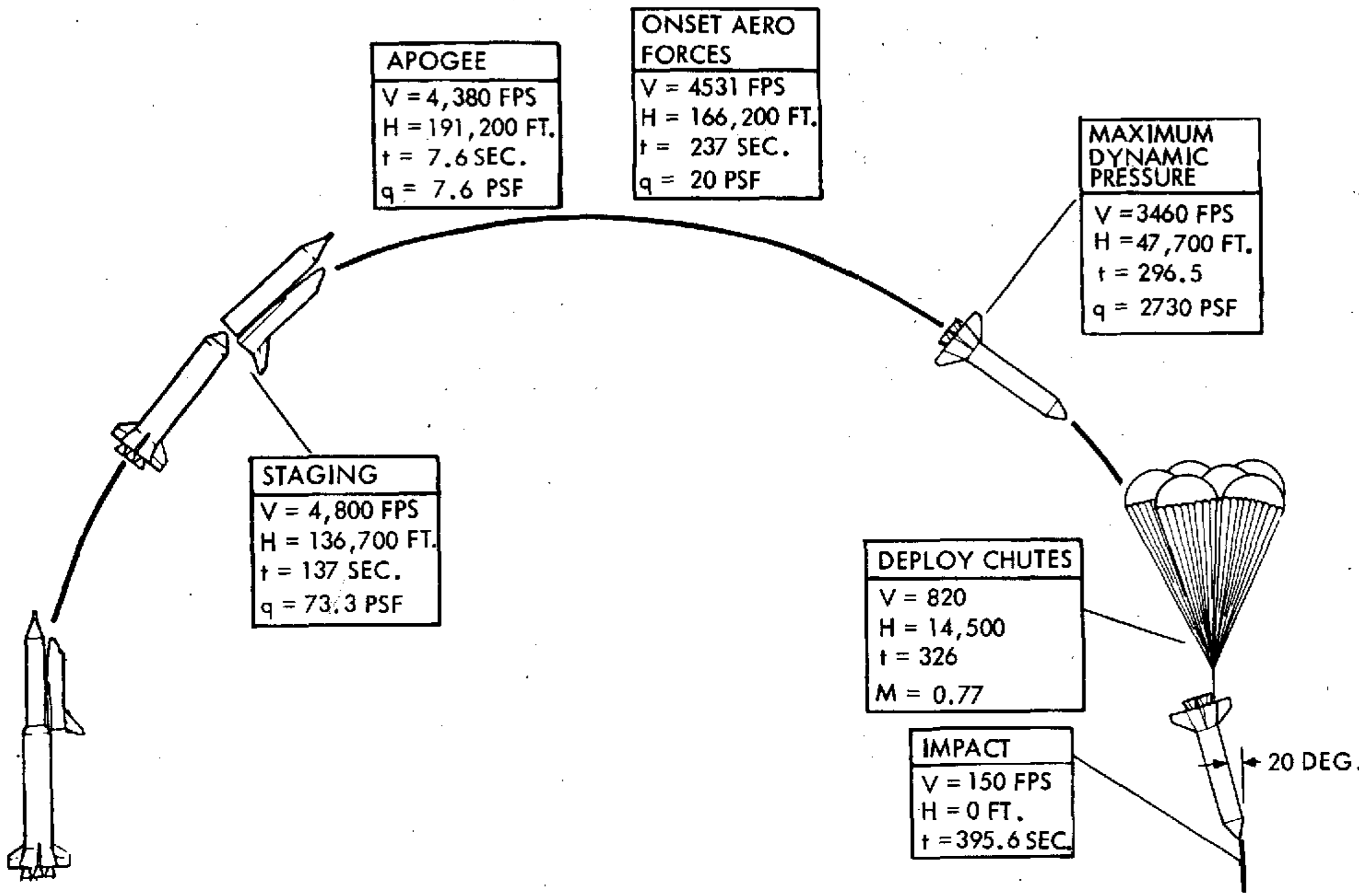


Figure 3-4. Mission Flight Profile, SPFB

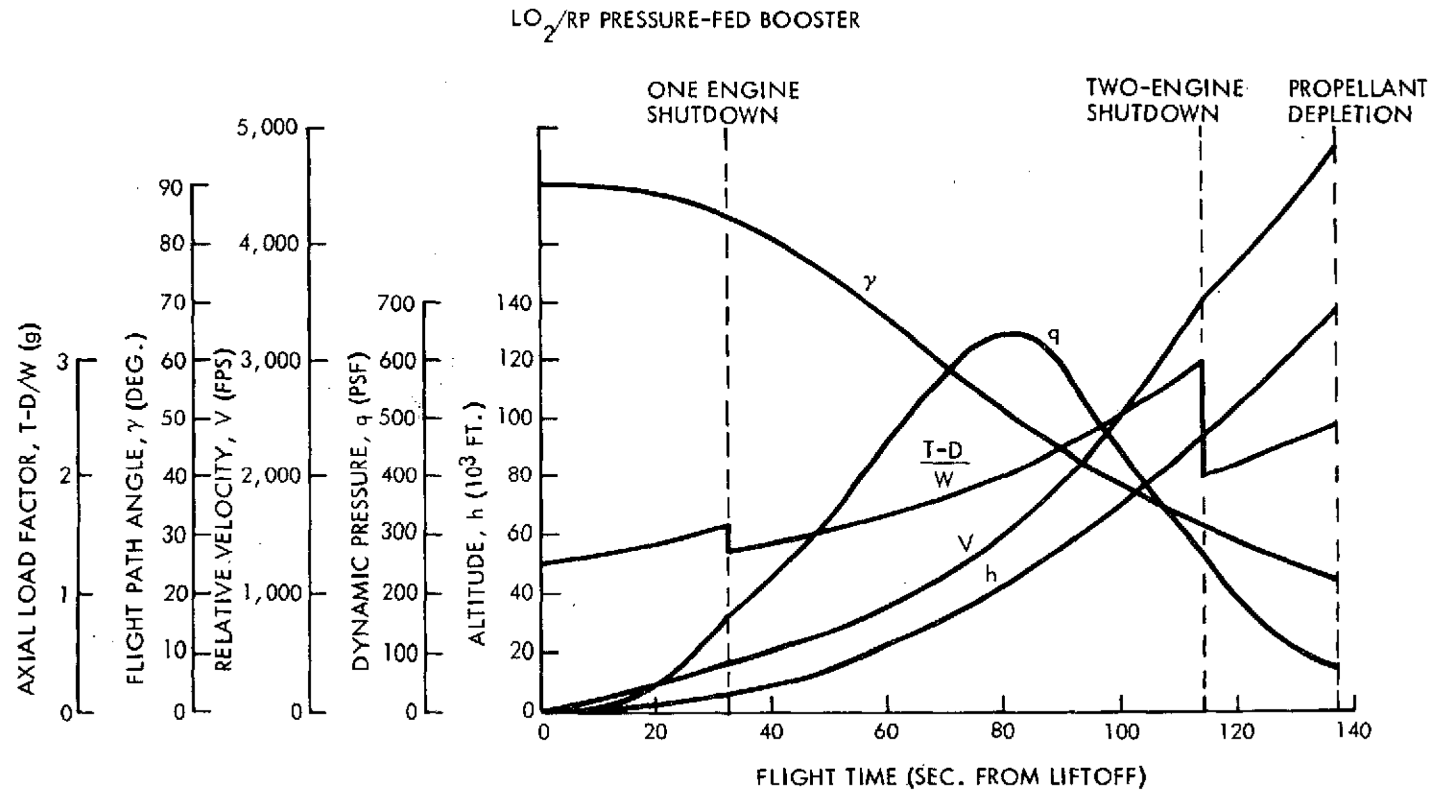


Figure 3-5. Ascent Trajectory Parameters, SPFB

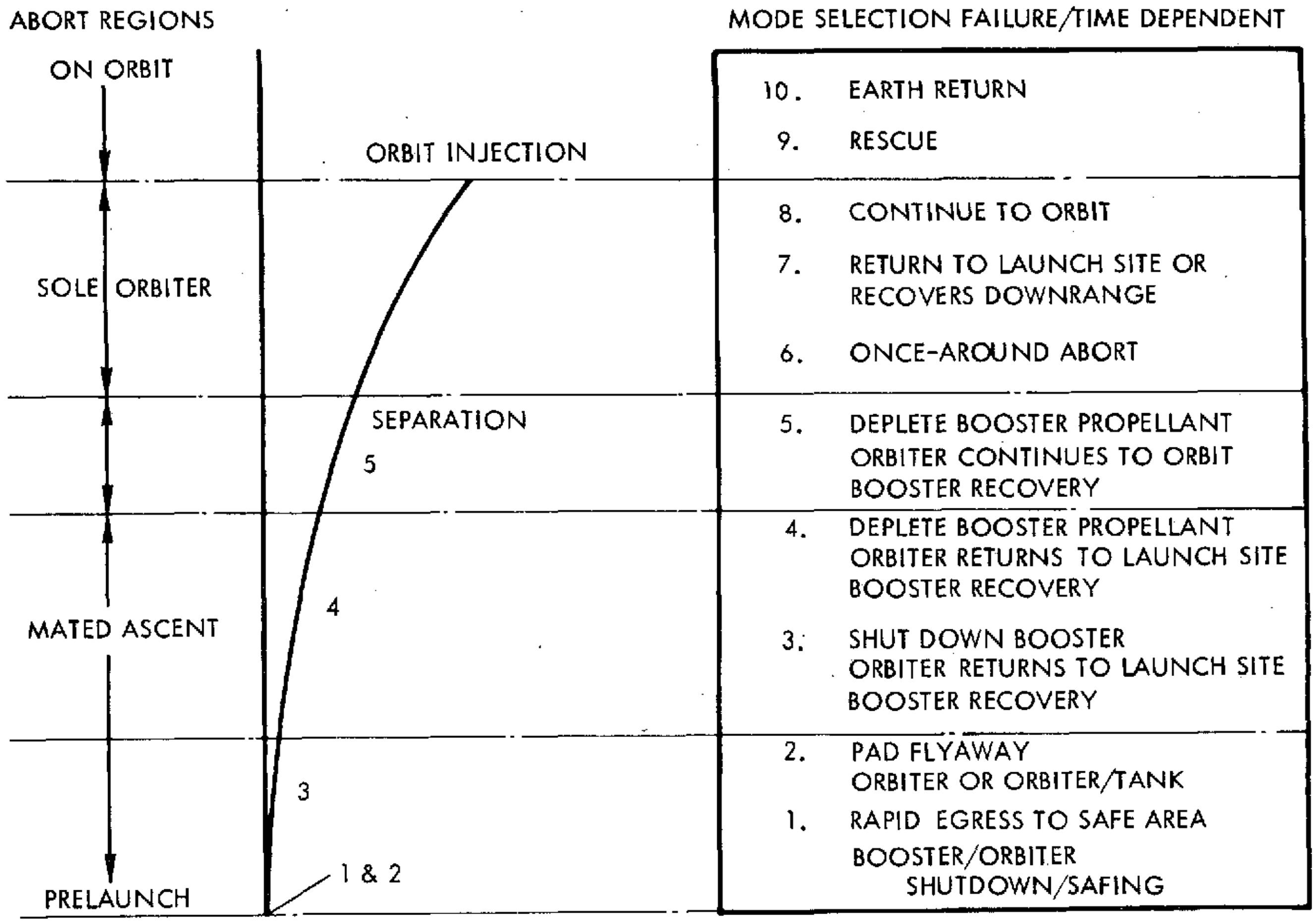


Figure 3-6. Abort Mode/Mission Completion Approach, SPFB

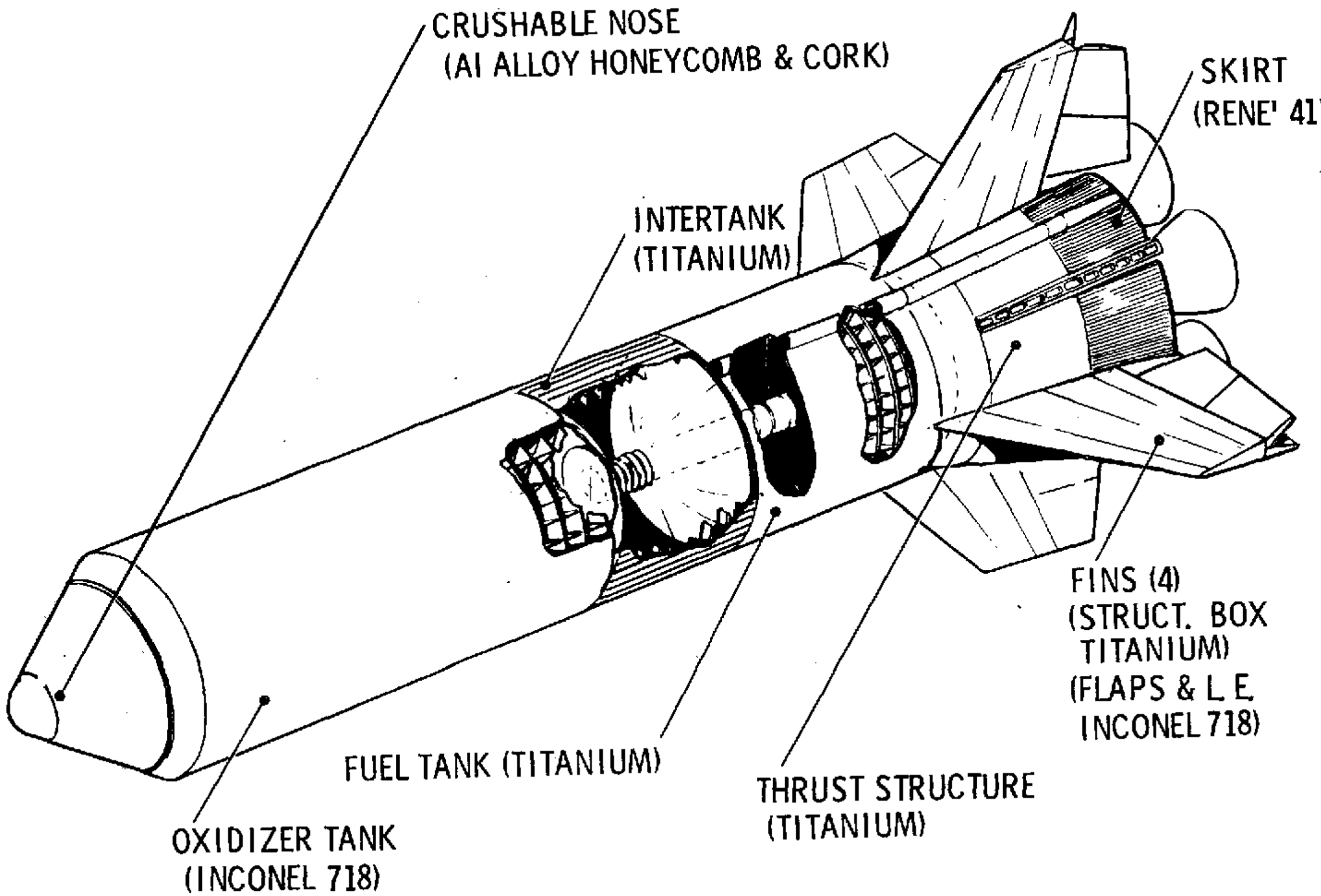


Figure 3-7. Structural Configuration, SPFB

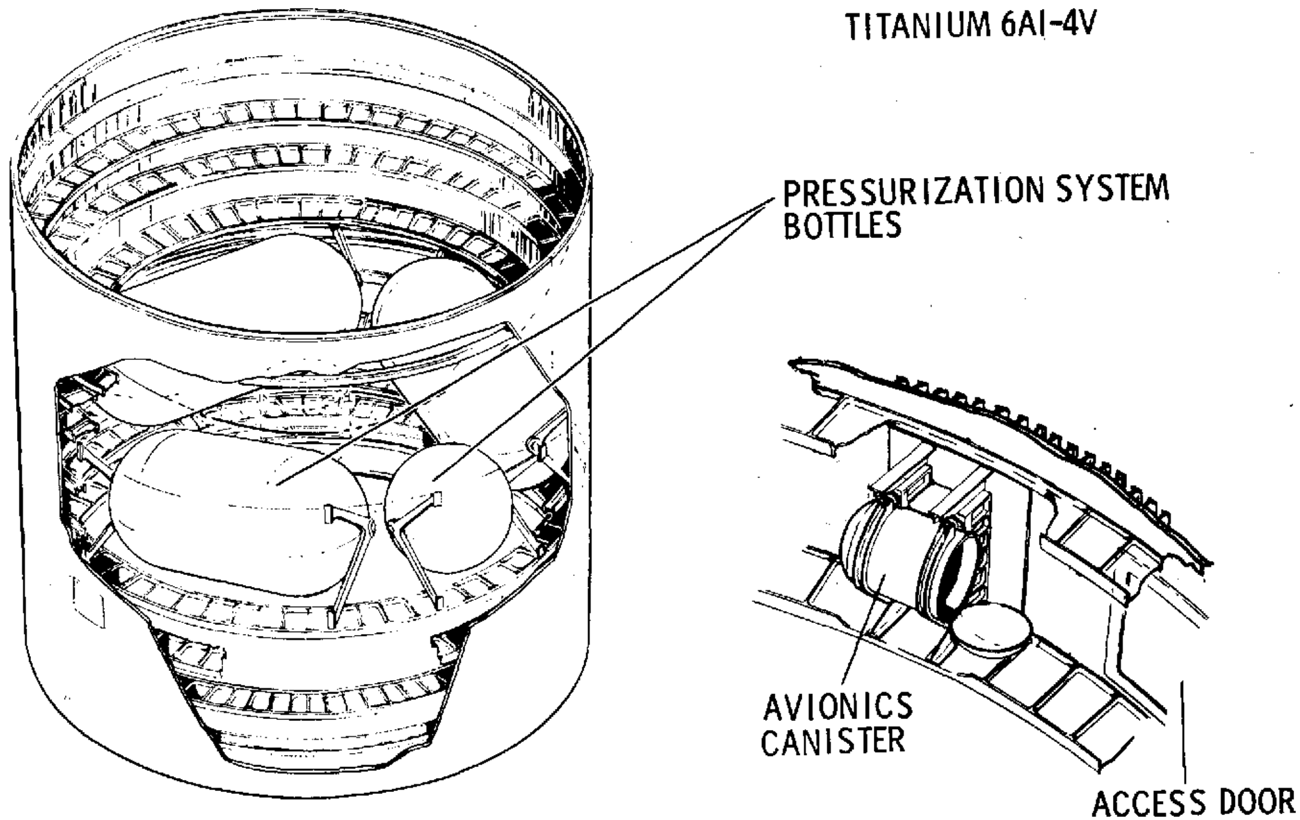


Figure 3-8. Intertank Structure, SPFB

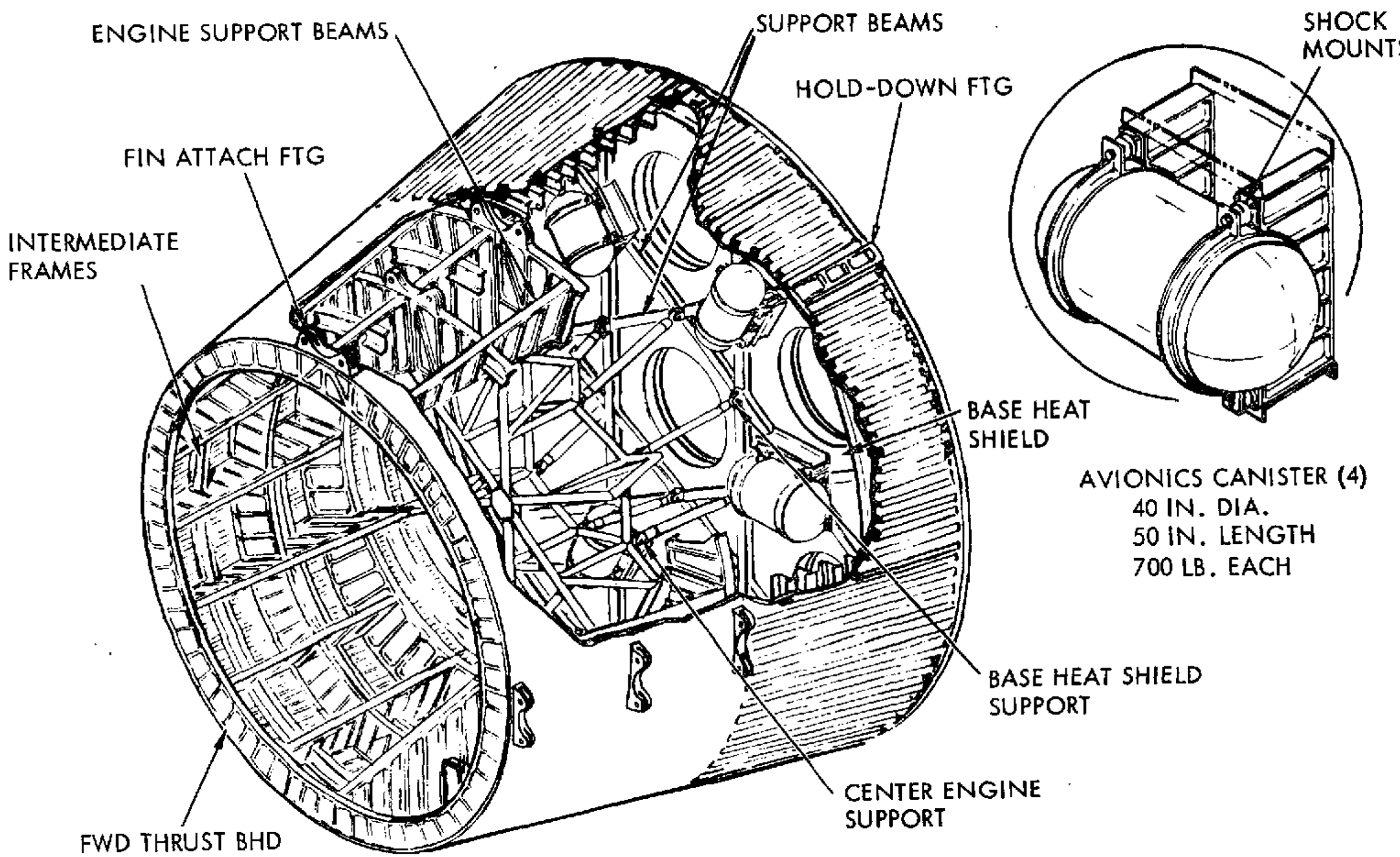


Figure 3-9. Thrust Structure, SPFB

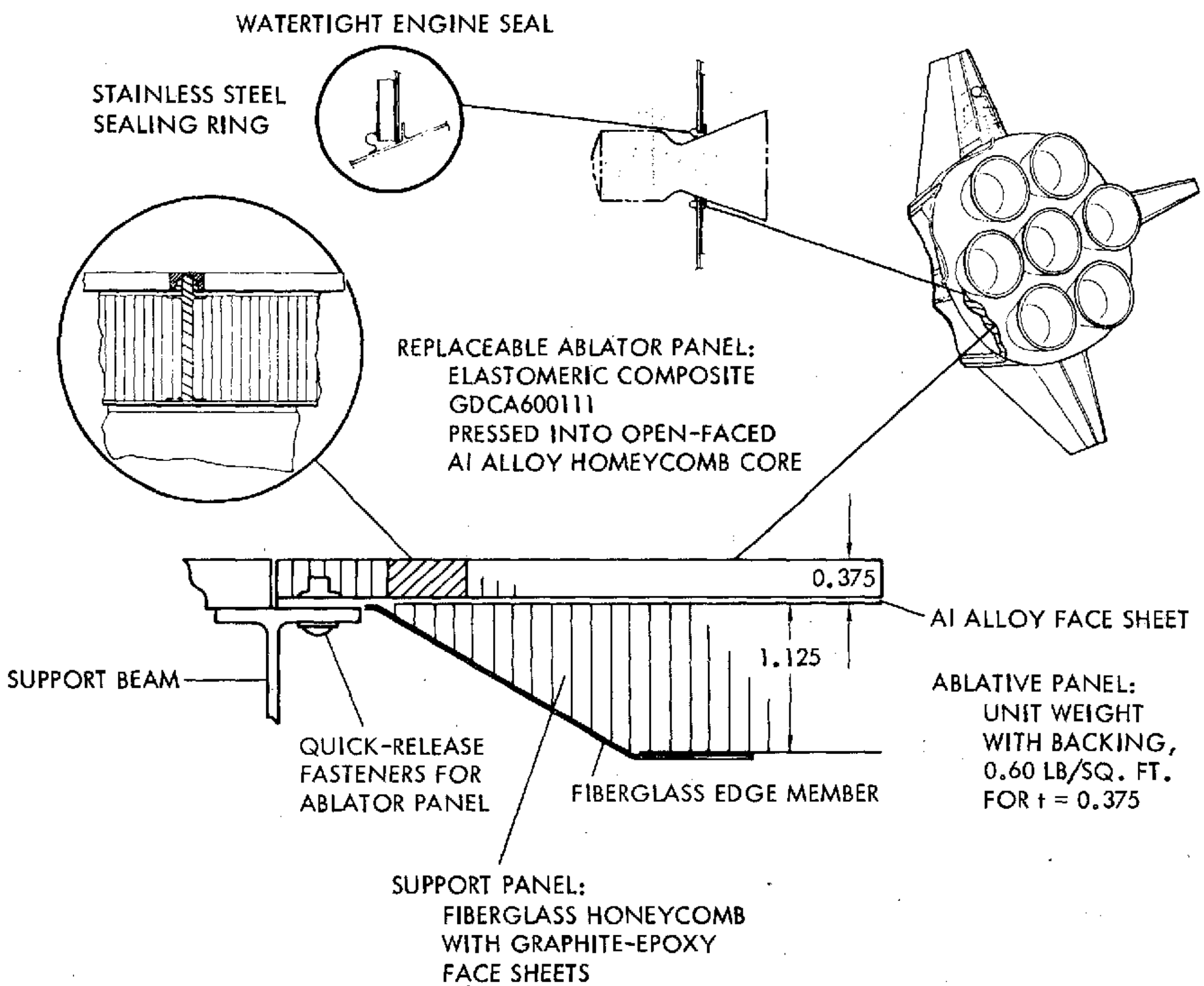


Figure 3-10. Basic Heat Shield, SPFB

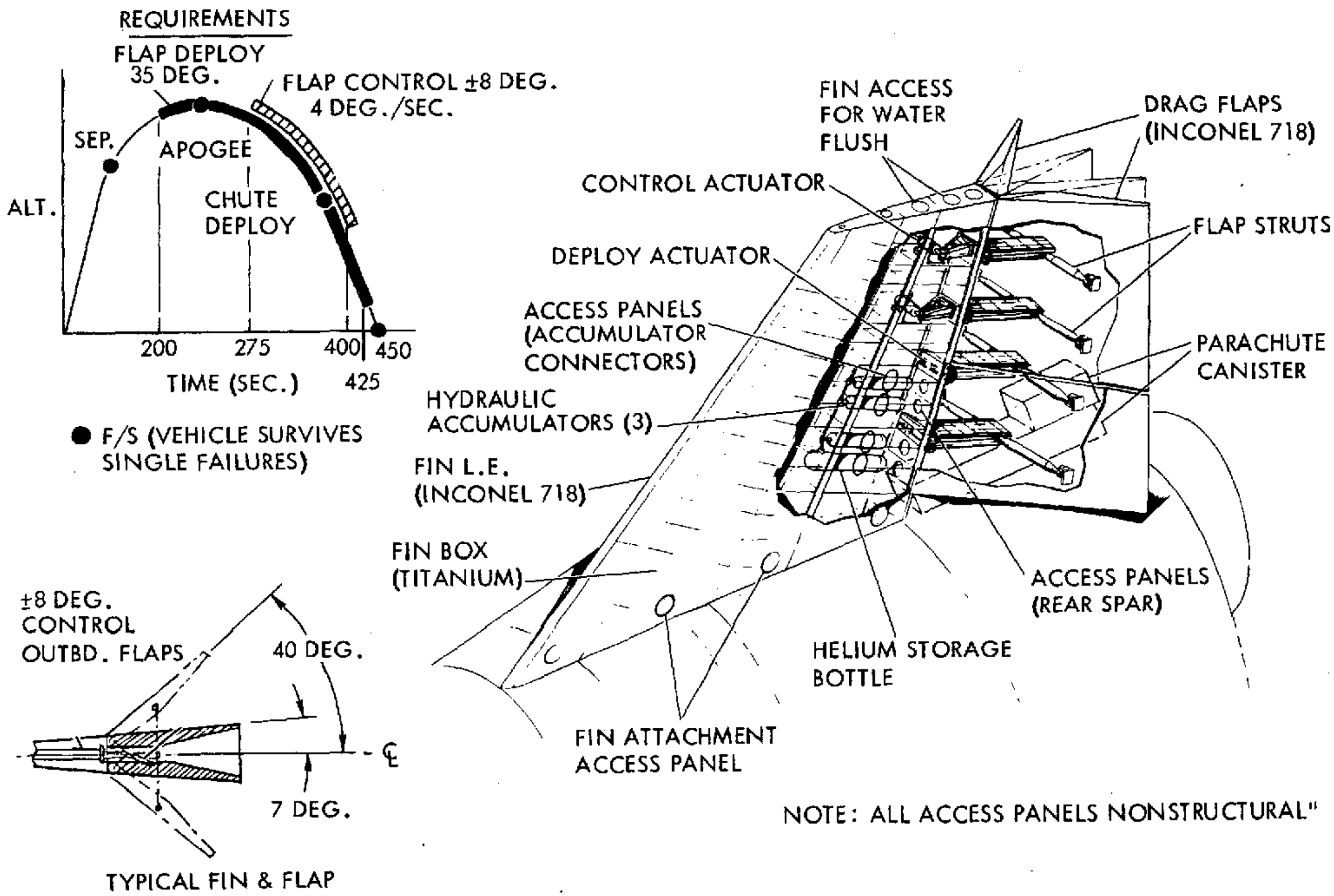


Figure 3-11. Fin and Drag Flap, SPFB

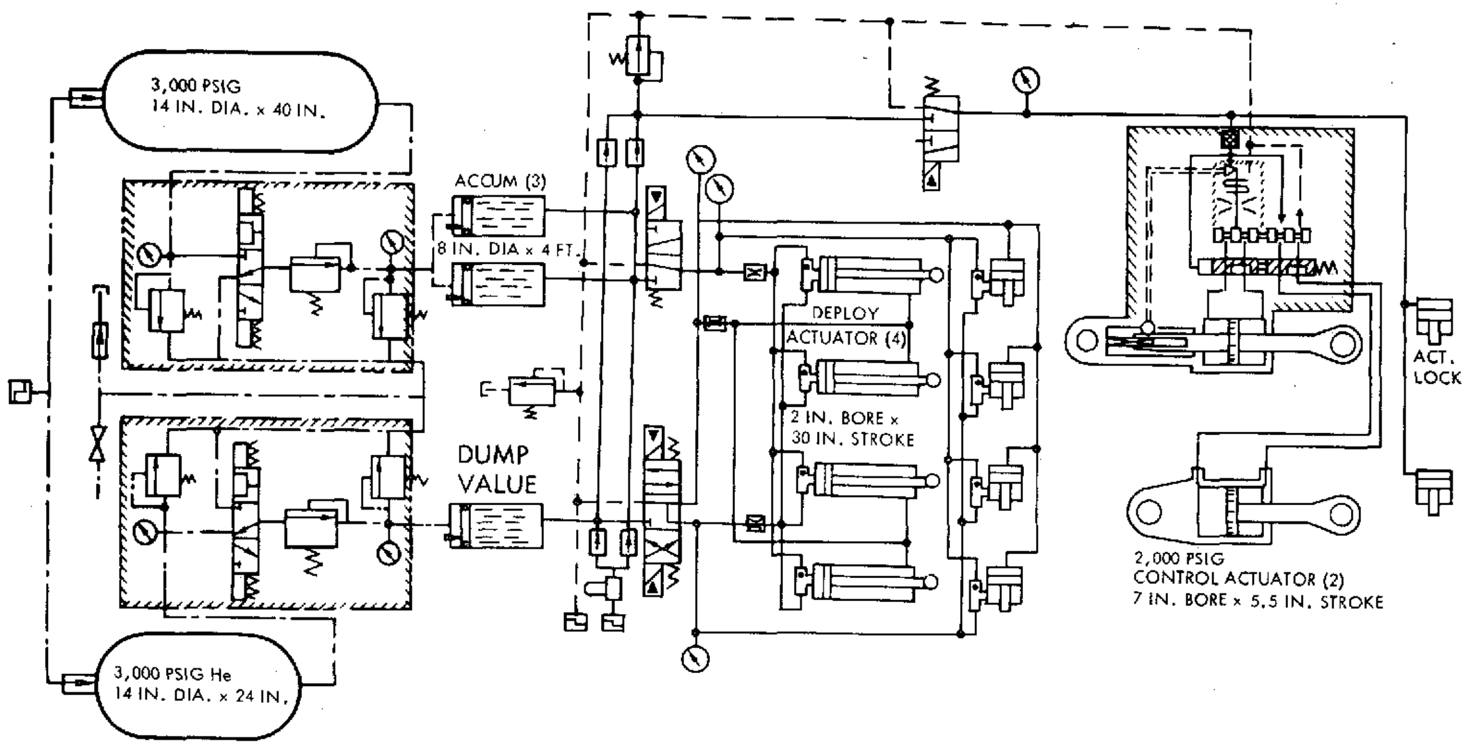


Figure 3-12. Hydraulic Drag Flap Actuation, SPFB

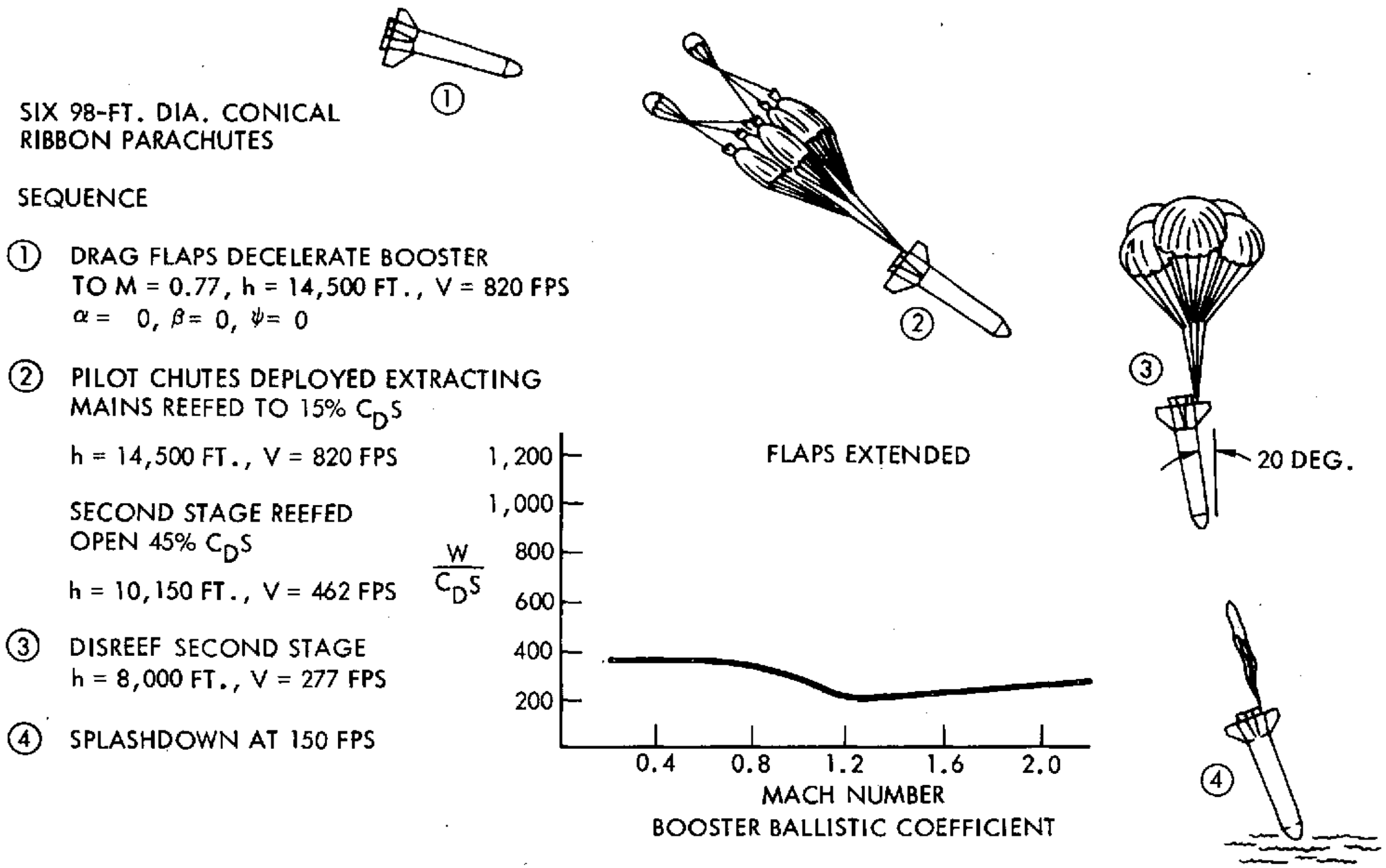


Figure 3-13. Recovery Concept, SPFB

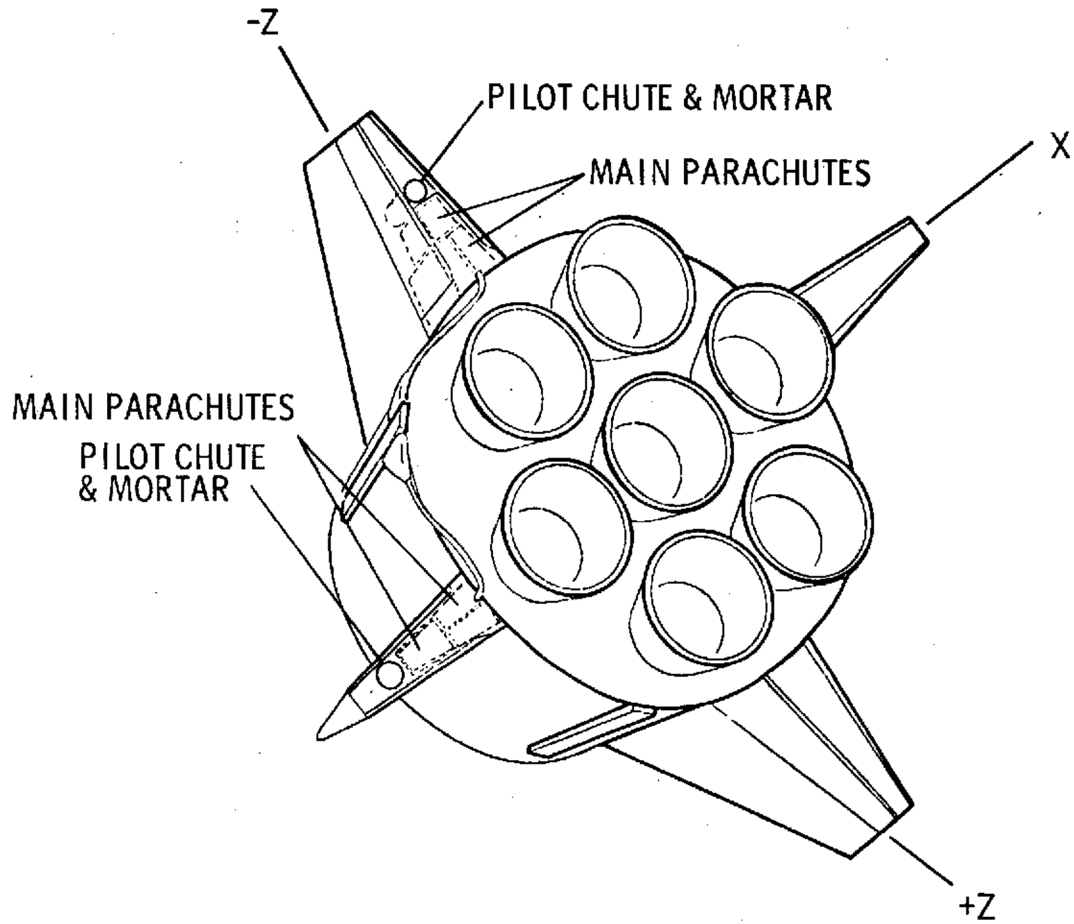


Figure 3-14. Recovery System Installation, SPFB

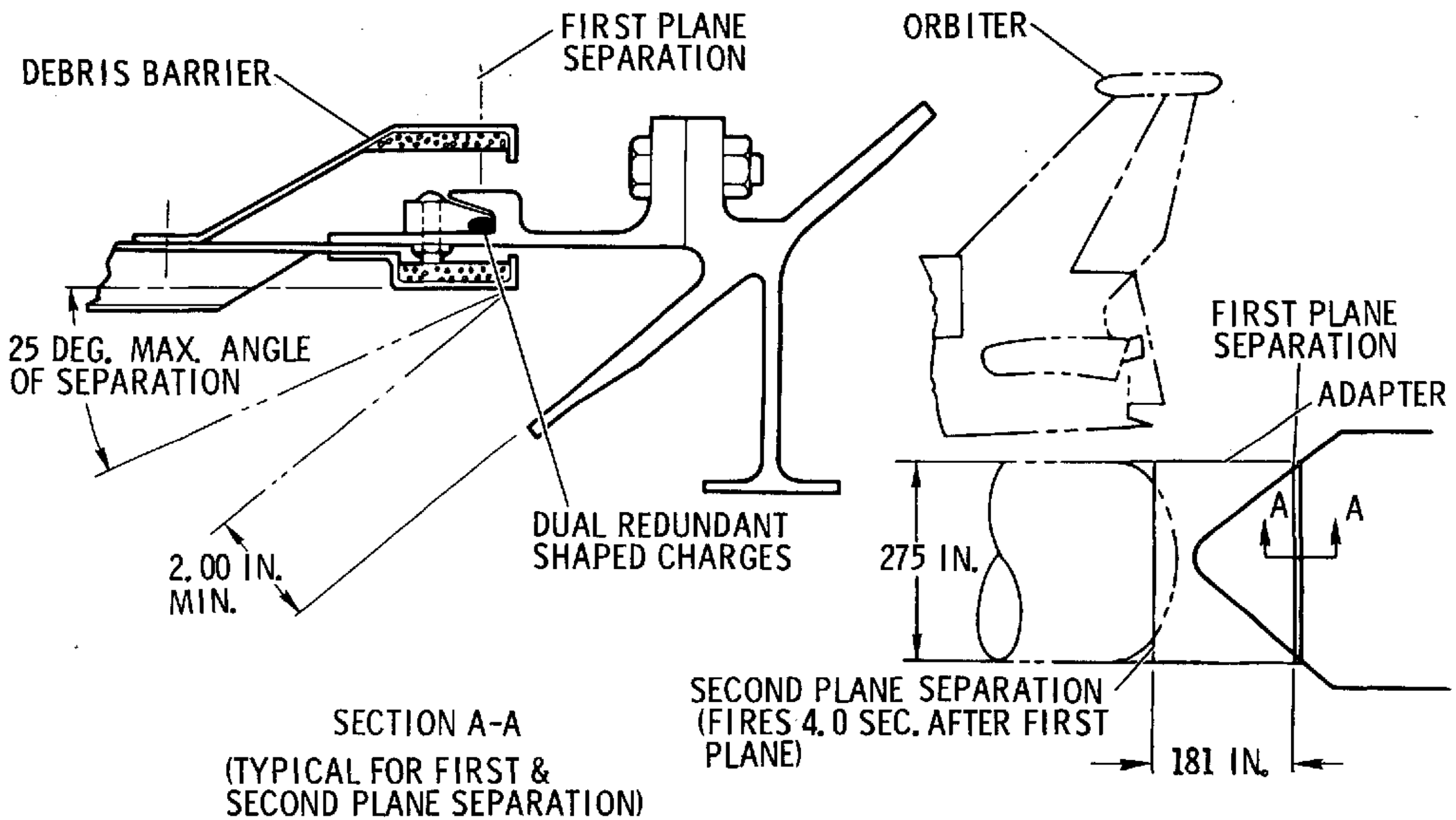


Figure 3-15. Mating/Separation System Installation, SPFB

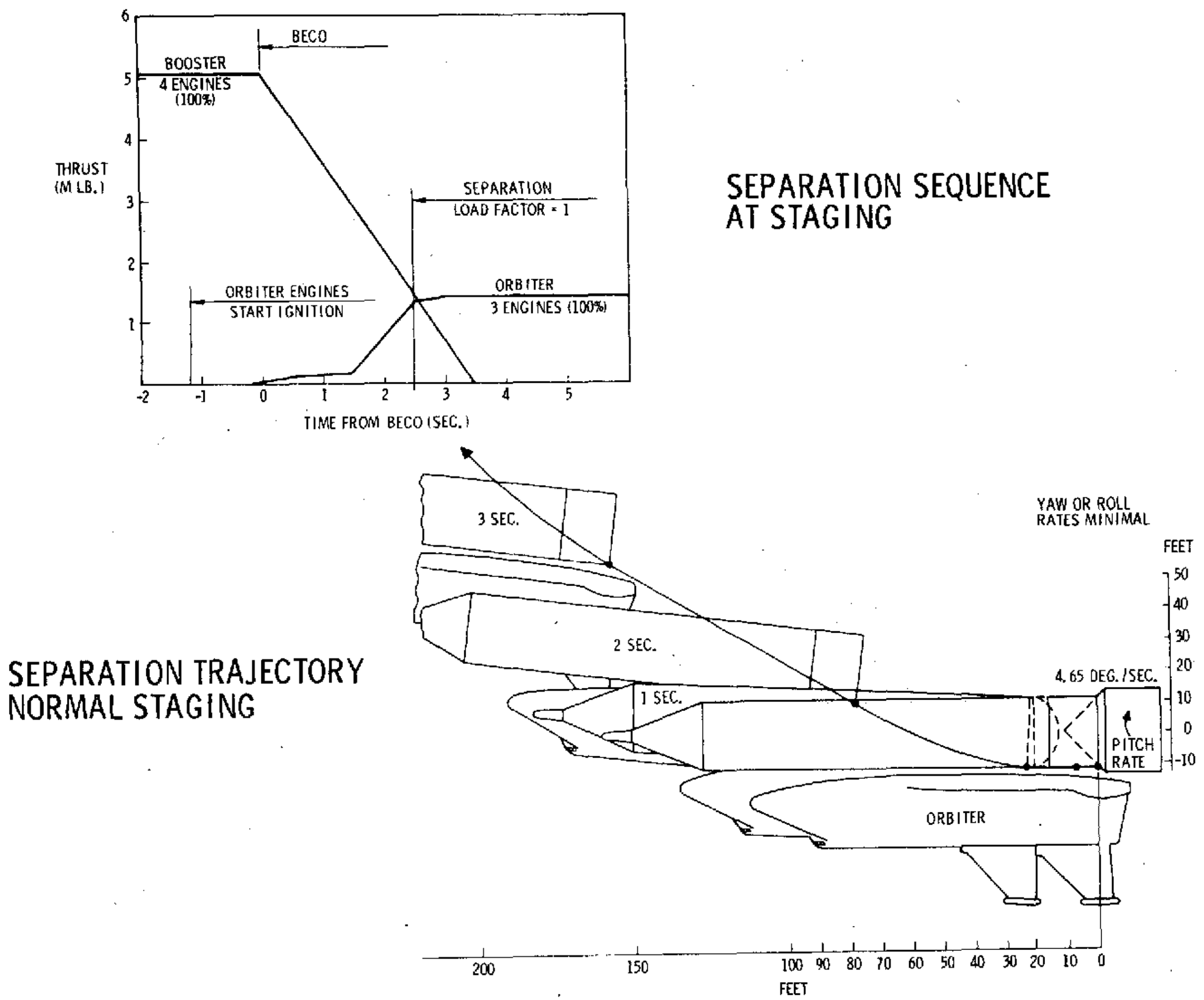


Figure 3-16. Separation Trajectory and Thrust History, SPFB

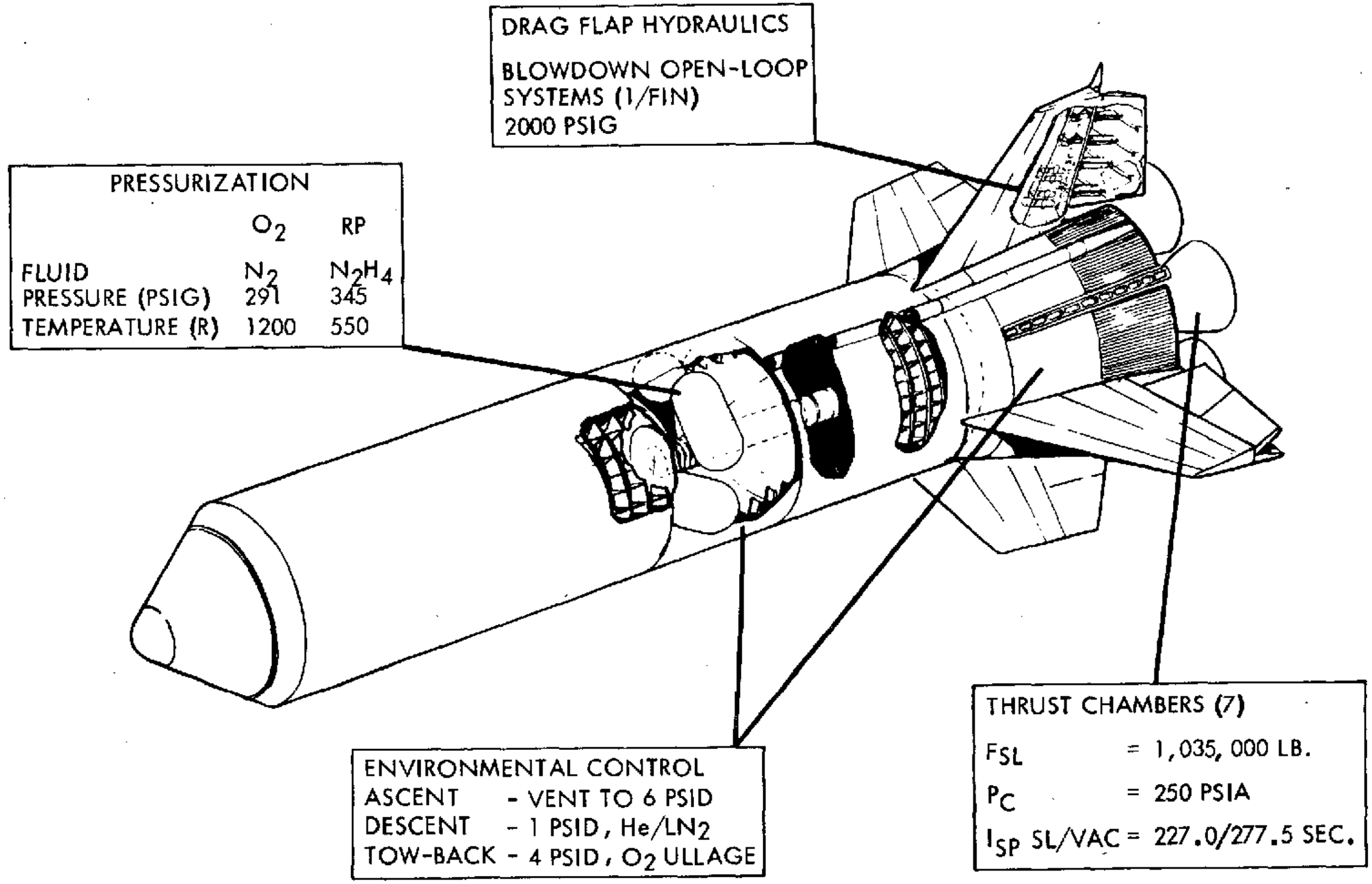
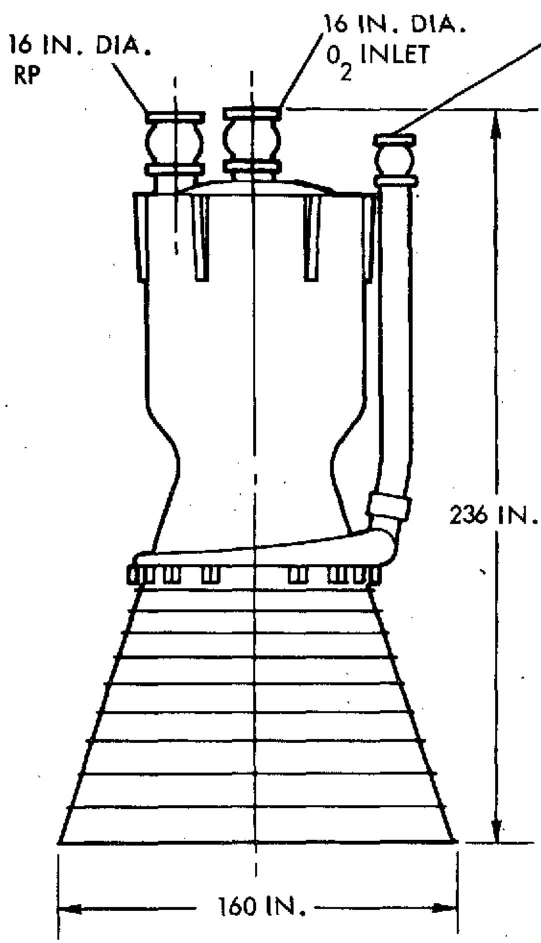


Figure 3-17. Propulsion System Configuration, SPFB



PROPELLANTS	O_2/RP
THRUST (SL)	1,035K
NOMINAL MIXTURE RATIO	2.4
ACTIVE MIXTURE RATIO CONTROL	±6%
DESIGN MIXTURE RATIO LIMITS	2.1 TO 2.9
AREA RATIO	5
I_{sp} (SL)	227.0
I_{sp} (VAC)	277.5
CHAMBER PRESSURE	250 PSIA
NOMINAL INLET PRESSURE, O/F	380/380 PSIA
INLET PRESSURE RANGE	
OXIDIZER	360 - 402 PSIA
FUEL	334 - 386 PSIA
WEIGHT DRY (INCL. 10% GROWTH)	12,411 LB.

LITVC – LIQUID OXYGEN, 5 DEG. EFFECTIVE ANGLE MAX.

LIFE	75 MISSIONS

Figure 3-18. Engine Characteristics, SPFB

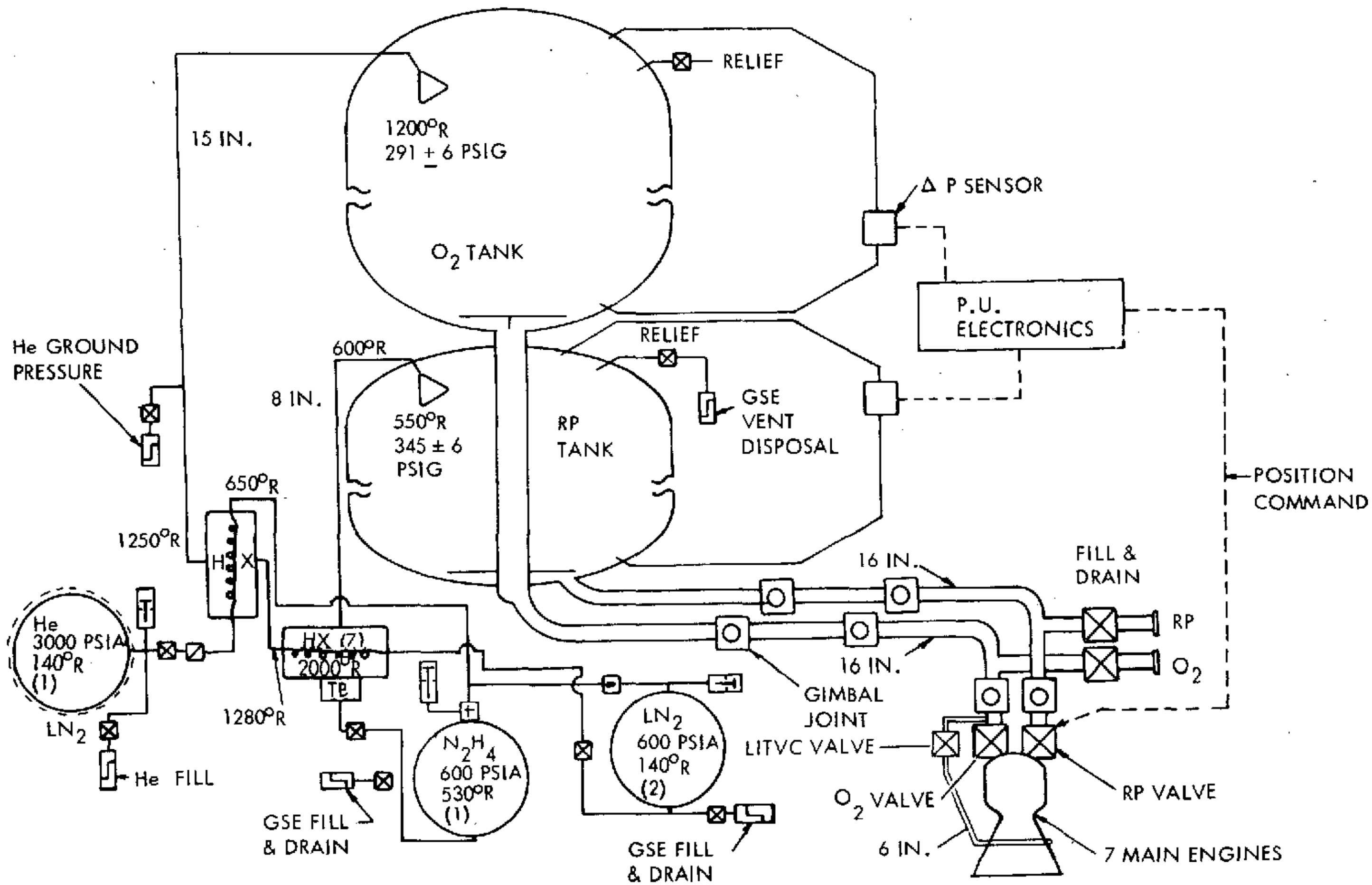


Figure 3-19. Pressurization System, SPFB

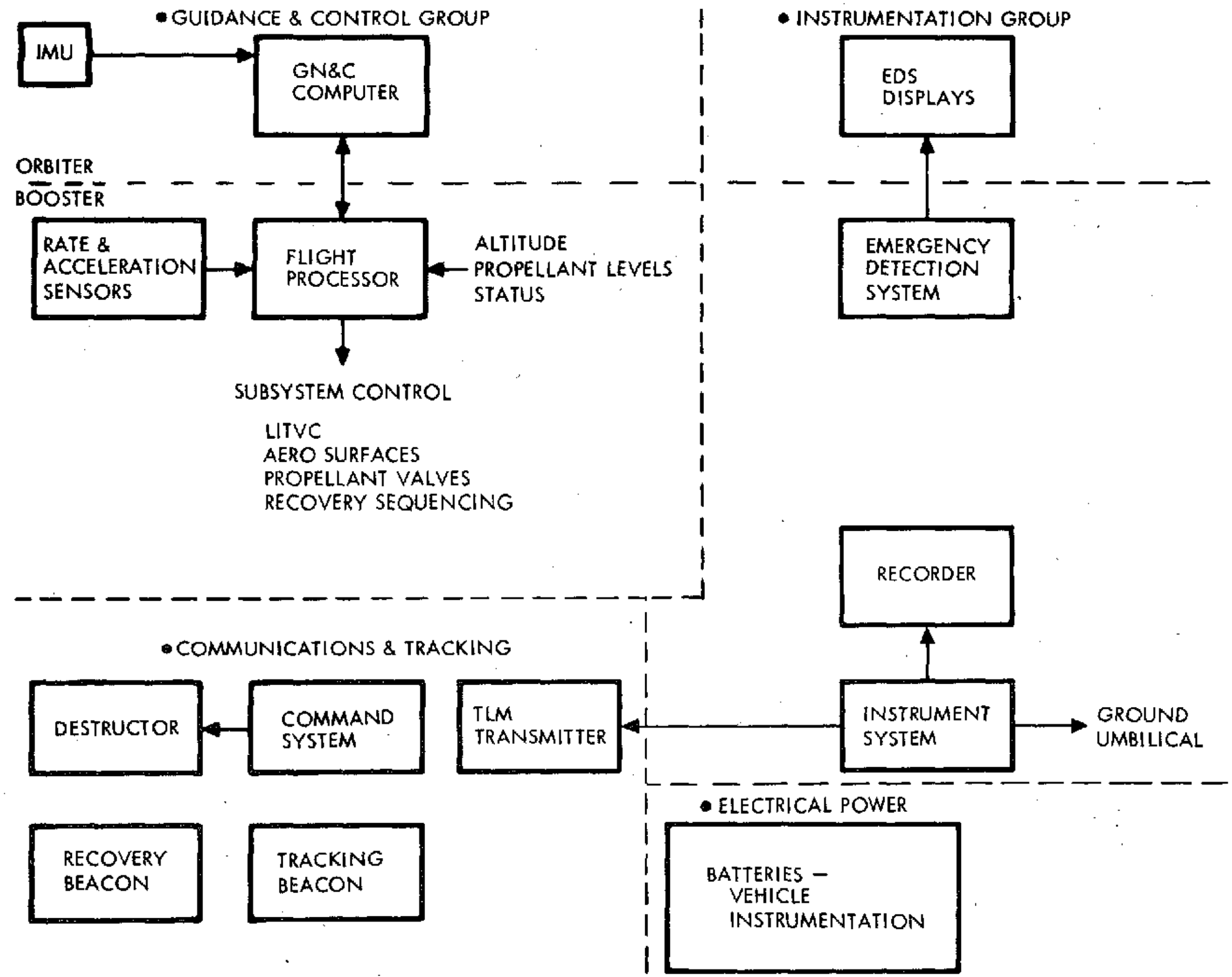


Figure 3-20. PFB Avionics System, SPFB

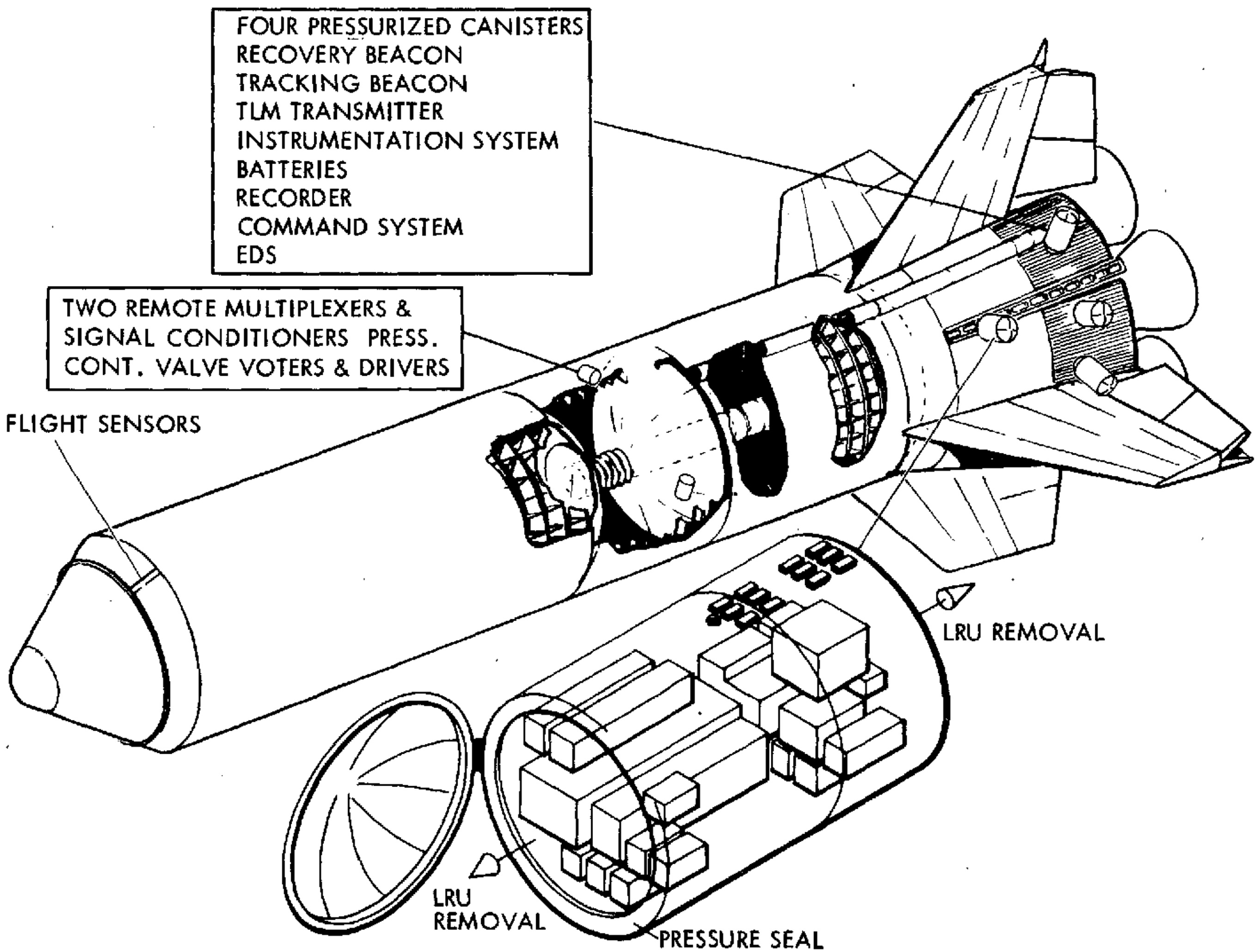


Figure 3-21. Avionics System Installation, SPFB

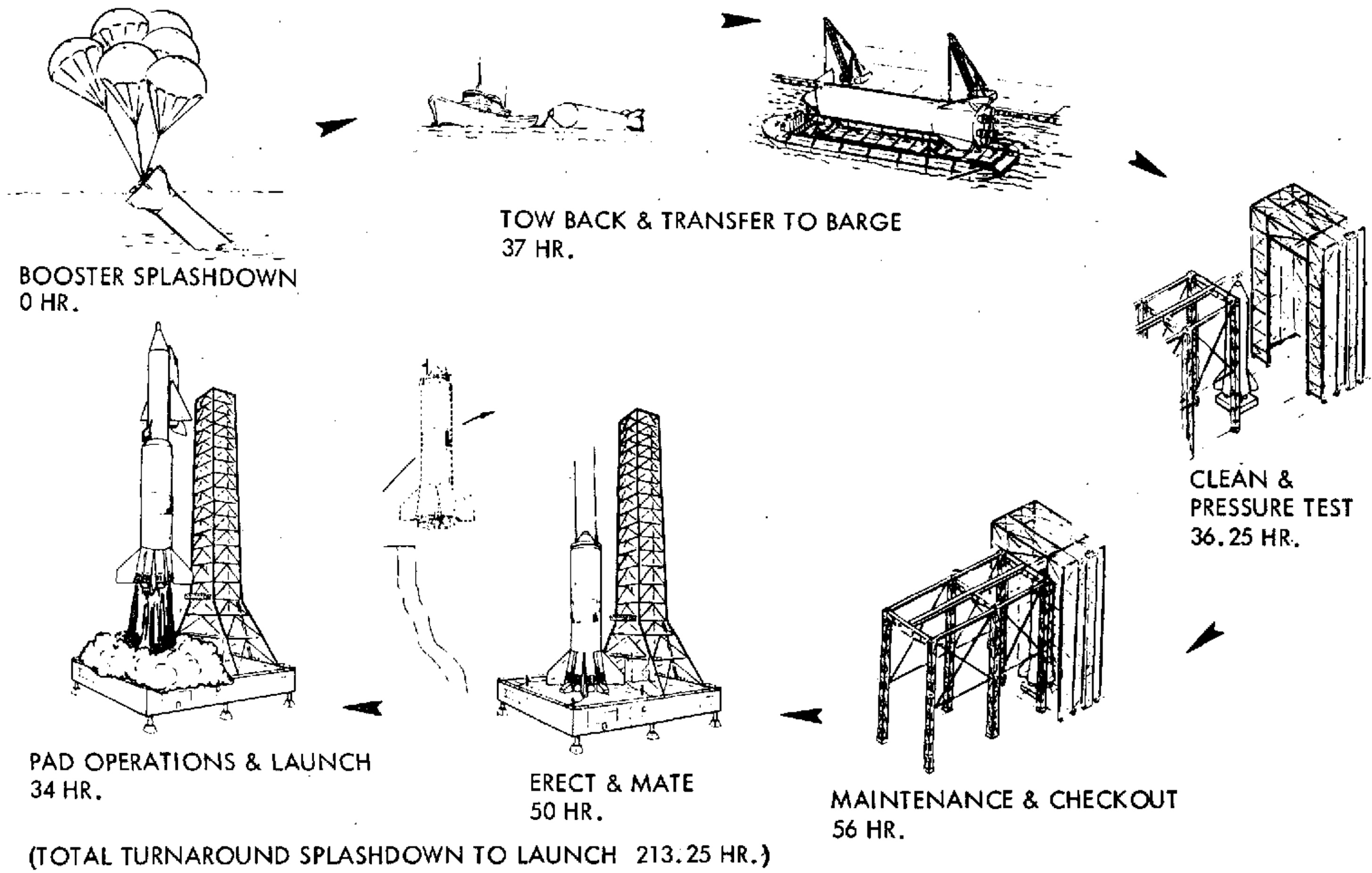


Figure 3-22. Summary Timeline, SPFB

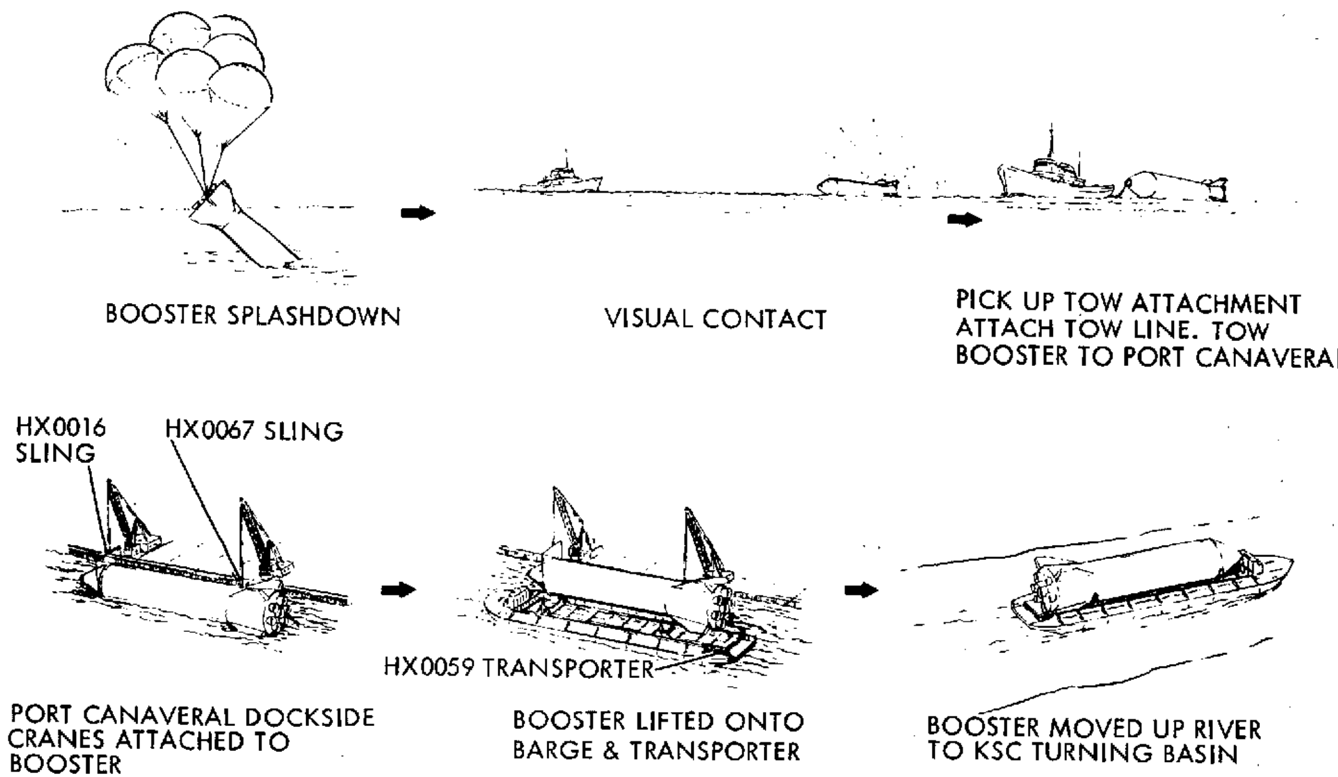


Figure 3-23. KSC Retrieval Concept, SPFB

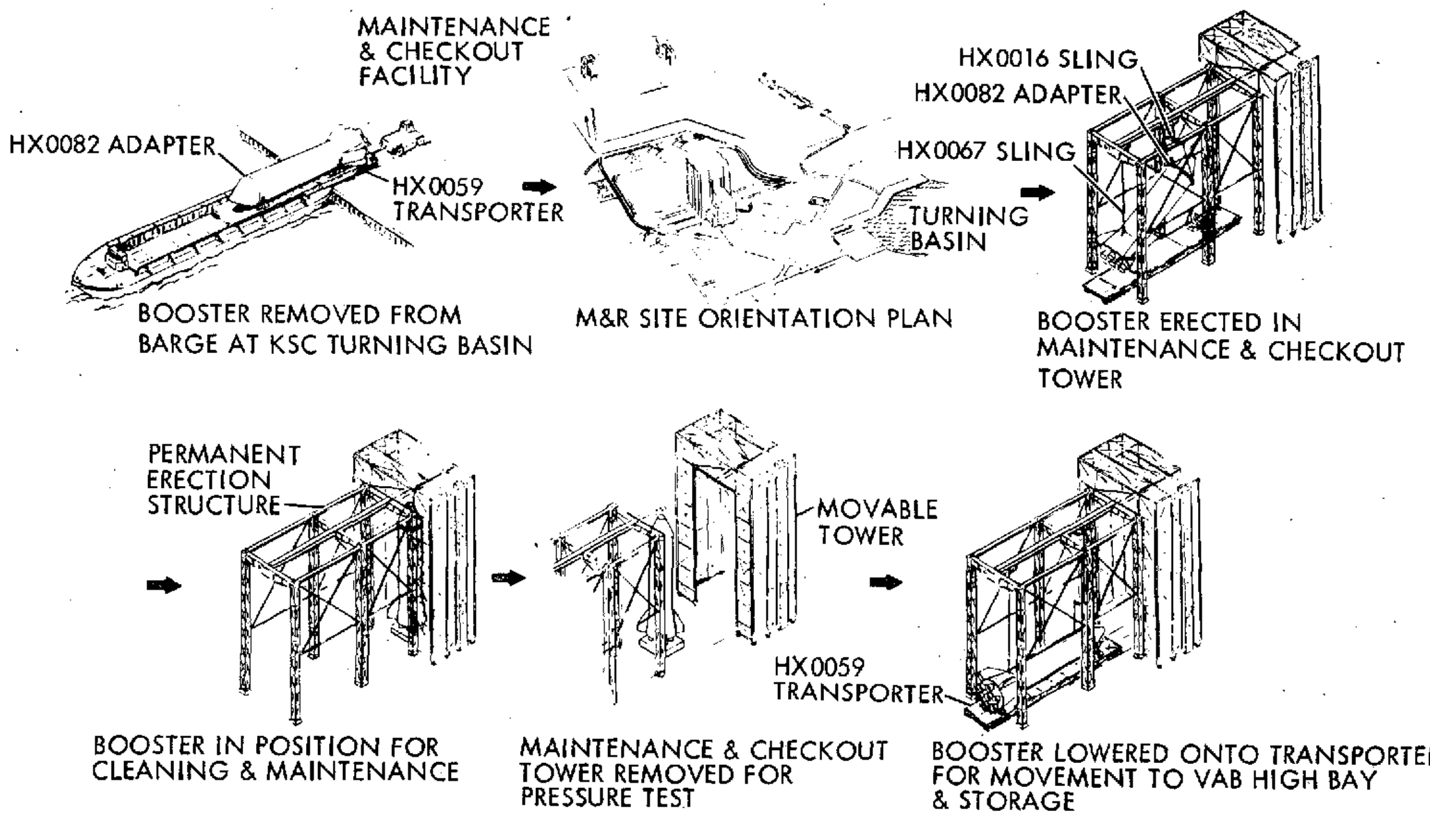


Figure 3-24. KSC Maintenance/Refurbish Concept, SPFB

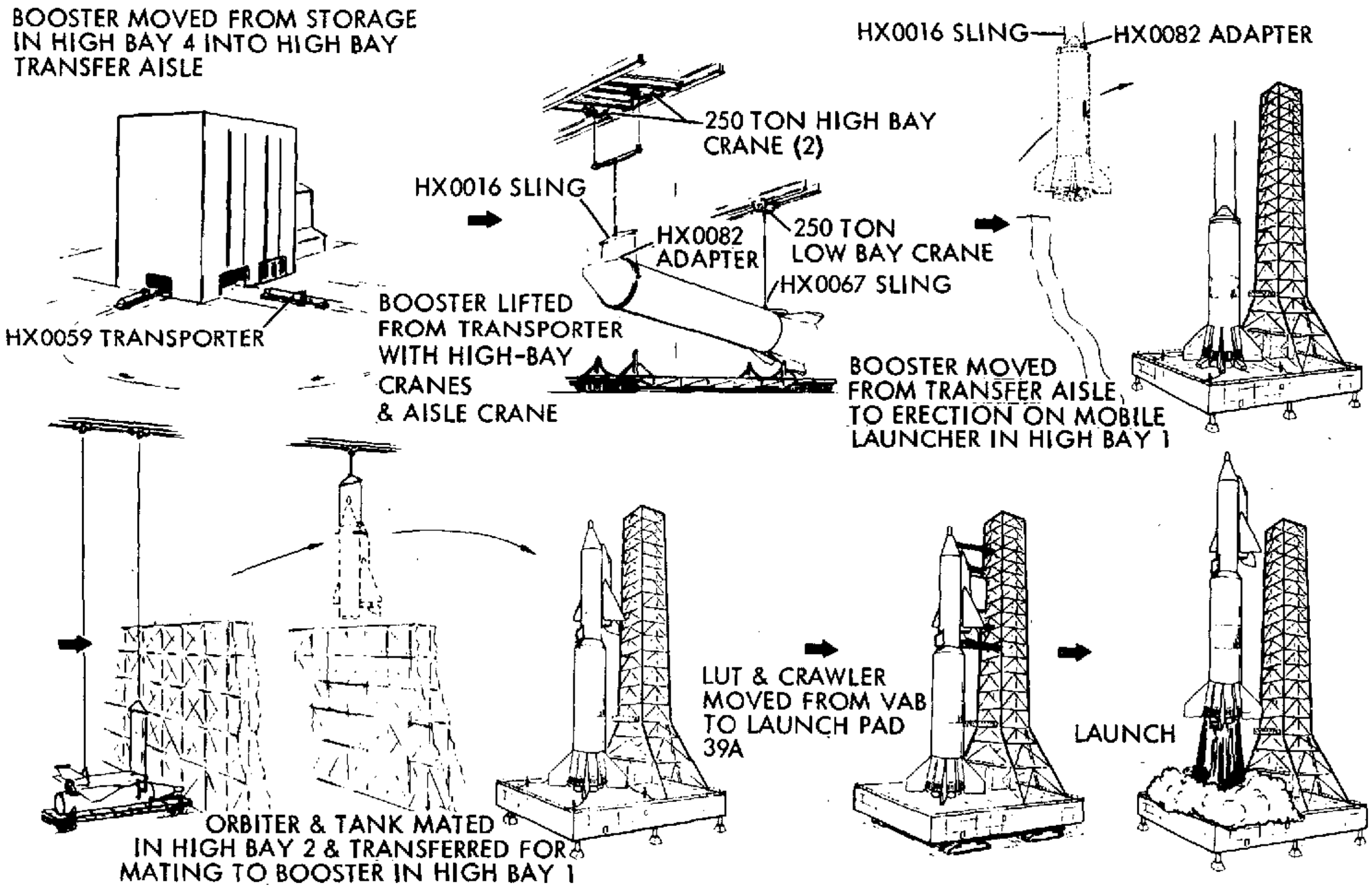


Figure 3-25. KSC Mate/Erect/Launch Concept, SPFB

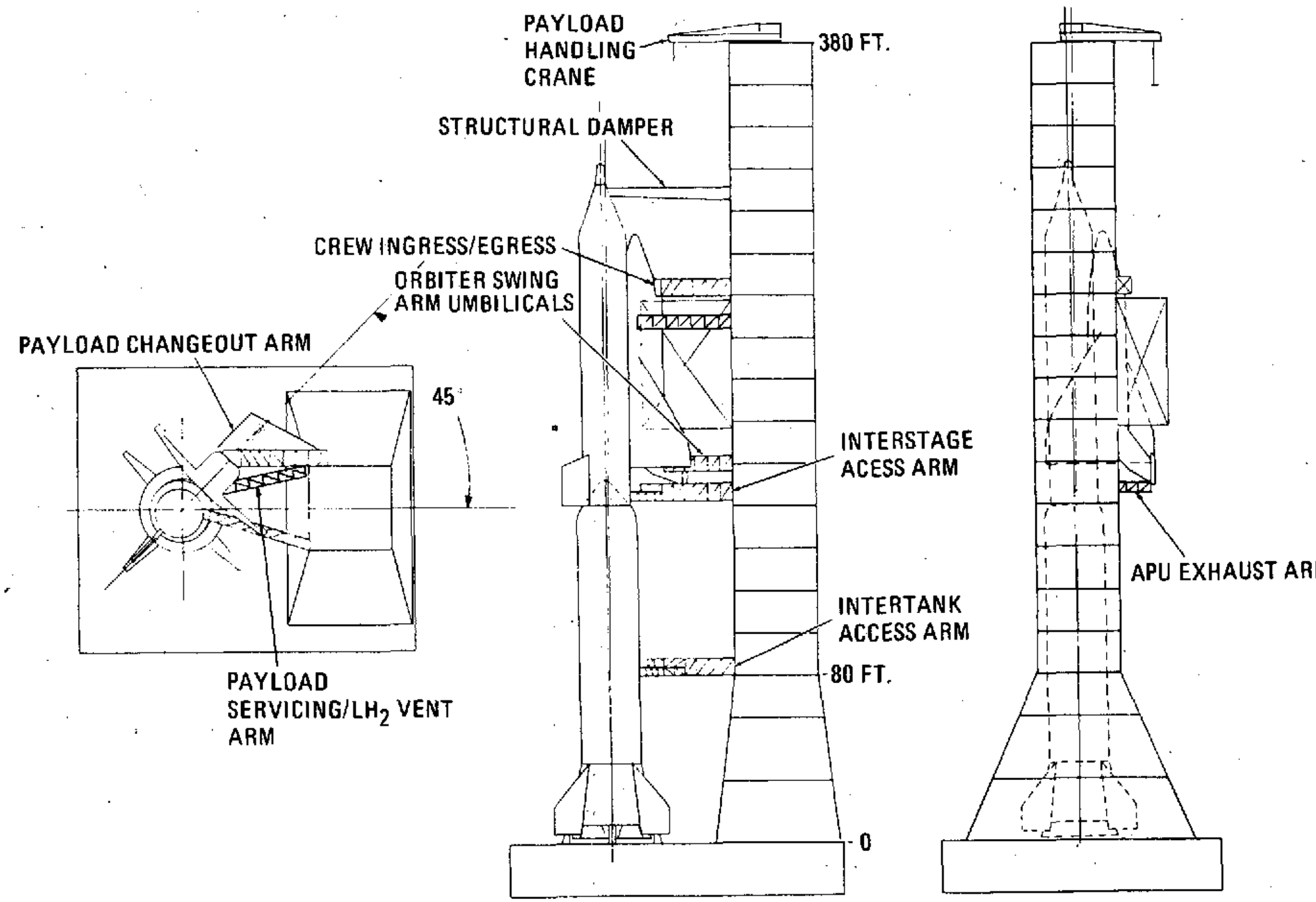


Figure 3-26. Launch Pad Configuration, SPFB

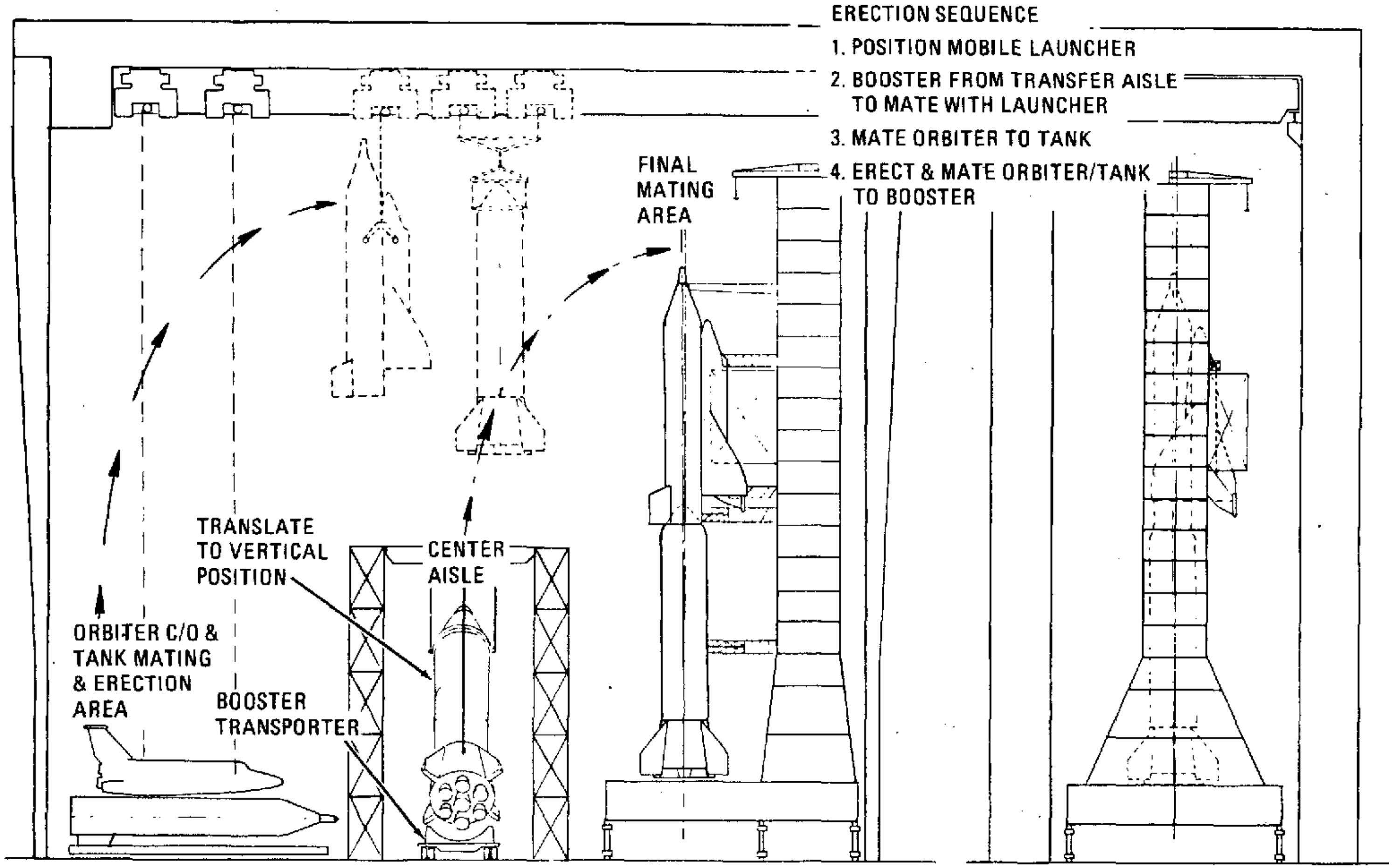


Figure 3-27. VAB Vertical Erection and Mate, SPFB

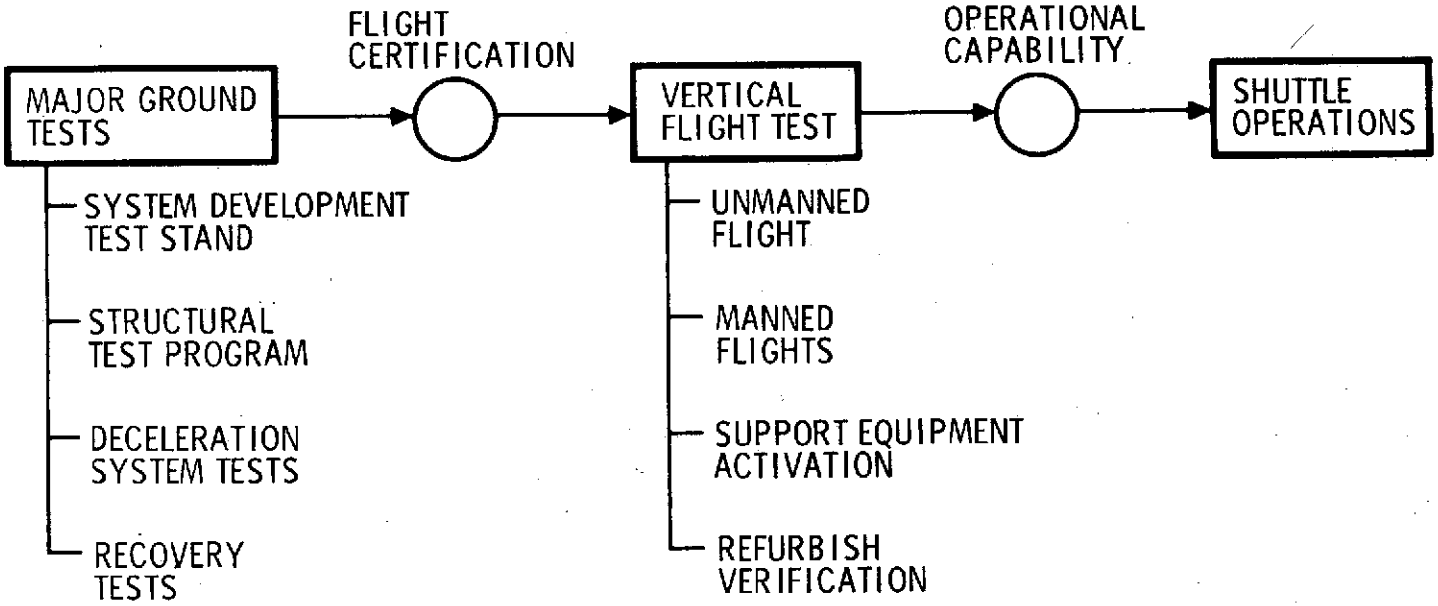


Figure 3-28. Booster Test Program, SPFB

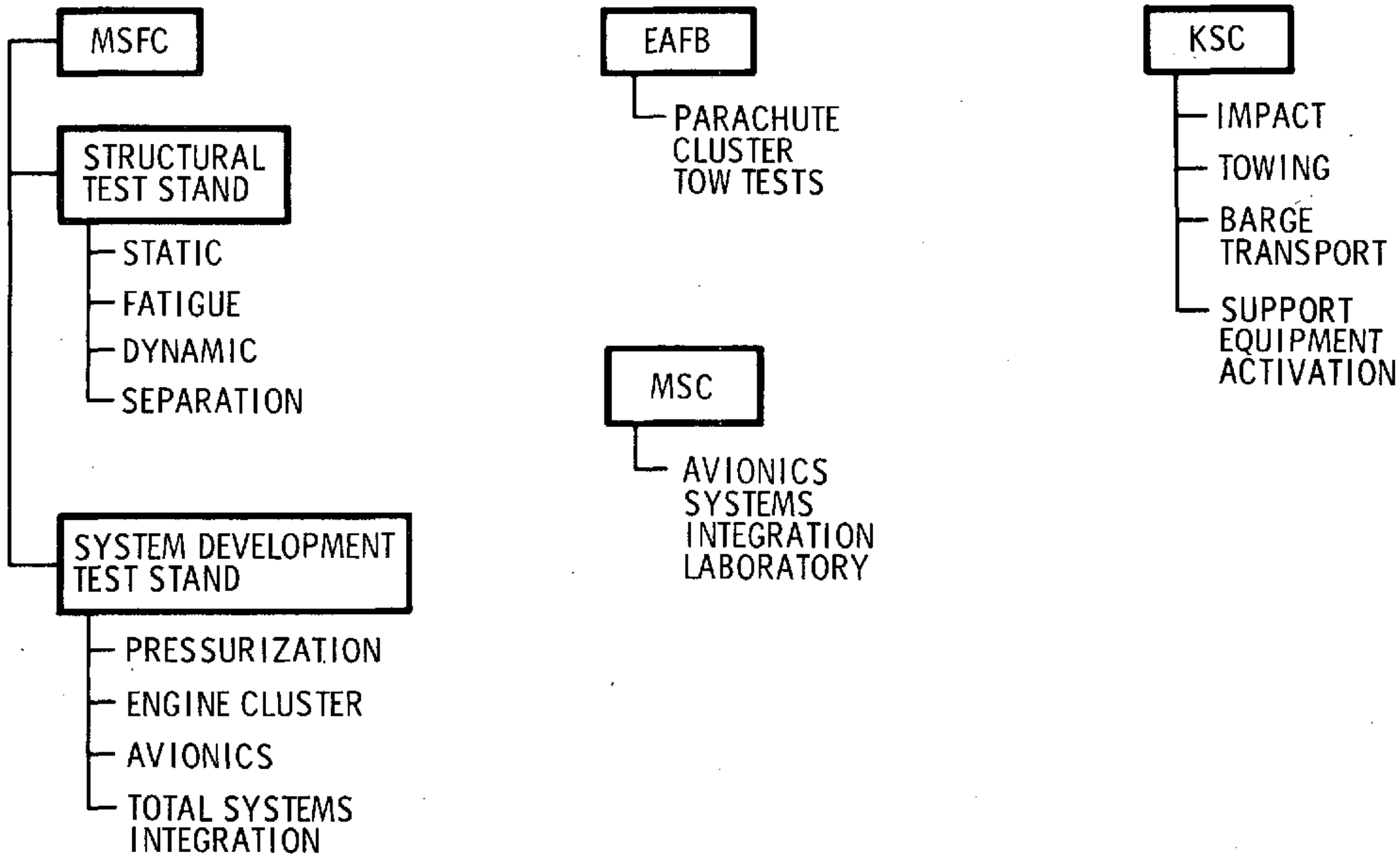


Figure 3-29. Major Ground Tests, SPFB

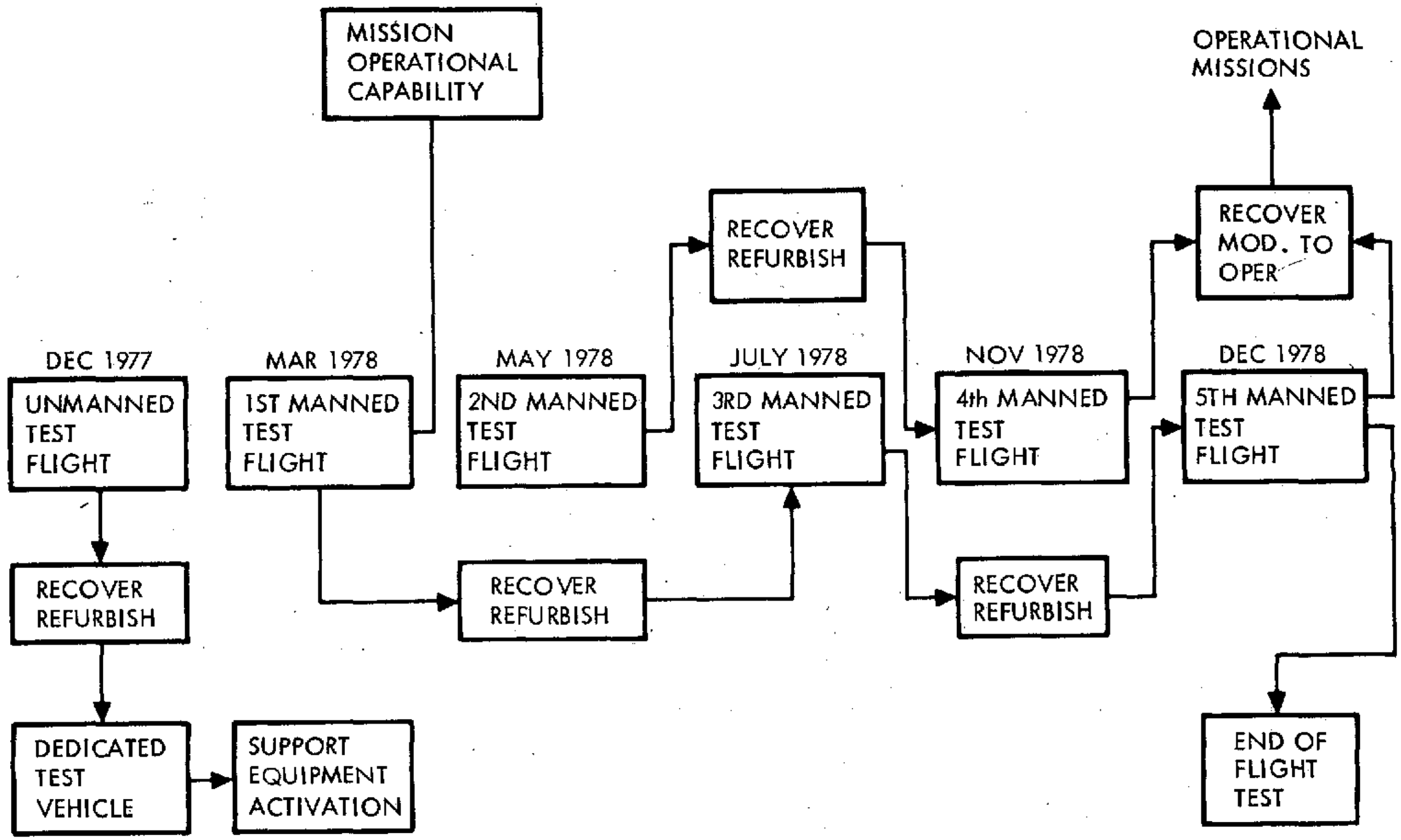


Figure 3-30. Vertical Flight Test Program, SPFB

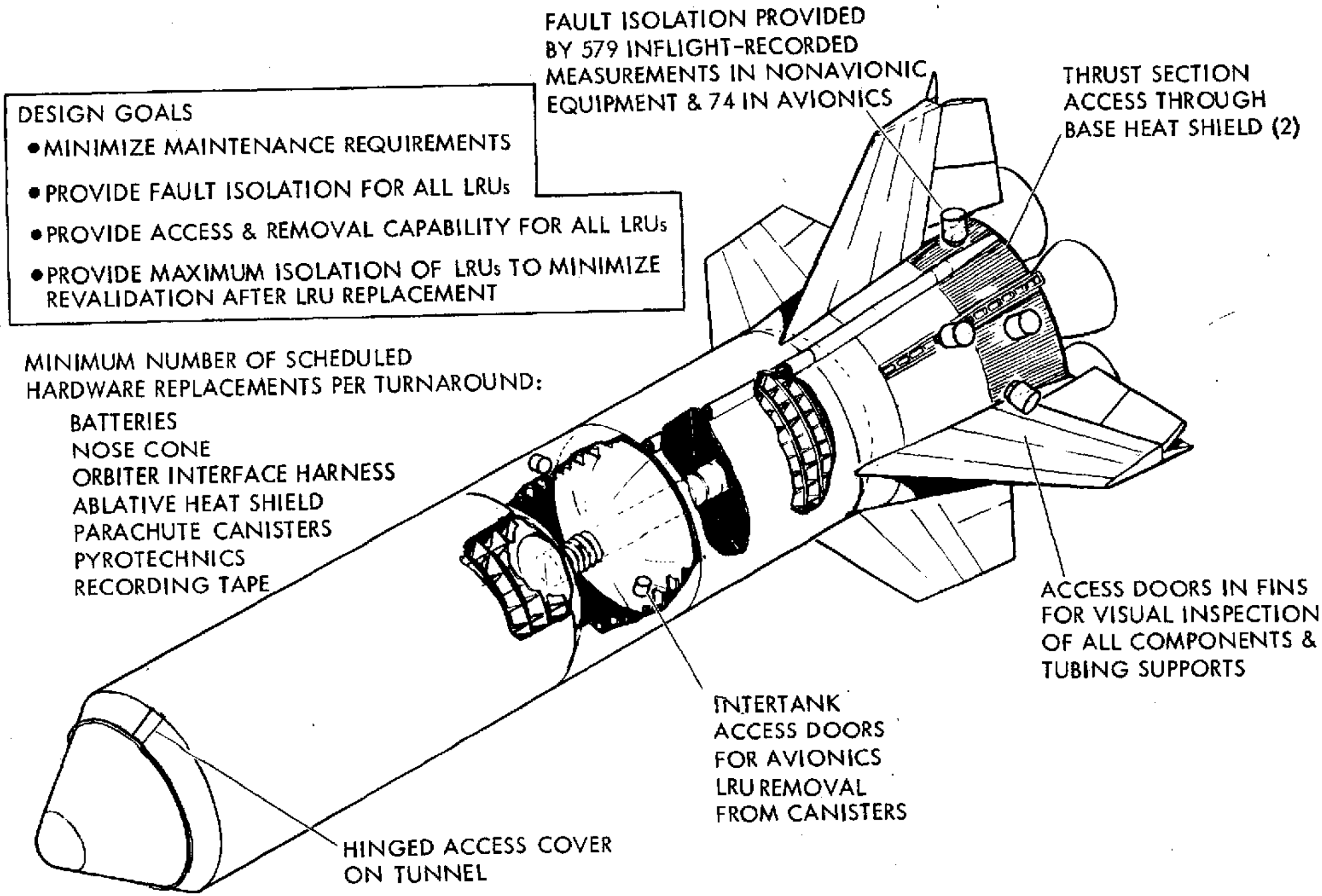


Figure 3-31. Maintainability Design Goals and Major Features, SPFB

WBS DESCRIPTION	COST $M	PLANNING FACTORS
NOSE	137.58	100% LOSS FRANGIBLE NOSE, 50% REPLACEMENT DEPLOYMENT SYSTEM
BASE HEAT SHIELD	127.36	ABLATIVE PANEL REPLACED EACH MISSION
MAIN ENGINE	56.59	NO RESTRICTIVE LIFE LIMIT, ONE UNSCHEDULED REMOVAL EVERY OTHER FLIGHT
PARACHUTES	40.83	15 TO 20% LOSS CHUTES
PROPELLANT UTILIZATION	19.78	20% REMOVAL ELECTRONIC CONTROL
INSTRUMENT	19.28	SIGNAL CONDITIONERS KEY ITEM AT 60% REMOVAL
THRUST STRUCTURE	15.13	SKIN PANELS 3% REMOVAL & 50% REPLACEMENT
GROUND SUPPORT EQUIPMENT	13.06	10% OF DEVELOPMENT & PRODUCTION COST
FAIRING	10.79	5% REMOVAL & 60% REPLACEMENT
OTHER	41.54	LARGELY PROPELLANT FEED, ELECTRICAL POWER & GN&C

KEY ASSUMPTIONS

- 12-MONTH SHELF STOCK OF REPAIR PARTS PROVIDED
- REMOVED UNITS WILL BE REPAIRED
- MAJOR STRUCTURAL ASSEMBLIES (FINS, TANKS, ETC.) DESIGNED FOR 100 MISSIONS; THEREFORE, LOW SPARES NEED
- SPARES QUANTIFICATION WILL BE DETERMINED AS DESIGN PROGRESSES

Figure 3-32. Operational Spares Requirements

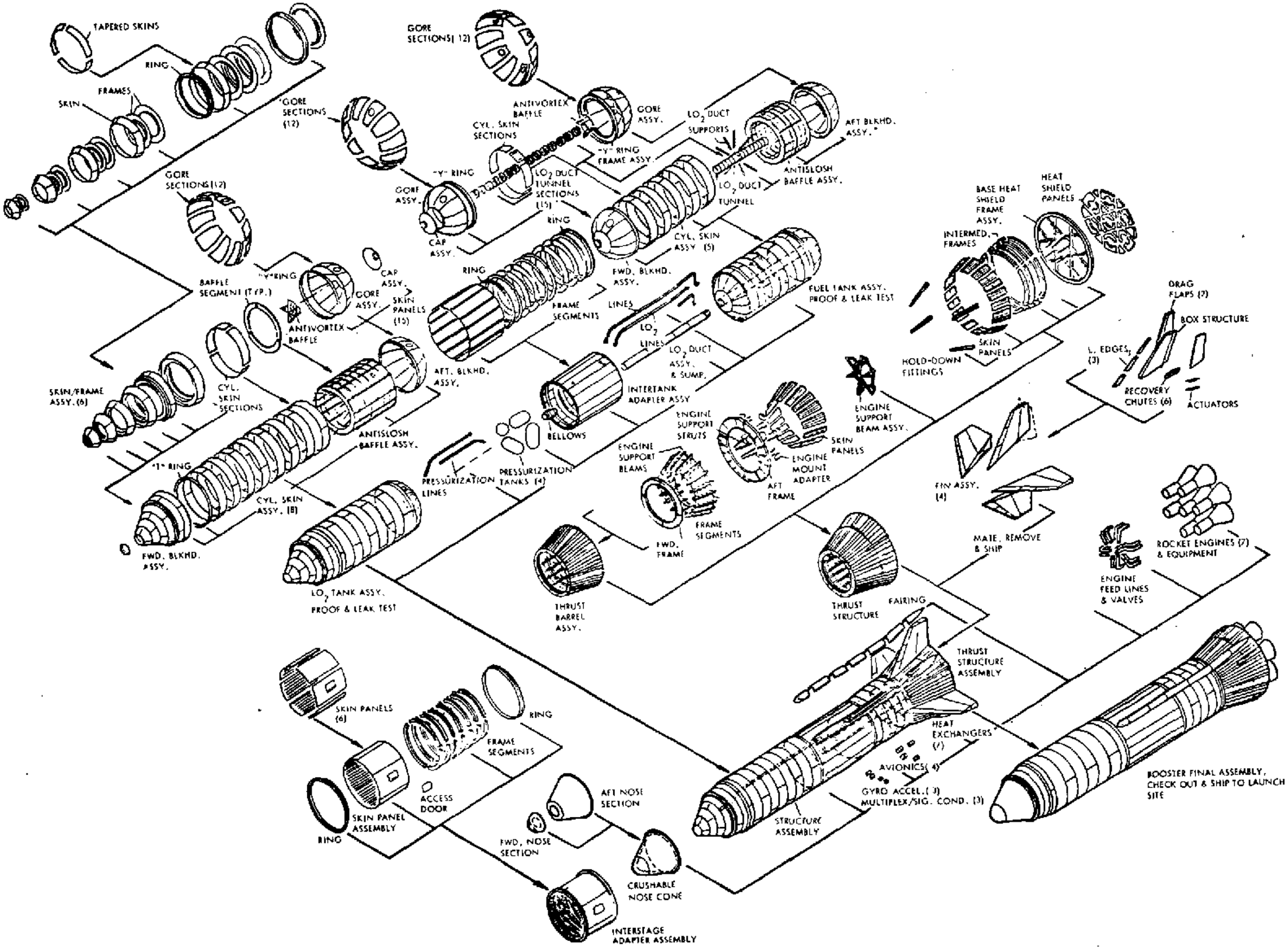


Figure 3-33. Manufacturing and Sequence Flow, SPFB B-19B8

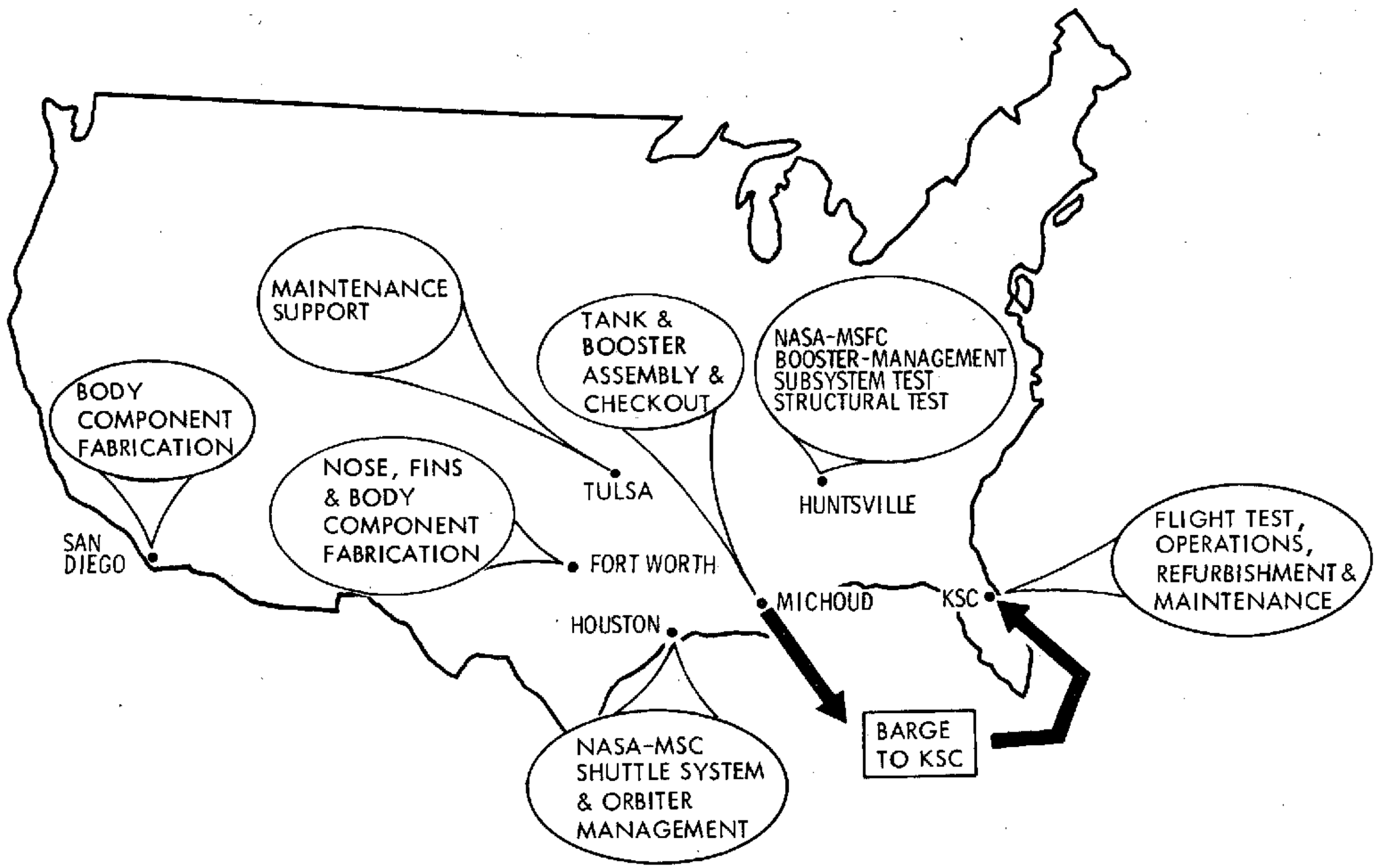


Figure 3-34. Graphic Dispersion of Manufacturing Tasks, SPFB

3.1.2 SRM (156 IN.) PARALLEL BURN

3.1.2 SRM (156 IN.) PARALLEL BURN

3.1.3 F-1 SERIES BURN — 4 ENG

3.1.4 F-1 SERIES BURN — 5 ENG

3.1.4 F-1 SERIES BURN — 5 ENG

3.1.2 Booster Description - SRM (156 in.)

The solid-rocket-motor (156 in.) booster is an expendable vehicle configured for a parallel arrangement with the orbiter and its external oxygen/hydrogen tank. The vehicle system is a parallel-burn type featuring a booster liftoff weight of 3,112,000 pounds with a staging velocity of 5,333 fps. Both normal separation and abort considerations drive the configuration arrangement.

The booster arrangement features two SRMs (156 in.) attached to the external oxygen/hydrogen tank. A nose enclosure structure, attachment, and separation system are provided for the SRM booster system. Gimbaled nozzles are provided for control. Aft thrust termination ports are provided to reduce the thrust for abort capabilities. A malfunction detection system is also provided for motor monitoring. Figure 3-35 illustrates this configuration. Table 3-3 defines system summary. Table 3-4 defines system growth comparison. Table 3-5 defines system weights.

3.1.3 Booster Description - Series Pump-Fed - Four Engines

The pump-fed booster is a reusable vehicle configured for a tandem arrangement with the orbiter and its external oxygen/hydrogen tank. The vehicle system is a series-burn type featuring a booster liftoff weight of 4,032,000 pounds, a staging velocity of 5889 fps, and a subsonically deployed parachute recovery system. The recovery weight is 460,000 pounds. The booster arrangement features sizing and configuration for commonality with Saturn S-1C to utilize existing technologies, tooling, and components. The after end features an engine protection closure and four fins. The main propulsion system uses four uprated F-1 engines with gimbaled nozzles. The propellant is LO_2/RP.

Figure 3-36 illustrates the configuration. Table 3-6 defines system summary. Table 3-7 defines growth comparison. Table 3-8 defines system weights.

3.1.4 Booster Description - Series Pump-Fed - Five Engines

The pump-fed booster is a reusable vehicle configured for a tandem arrangement with the orbiter and its external oxygen/hydrogen tank. The vehicle system is a series burn type featuring a booster liftoff weight of 4,187,000 pounds, a staging velocity of 5890 fps, and a subsonically deployed parachute recovery system. The recovery weight is 500,000 pounds. The series pump-fed booster study using five engines was accomplished to define a configuration capable of liftoff with one engine out with present F-1 engines.

FOLDOUT FRAME

FOLDOUT FRAME 2

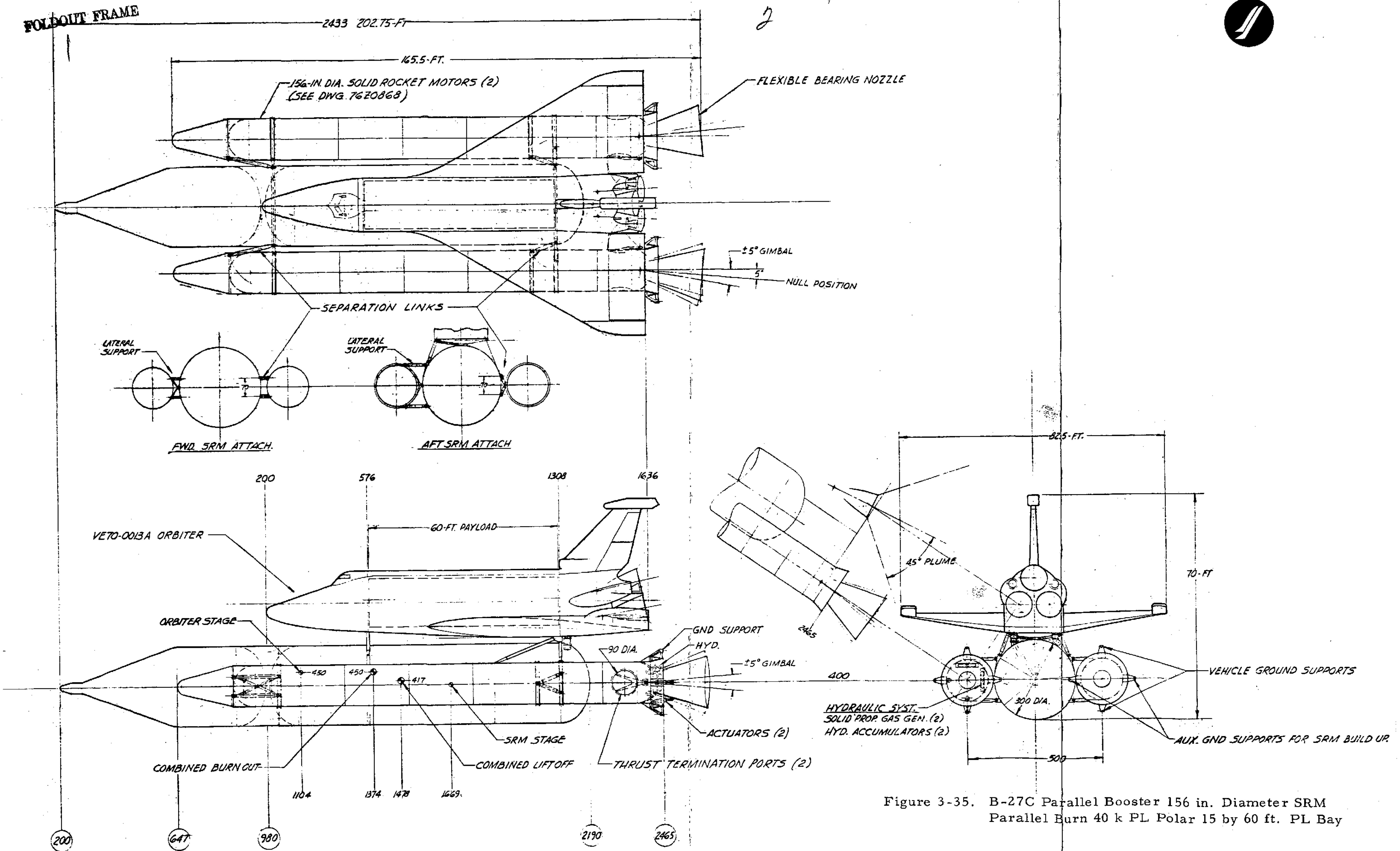


Figure 3-35. B-27C Parallel Booster 156 in. Diameter SRM Parallel Burn 40 k PL Polar 15 by 60 ft. PL Bay

Table 3-3. System Summary

System	156 inch SRM Parallel Burn (Final Configuration)	Payload Weight 40 k lb Polar Payload Bay Size 15 ft diameter by 60 ft

Item	Units	Design Point
Gross Liftoff Weight	M lb	4.898
Booster Gross Weight	M lb	3.112
Booster Ascent Propellant	M lb	2.740
Orbiter Gross Weight**	M lb	1.785
Orbiter Weight at Staging	M lb	1.400
Orbiter Ascent Propellant	M lb	1.392
Orbiter Spacecraft Weight	k lb	176
Orbiter Tank Weight (burnout)	k lb	90.0
Relative Staging Velocity	fps	5333
Staging Flight Path Angle	deg	26
Staging Dynamic Pressure	psf	43
Staging Altitude	kft	154.6
Maximum Dynamic Pressure	psf	653
SL Thrust/Booster Engine	M lb	2.939
Vac Thrust/Orbiter Engine	k lb	470
No. Engines Booster	-	2 Elements
No. Engines Orbiter	-	3
T/W at Liftoff	-	1.423
T/W Orbiter at Staging*	-	1.44
Booster Burn Time	sec	130.1
Maximum q Limited by Grain Shaping		

*Includes abort rocket thrust
**Includes abort rocket weight

Remarks: Has 10% extra growth capability in orbiter spacecraft weights.

Synthesis Ref: SS-20-3T15

Three-view drawing 76Z0864

3.2.1 PFB PARALLEL BURN

3.2.1 PFB PARALLEL BURN

Table 3-4. Effect of Growth on 156-Inch SRM Parallel-Burn System

40k PL 40k Down 15- by 60-foot PL Bay	Units	Baseline		No Growth Provisions
		Impending* Growth	Including Growth	
Overall Contingency ($B - B_{Attach} - O_{Tank} - O_{RV}$)	%	10-10-2-10	-20-2-20	10-10-2-10
Staging Velocity	fps	5333	4610	4747
GLOW	M lb	4.898	5.123	4.765
BLOW	M lb	3.112	3.116	2.899
OLOW	M lb	1.785	2.007	1.866
$W_{Booster\ Dry}$	k lb	342	345	324
$W_{Orbiter\ Tank\ (BO)}$	k lb	90.0	99.7	92.8
$F_{SL/Boost\ Element}$	M lb	2.939	3.074	2.852

*Current design point.

The booster arrangement features sizing and configuration for commonality with Saturn S-1C to utilize existing technologies, tooling, and components. The aft end features an engine protection closure and four fins.

The main propulsion system uses five F-1 engines with gimbaled nozzles. The propellants are LO_2/RP.

Figure 3-37 illustrates the configuration. Table 3-9 defines system summary, and Table 3-10 defines the weight.

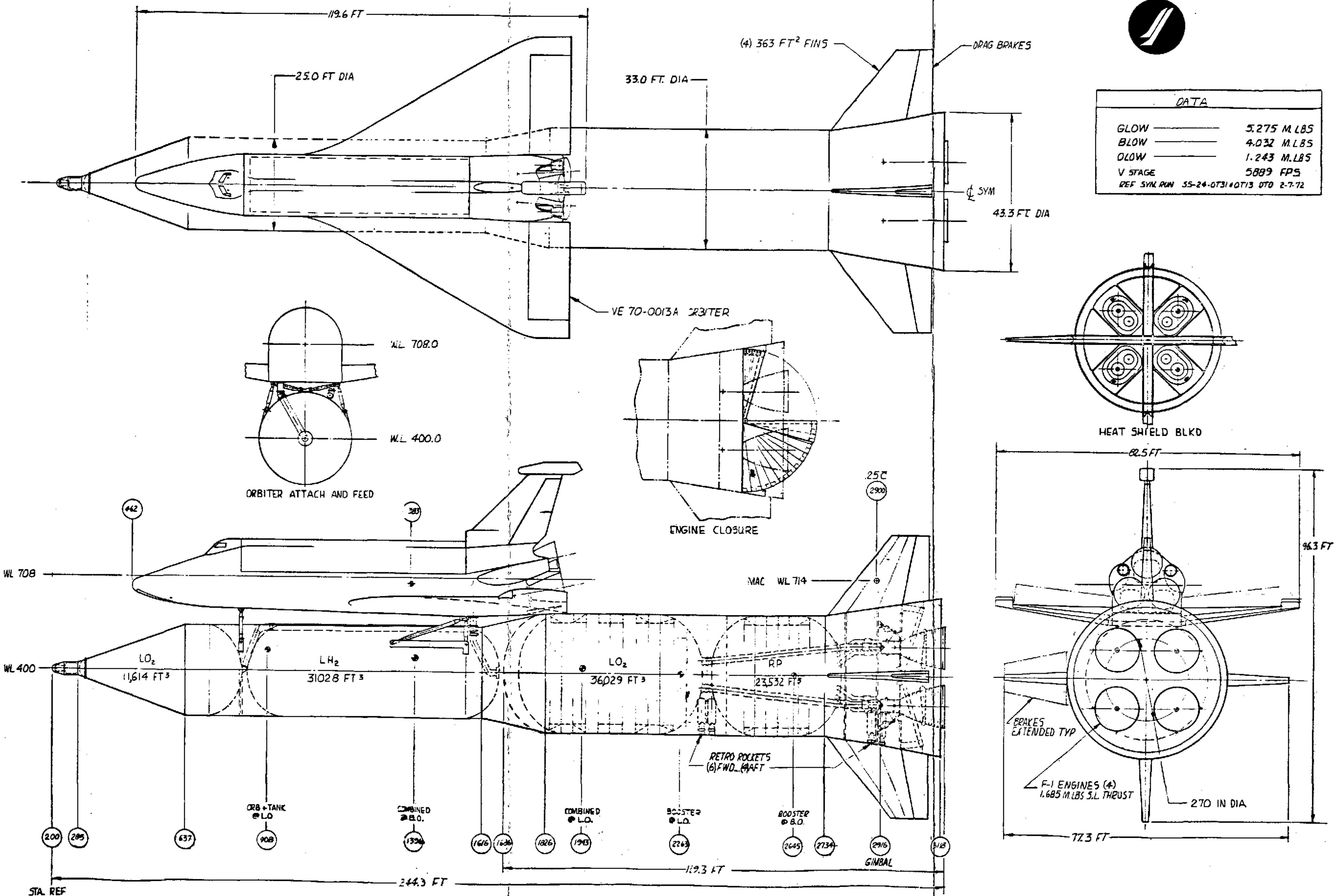
3.2 OTHER STUDIES

3.2.1 Pressure-Fed Booster - Parallel

Figure 3-38 illustrates this configuration. Table 3-11 presents the system summary.

Table 3-5. 156-Inch SRM Booster, Parallel - Two Elements, Weight Summary

	Weight (lb)
Motor Cases (including reinforcing rings)	182,878
TVC System (gimbal, including actuator fairings)	7,620
Nozzles	39,139
Liner and Insulation	24,766
External Insulation	2,804
Thrust Termination	2,611
Igniters	1,165
Electrical and Instrumentation	2,196
Nose Cones	3,600
Forward Skirt	16,840
Aft Skirt and Pad Supports	22,700
Attach/Separation Links and Mechanisms, fwd	2,346
Attach/Separation Links and Mechanisms, aft	2,244
Growth (10% of above)	31,091
Dry Weight	342,000
Igniter Charges	500
APU Propellant	200
Hydraulic Fluid	500
Residual Propellant	28,800
Ascent Propellant	2,740,000
Booster Liftoff Weight	3,112,000



DATA	
GLOW	5.275 M LBS
BLOW	4.032 M LBS
OLOW	1.243 M LBS
V STAGE	5889 FPS
REF SYN RUN 55-24-0T31 40T13 DTO 2-7-72	

Figure 3-36. B24-B General Arrangement F-1 Ballistic Recoverable Pump Fed Booster

FOLDOUT FRAME

FOLDOUT FRAME

Table 3-6. System Summary

System	F-1 Pump-Fed, Ballistic Recoverable (4 eng)	Payload Weight 40k lb Polar Payload Bay Size 15 ft diameter by 60 ft

Item	Units	Design Point
Gross Liftoff Weight	M lb	5.274
Booster Gross Weight	M lb	4.032
Booster Ascent Propellant	M lb	3.517
Orbiter Gross Weight**	M lb	1.242
Orbiter Weight at Staging	M lb	1.242
Orbiter Ascent Propellant	M lb	0.867
Orbiter Spacecraft Weight	k lb	176
Orbiter Tank Weight (burnout)	k lb	70.1
Relative Staging Velocity	fps	5889
Staging Flight Path Angle	deg	25
Staging Dynamic Pressure	psf	5
Staging Altitude	kft	219.5
Maximum Dynamic Pressure	psf	648
SL Thrust/Booster Engine	M lb	1.648
Vac Thrust/Orbiter Engine	k lb	470
No. Engines Booster	-	4
No. Engines Orbiter	-	3
T/W at Liftoff	-	1.25
T/W Orbiter at Staging*	-	1.62 (1.13 w/o abort rockets)
Booster Burn Time	sec	166

*Includes abort rocket thrust
**Includes abort rocket weight

Synthesis Ref: SS-24-0T31

Remarks: Has 10% extra growth capability in orbiter spacecraft and booster dry weights

Three-view drawing 76Z0862

3.2.2 SRM PARAMETRIC STUDY

3.2.2 SRM PARAMETRIC STUDY

Table 3-7. Effect of Growth on Four F-1 Pump-Fed System

40k PL 40k Down 15- by 60-foot PL Bay	Units	Baseline		No Growth Provisions
		Impending Growth*	Including Growth	
Overall Contingency ($B - B_{Attach} - O_{Tank} - O_{RV}$)	%	10-10-2-10	-20-2-20	10-10-2-10
Staging Velocity	fps	5889	4655	4563
GLOW	M lb	5.274	5.617	4.878
BLOW	M lb	4.032	4.062	3.393
OLOW	M lb	1.242	1.555	1.485
$W_{Booster\ Dry}$	k lb	430	457	380
$W_{Orbiter\ Tank\ (BO)}$	k lb	70.1	87.7	84.3
$F_{SL/Boost\ Element}$	M lb	1.65	1.68	1.52

*Current Design Point

3.2.2 SRM Parametric Study

The configurations shown in this section were developed for comparison of 156-inch SRM versus 120-inch SRM, parallel versus series burn, and 40k pound Polar versus 45k East Launch missions. The parallel systems are similar in general concept to the 156-inch SRM described previously. The tandem systems consist of clustered SRM elements with an adapter attaching to the end-loaded orbiter tank. The effect of fins versus no-fins was explored on some of the series-burn, tandem-stage candidates for the effect on performance. In general the cost in gross liftoff weight (GLOW) is about +2% (for adding fins to give neutral upflight stability at all times) and about +7% in booster system dry weight.

The use of 120-inch SRMs leads to a large number of elements that appear to be unwieldy, especially in the parallel-staged case where separation from the orbiter tank becomes a problem. This is one of the major reasons for selection of the 156-inch SRM systems as ongoing candidates.

Table 3-8. F-1 Pump-Fed Ballistic Weight Summary

	4 Engine
Fins, Drag Flaps, Actuation	39,647
Fuel Tank	32,755
Oxidizer Tank	46,948
Nose Structure and Retrieval System	13,563
Intertank	12,952
Thrust Structure, Hold-Downs	18,845
Aft Skirt	31,728
Raceways, Fairings, Separation System	1,500
Base Heat Protection	9,554
Aft Closure System	12,759
Parachutes, Landing Rockets	51,000
Engines, Accessories, TVC	78,608
Propellant Systems	39,852
ACS	2,334
Electronics, Avionics, ECS	5,800
Growth (10%, excluding bare engines)	31,923
Dry Weight	429,768
Residual Fuel	23,842
Residual Oxidizer	28,308
Hydraulic Fluid	876
ACS Propellants	2,500
Thrust Decay Propellants	20,376
Main Impulse Propellants	3,516,504
Booster Liftoff Weight	4,022,174
Adapter	10,100
Booster, Including Adapter	4,032,274
Water Impact Weight	460,000

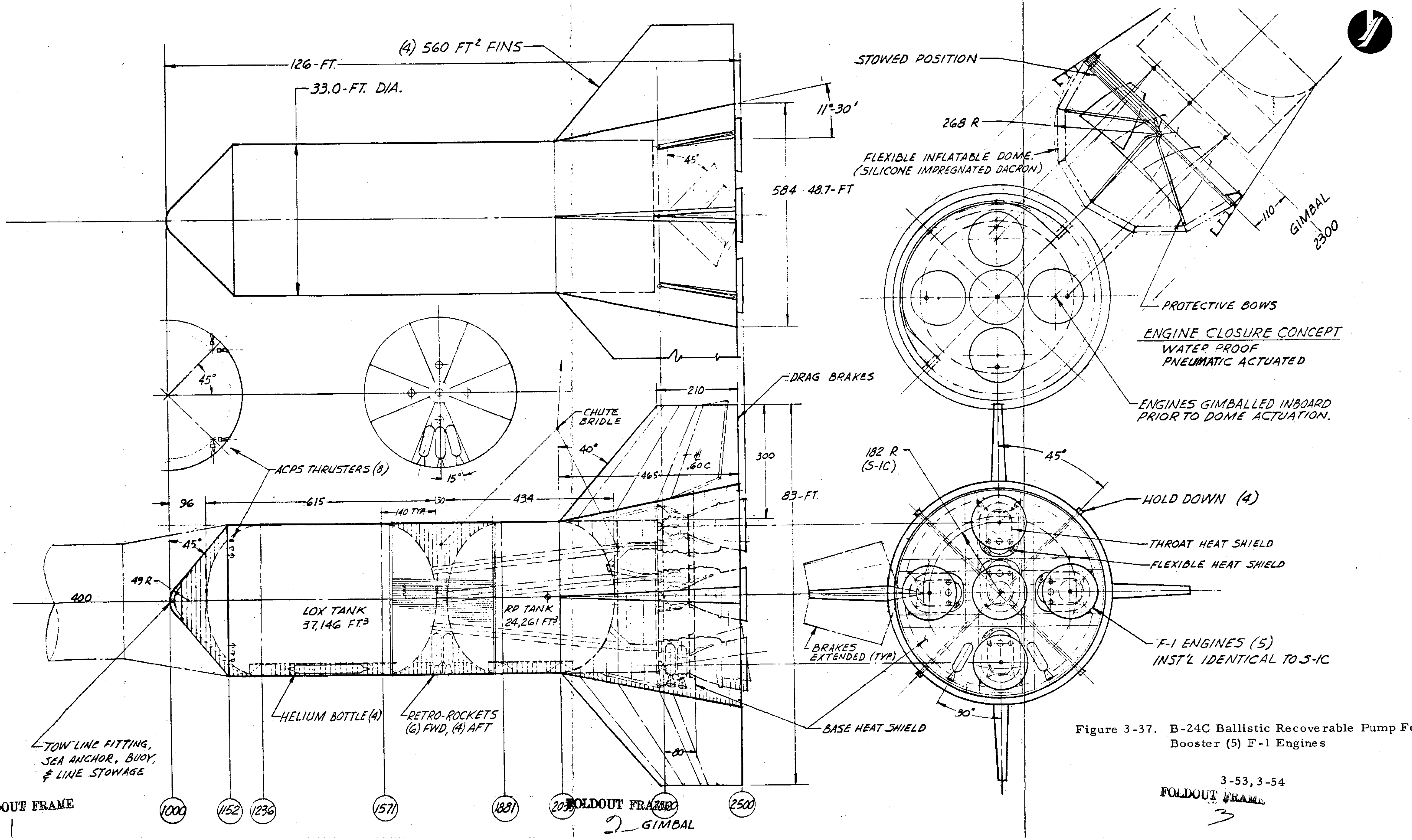


Figure 3-37. B-24C Ballistic Recoverable Pump Fed Booster (5) F-1 Engines

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

Table 3-9. System Summary

System	F-1 Pump-Fed, Ballistic Recoverable (5 Eng.)	Payload Weight 40k lb Polar Payload Bay Size 15 ft diameter by 50 ft
Item	**Units**	**Design Point**
Gross Liftoff Weight	M lb	5.429
Booster Gross Weight	M lb	4.187
Booster Ascent Propellant	M lb	3.626
Orbiter Gross Weight**	M lb	1.242
Orbiter Weight at Staging	M lb	1.242
Orbiter Ascent Propellant	M lb	0.867
Orbiter Spacecraft Weight	k lb	176
Orbiter Tank Weight (burnout)	k lb	70.1
Relative Staging Velocity	fps	5890
Staging Flight Path Angle	deg	25
Staging Dynamic Pressure	psf	5
Staging Altitude	kft	219.5
Maximum Dynamic Pressure	psf	650
SL Thrust/Booster Engine	M lb	1.455
Vac Thrust/Orbiter Engine	k lb	470
No. Engines Booster	-	5
No. Engines Orbiter	-	3
T/W at Liftoff	-	1.34
T/W Orbiter at Staging*	-	1.62 (1.13 w/o abort rockets)

*Includes abort rocket thrust
**Includes abort rocket weight

Synthesis Ref: 02/17/72

Remarks: Has 10% extra growth capability in orbiter spacecraft and booster dry weights

Three-view drawing 76Z0871

Table 3-10. F-1 Pump-Fed, Ballistic Weight Summary

	Weight (lb) (5 Engine)
Fins, Drag Flaps, Actuation	40,000
Fuel Tank	33,000
Oxidizer Tank	47,000
Nose Structure and Retrieval System	15,000
Intertank	13,000
Thrust Structure, Hold-Downs	20,000
Aft Skirt	45,000
Raceways, Fairings, Separation System	1,500
Base Heat Protection	10,000
Aft Closure System	15,000
Parachutes, Landing Rockets	55,000
Engines, Accessories, TVC	93,000
Propellant Systems	42,000
ACS	2,500
Electronics, Avionics, ECS	6,000
Growth (10%, excluding bare engines)	35,000
Dry Weight	473,000
Residual Fuel	24,000
Residual Oxidizer	29,000
Hydraulic Fluid	1,000
ACS Propellants	2,500
Thrust Decay Propellants	21,900
Main Impulse Propellants	3,625,500
Booster Liftoff Weight	4,176,900
Adapter	10,100
Booster, Including Adapter	4,187,000
Water Impact Weight	500,000

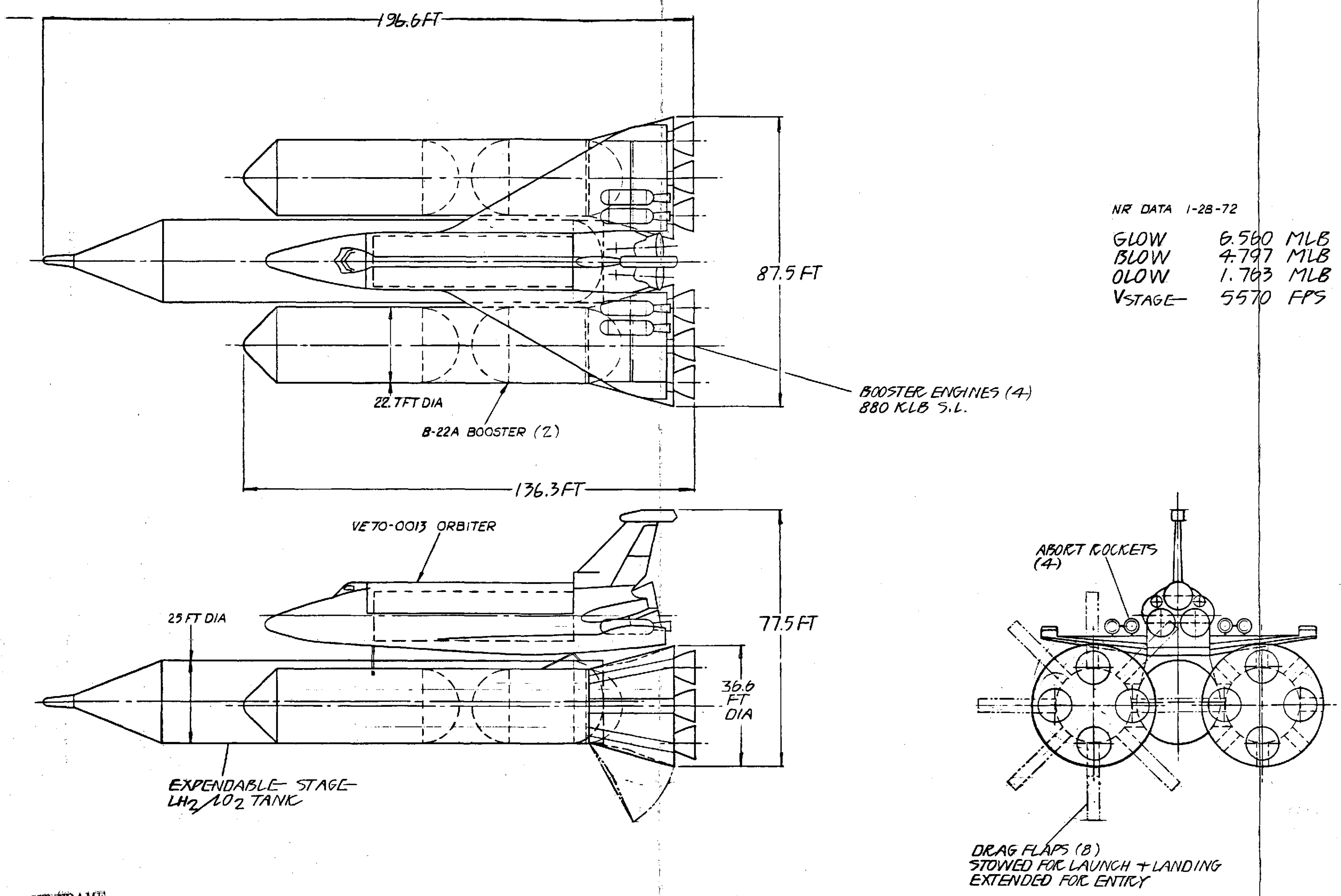


Figure 3-38. B-22A Twin Pressure Fed Booster - Parallel Burn NR LO_2/LH_2 External Tank Orbiter

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

Table 3-11. System Summary

System	Pressure Fed Booster Series	Payload Weight 40k lb Polar Payload Bay Size 15 ft diameter by 60 ft
Item	**Units**	**Design Point**
Gross Liftoff Weight	M lb	6.560
Booster Gross Weight	M lb	4.797
Booster Ascent Propellant	M lb	3.999
Orbiter Gross Weight**	M lb	1.763
Orbiter Weight at Staging	M lb	1.370
Orbiter Ascent Propellant	M lb	1.372
Orbiter Spacecraft Weight	k lb	176
Orbiter Tank Weight (burnout)	k lb	89
Relative Staging Velocity	fps	5570
Staging Flight Path Angle	deg	19.1
Staging Dynamic Pressure	psf	38
Staging Altitude	kft	160
Maximum Dynamic Pressure	psf	650
SL Thrust/Booster Engine	M lb	0.890
Vac Thrust/Orbiter Engine	k lb	470
No. Engines Booster	–	2 × 4
No. Engines Orbiter	–	3
T/W at Liftoff	–	1.25
T/W Orbiter at Staging*	–	1.517
		(1.06 w/o abort rockets)

*Includes abort rocket thrust
**Includes abort rocket weight

Remarks:

Synthesis Ref: NR 01/28/72

Three-view drawing 76Z0861

The selected design points were based on minimum system GLOW and dry weights after surveying the staging flightpath angle and system staging velocity ranges. The maximum dynamic pressure was constrained to 650 psf by grain shaping and proper selection of T/W at liftoff. Figure 3-39 shows an example.

The study matrix, system summary results, and layouts are contained in Tables 3-12 through 3-15 and Figures 3-40 through 3-47.

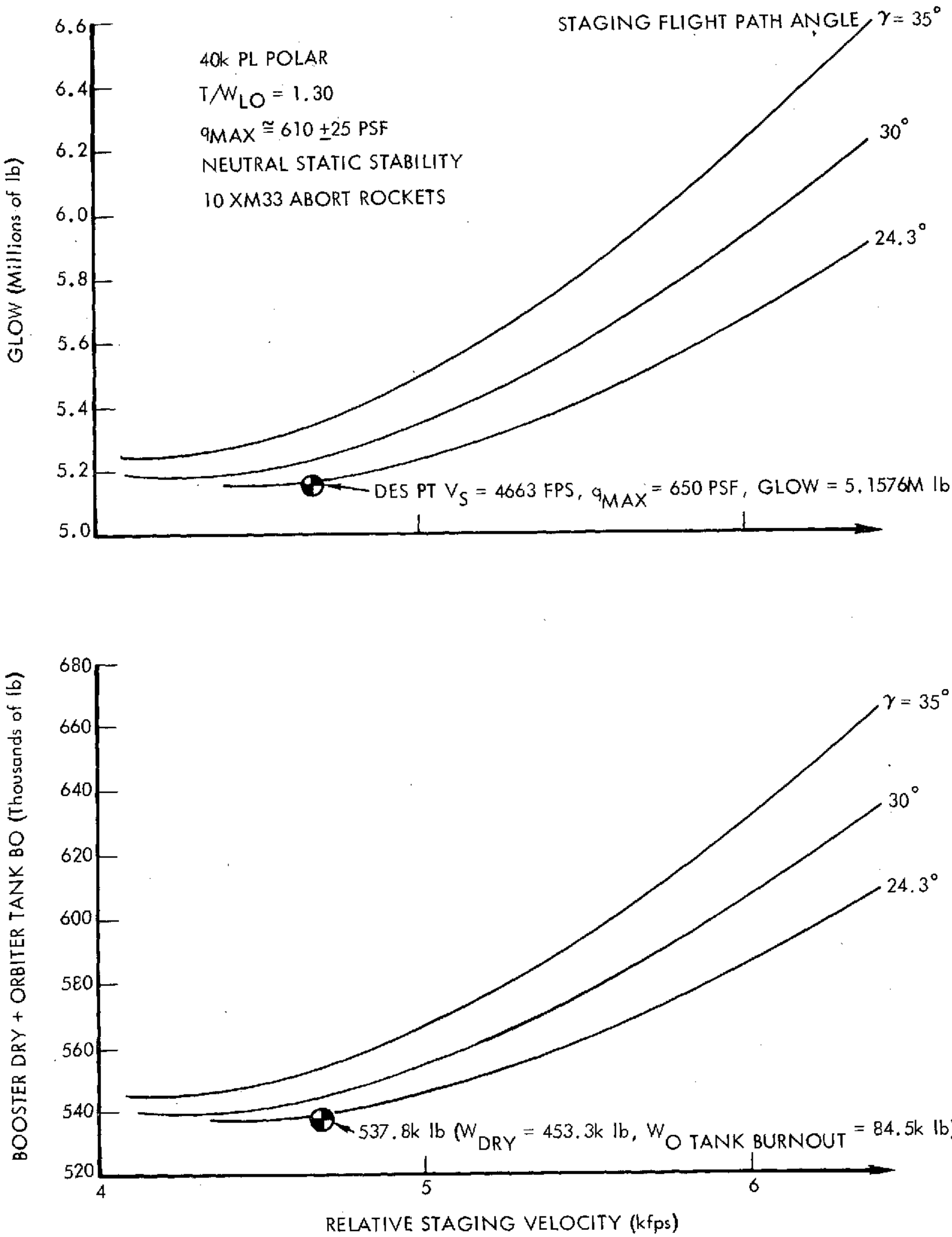


Figure 3-39. Series Burn 156-Inch SRM System GLOW and Dry Weight Versus Staging Velocity and Flight Path Angle

Table 3-12. SRM Booster Sizing

Ground Rules

- 40k Polar is critical mission
- 45k PL East is alternative mission

		Series Burn				Parallel Burn			
120-Inch Diameter	40k Polar	GLOW	5.541 M	V_s	4888 fps	GLOW	5.254M lb	V_s	5214 fps
		BLOW	4.134 M	γ_s	25 deg	BLOW	3.438M lb	γ_s	30 deg
		OLOW	1.407 M	Elements*	6/7	OLOW	1.816M lb	Elements	5/7
	45k East	GLOW	4.674 M	V_s	4654 fps	GLOW	4.357M	V_s	5198 fps
		BLOW	3.462 M	γ_s	30 deg	BLOW	2.750M	γ_s	26 deg
		OLOW	1.212 M	Elements*	5/7	OLOW	1.607M	Elements	4/7
156-Inch Diameter	40k Polar	GLOW	5.158 M	V_s	4663 fps	GLOW	4.765M lb	V_s	4747 fps
		BLOW	3.673 M	γ_s	25 deg	BLOW	2.899M lb	γ_s	30 deg
		OLOW	1.485 M	Elements	3/3	OLOW	1.866M lb	Elements	2/4
	45k East	GLOW	4.365 M	V_s	4564 fps	GLOW	4.096M lb	V_s	5,051 fps
		BLOW	3.128 M	γ_s	25 deg	BLOW	2.500M lb	γ_s	30 deg
		OLOW	1.237 M	Elements	3/3	OLOW	1.596M lb	Elements	2/3

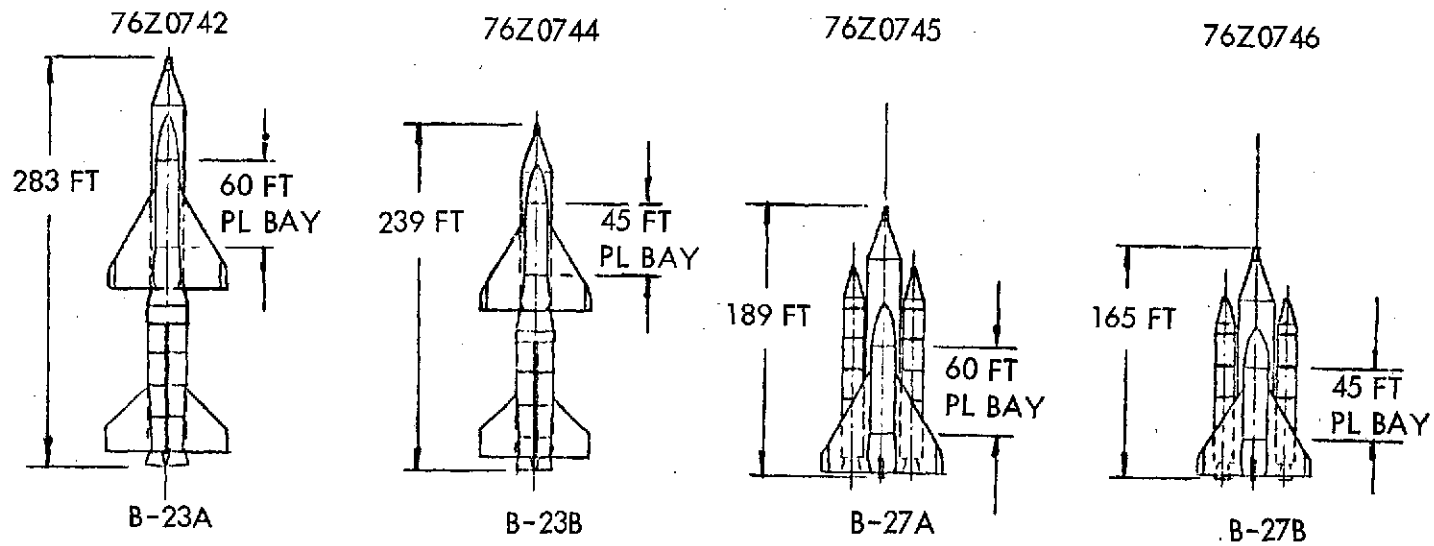
*Number of booster solid rocket elements/segment

Table 3-13. SRM Booster Shuttle System Selected System Summary

SRM Diameter		156 Inch				120 Inch			
PL Wt, Mission, Bay Size		40k Polar 15×60 ft		45k East 14×45 ft		40k Polar		45k East 14×45 ft	
Burn Mode		Series	Parallel	Series	Parallel	Series	Parallel	Series	Parallel
GLOW	M lb	5.158	4.765	4.365	4.096	5.541	5.254	4.675	4.357
BLOW	M lb	3.673	2.899	3.128	2.500	4.134	3.438	3.462	2.750
$OLOW_{LO}$	M lb	1.484	1.866	1.237	1.596	1.407	1.816	1.212	1.607
W_p Ascent Booster	M lb	3.218	2.549	2.724	2.191	3.511	2.932	2.943	2.345
W_p Ascent Orbiter	M lb	1.097	1.557	0.869	1.217	1.024	1.422	0.845	1.228
$W_{Dry\ Booster}$*	k lb	453	324	403	286	593	481	494	385
$W_{Orbiter\ Spacecraft}$**	k lb	176	176	166	166	176	176	166	166
$W_{Orbiter\ Tank\ Burnout}$	k lb	84.5	92.8	70.3	80.6	80.0	90.5	68.9	81.2
$V_{STAGE\ REL}$	fps	4663	4747	4564	5051	4888	5214	4654	5198
γ_{STAGE}	deg	25	30	25	30	25	30	30	26
h_{STAGE}	kft	117	142	117	151	142	162	146	150
q_{STAGE}	psf	162	56	153	45	62	31	46	49
t_{STAGE}	sec	122	123.1	123.5	123.5	128.3	128.3	127.3	128.3
No. Elements Booster		3×3 seg	2×4 seg	3×3 seg	2×3 seg	6×7 seg	5×7 seg	5×7 seg	4×7 seg
F_{SL} per Boost Element	M lb	2.235	2.852	1.891	2.457	1.297	1.308	1.404	1.307
q_{Max}	psf	650	645	651	669	674	651	650	651
F/W_{LO}	Total System	1.300	1.427	1.300	1.467	1.404	1.453	1.404	1.451
$OLOW_{Staging}$***	M lb	1.484	1.500	1.237	1.230	1.407	1.422	1.212	1.214
$F/W_{Orb\ w\ Abort\ Rocket}$	At	1.355	1.34	1.63	1.63	1.43	1.41	1.86	1.86
$F/W_{Orb\ w/o\ Abort\ Rocket}$	Staging	0.95	0.94	1.15	1.15	1.03	0.99	1.16	1.16
$\lambda_{Booster}$*		0.875	0.881	0.873	0.877	0.852	0.855	0.852	0.855
$\lambda_{Orbiter\ Tank}$		0.927	0.940	0.925	0.939	0.927	0.940	0.925	0.939
Synthesis Run No.		SS-20-0T21	SS-20 3T8	SS-20-0T30	SS-20-3T11	SS-20-1T8	SS-20-2T8	SS-20-1T11	SS-20-2T12

* Including Adaptor, ** Less Abort Rockets, ***Including Abort Rockets. (All orbitors have 3×470k vac H_LP_C plus 87,500 lb abort rockets)

Table 3-14. 156 Inch Diameter SRM - Configuration Comparison



BURN	SERIES	SERIES	PARALLEL	PARALLEL
PAYLOAD (lb)	40k	45k	40k	45k
MISSION	POLAR	EAST	POLAR	EAST
NO. SRM ELEMENTS	3	3	2	2
GLOW (lb)	5.159M	4.365M	4.765M	4.096M
BLOW (lb)	3.674M	3.128M	2.899M	2.500M
OLOW (lb)	1.485M	1.237M	1.866M	1.596M
V_{STAGE} fps	4,663	4,564	4,747	5,051

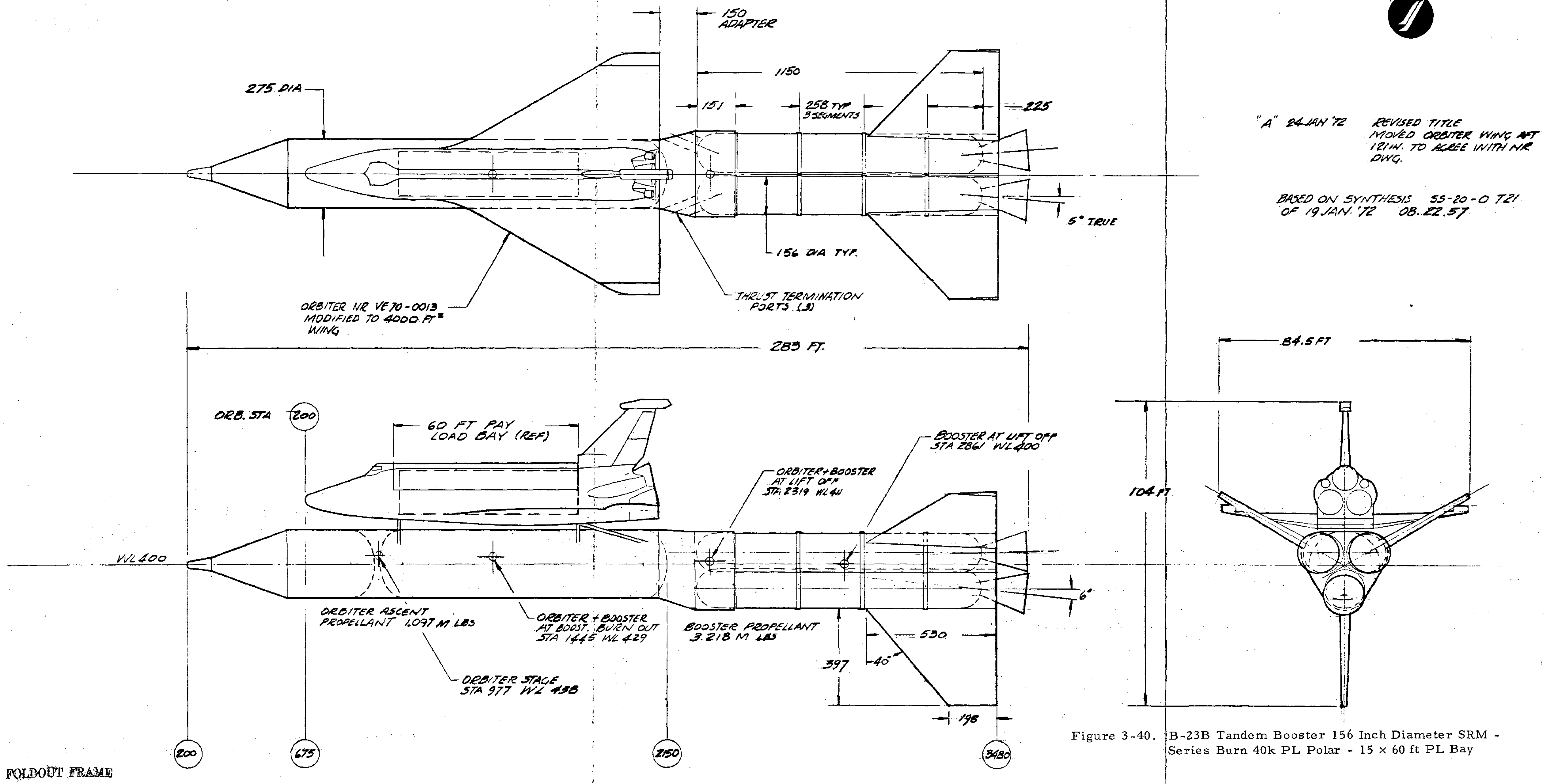


Figure 3-40. B-23B Tandem Booster 156 Inch Diameter SRM - Series Burn 40k PL Polar - 15 × 60 ft PL Bay

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

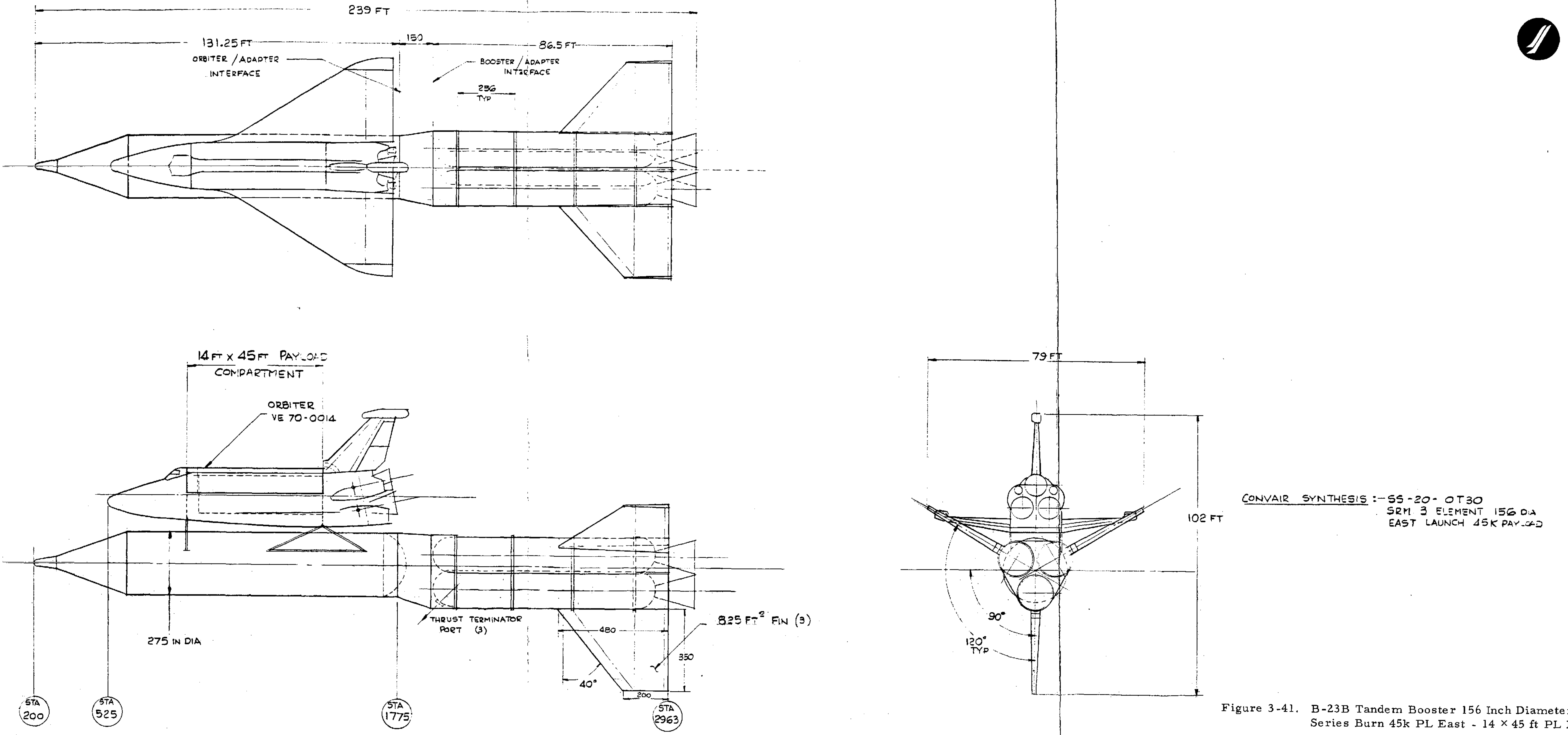
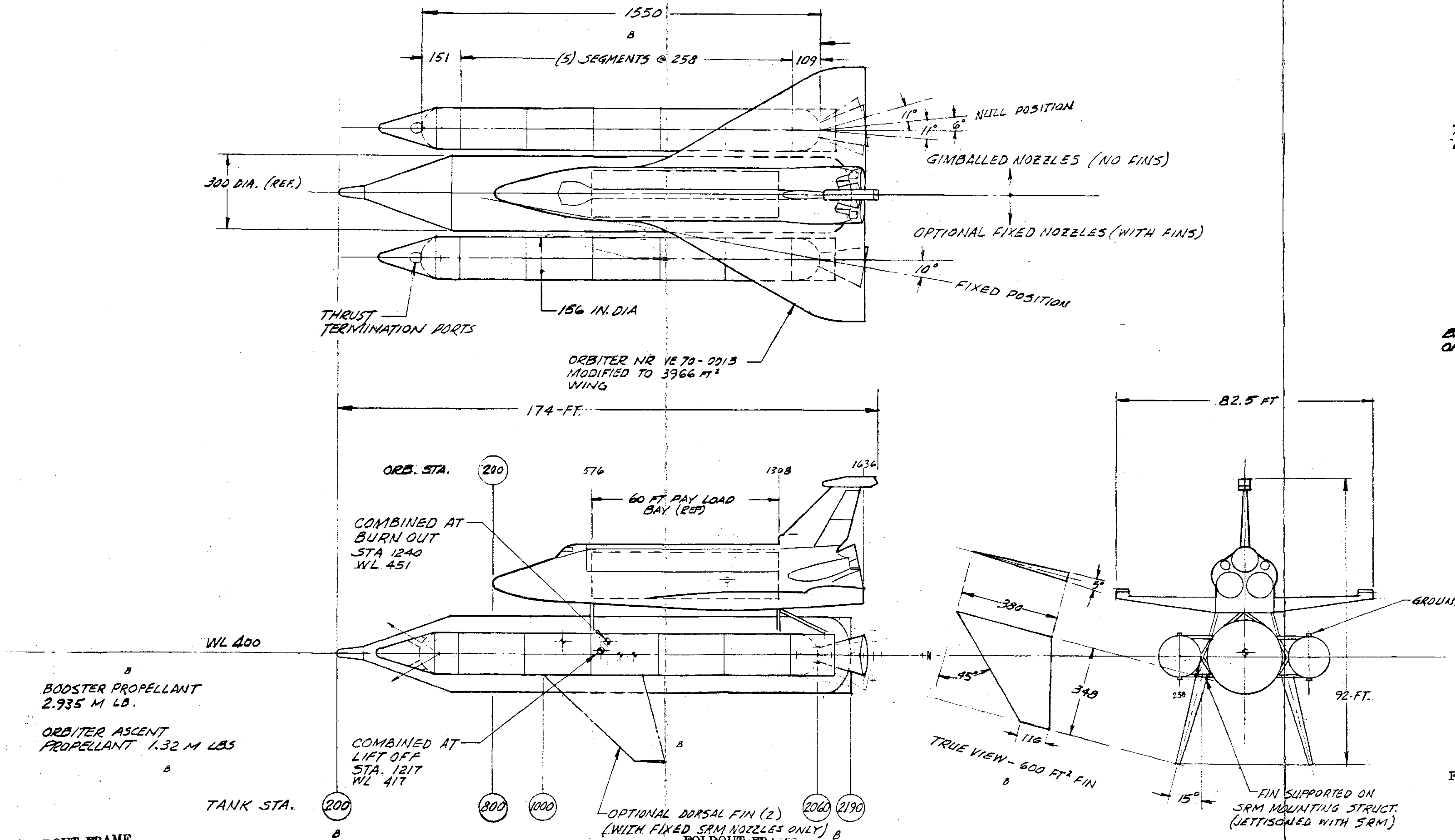


Figure 3-41. B-23B Tandem Booster 156 Inch Diameter SRM - Series Burn 45k PL East - 14 × 45 ft PL Bay

FOLDOUT FRAME 1

FOLDOUT FRAME 2-2

FOLDOUT FRAME 3



"A" CG DATA ADDED 27 JAN '72
"B" REVISED ORB TANK LENGTH.
(STA 2190 WAS 2370)
REVISED SRM LENGTH.
(1550 WAS 1355)
REVISED PROPELLANT WTS.
ADDED OPTIONAL DORSAL FINS.
ADDED GIMBALLED NOZZLES AND
OPTIONAL FIXED NOZZLES. 2 FEB '72.

BASED ON SYNTHESIS SS-20-3TB
OF 24 JANUARY '72 HR. 18:54:58

Figure 3-42. B-27A Parallel Booster 156 Inch Diameter SRM - Parallel Burn 40k PL Polar - 15 × 60 ft PL Bay

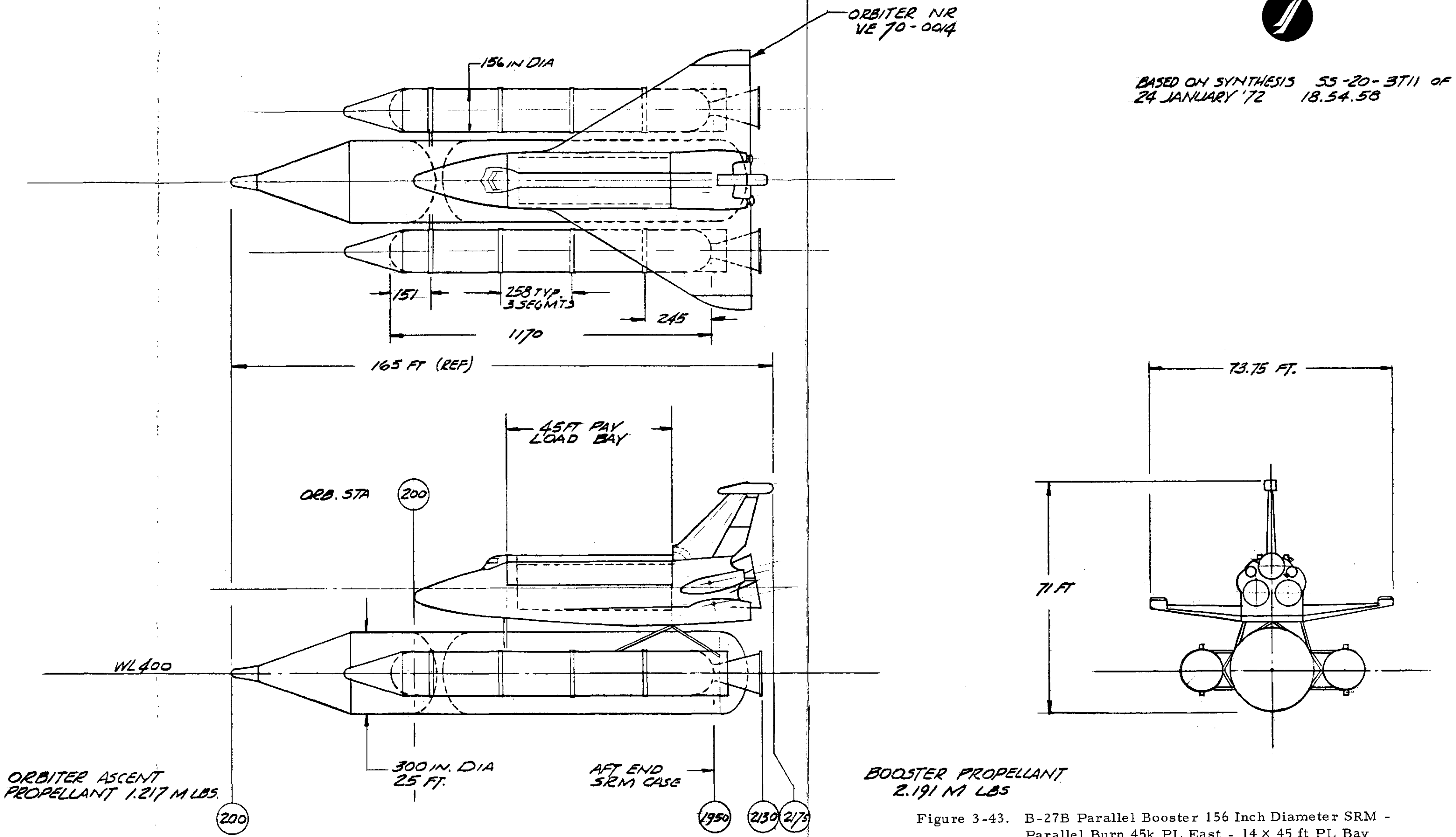
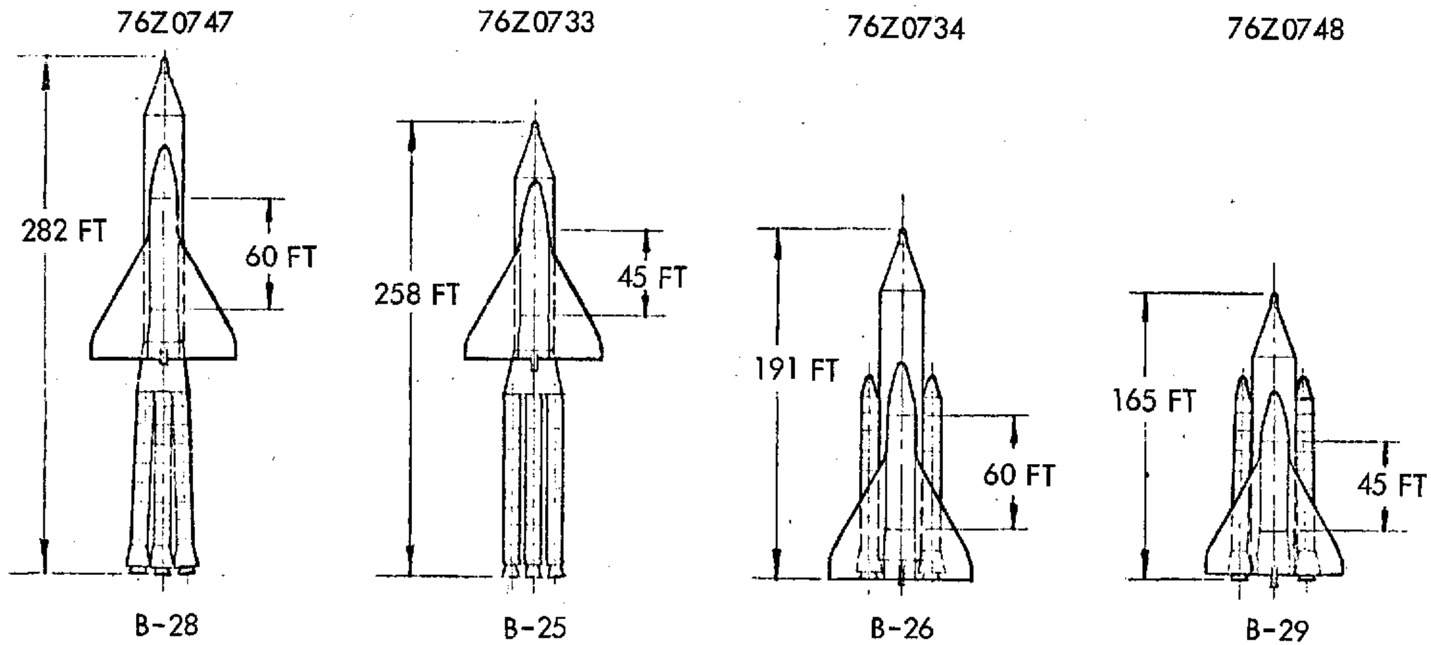


Figure 3-43. B-27B Parallel Booster 156 Inch Diameter SRM - Parallel Burn 45k PL East - 14 × 45 ft PL Bay

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 3-15. 120-Inch Diameter SRM - Configuration Comparison



	B-28	B-25	B-26	B-29
BURN	SERIES	SERIES	PARALLEL	PARALLEL
PAYLOAD (lb)	40k	45k	40k	45k
MISSION	POLAR	EAST	POLAR	EAST
NO. SRM ELEMENTS	6	5	5	4
GLOW (lb)	5.541M	4.675M	5.254M	4.357M
BLOW (lb)	4.134M	3.462M	3.438M	2.750M
OLOW (lb)	1.407M	1.212M	1.816M	1.607M
V_{STAGE} fps	4,888	4,654	5,214	5,198

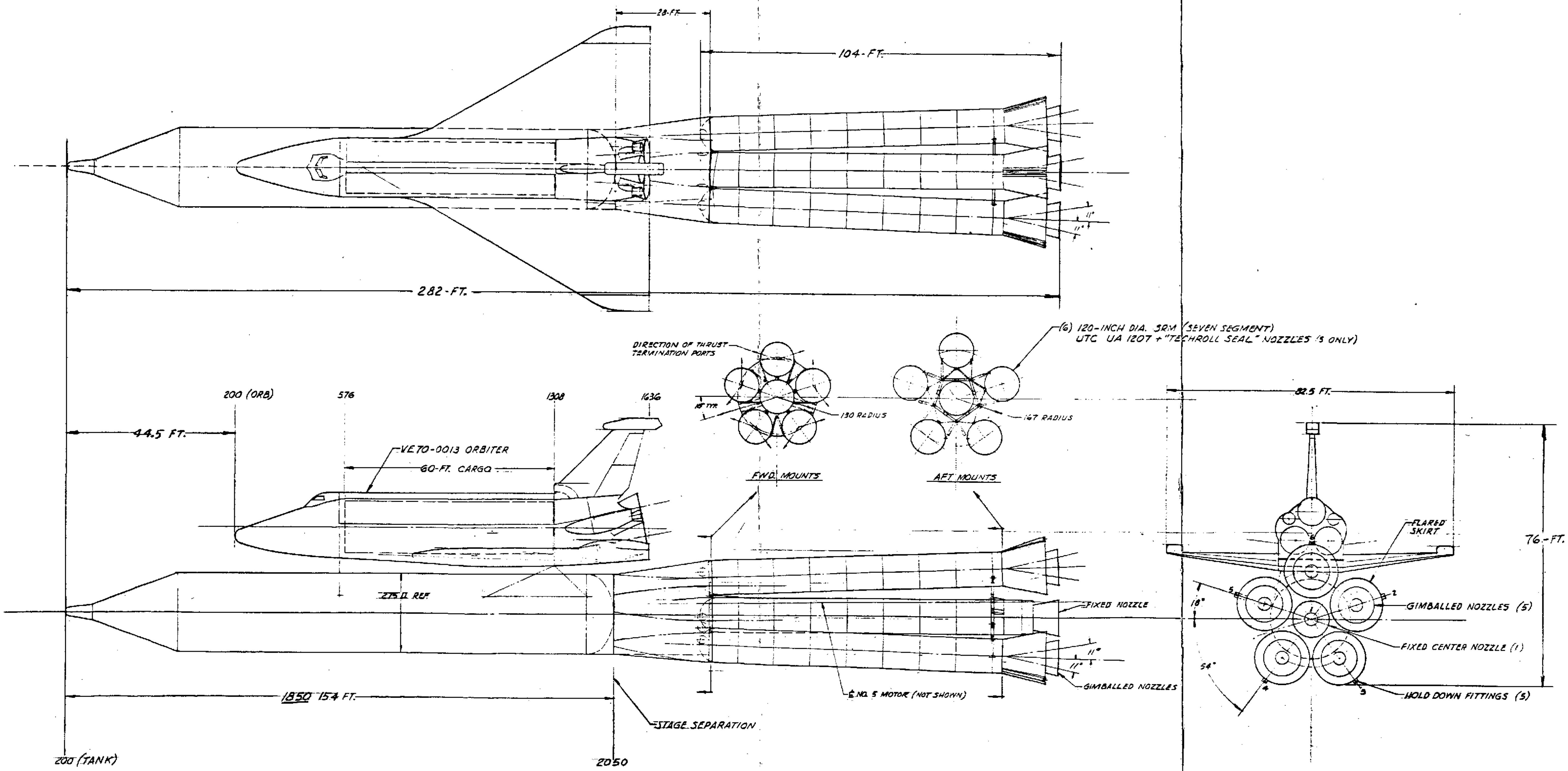


Figure 3-44. B-28 Tandem Booster 120 Inch Diameter SRM - Series Burn 40k PL Polar - 15 × 60 ft PL Bay

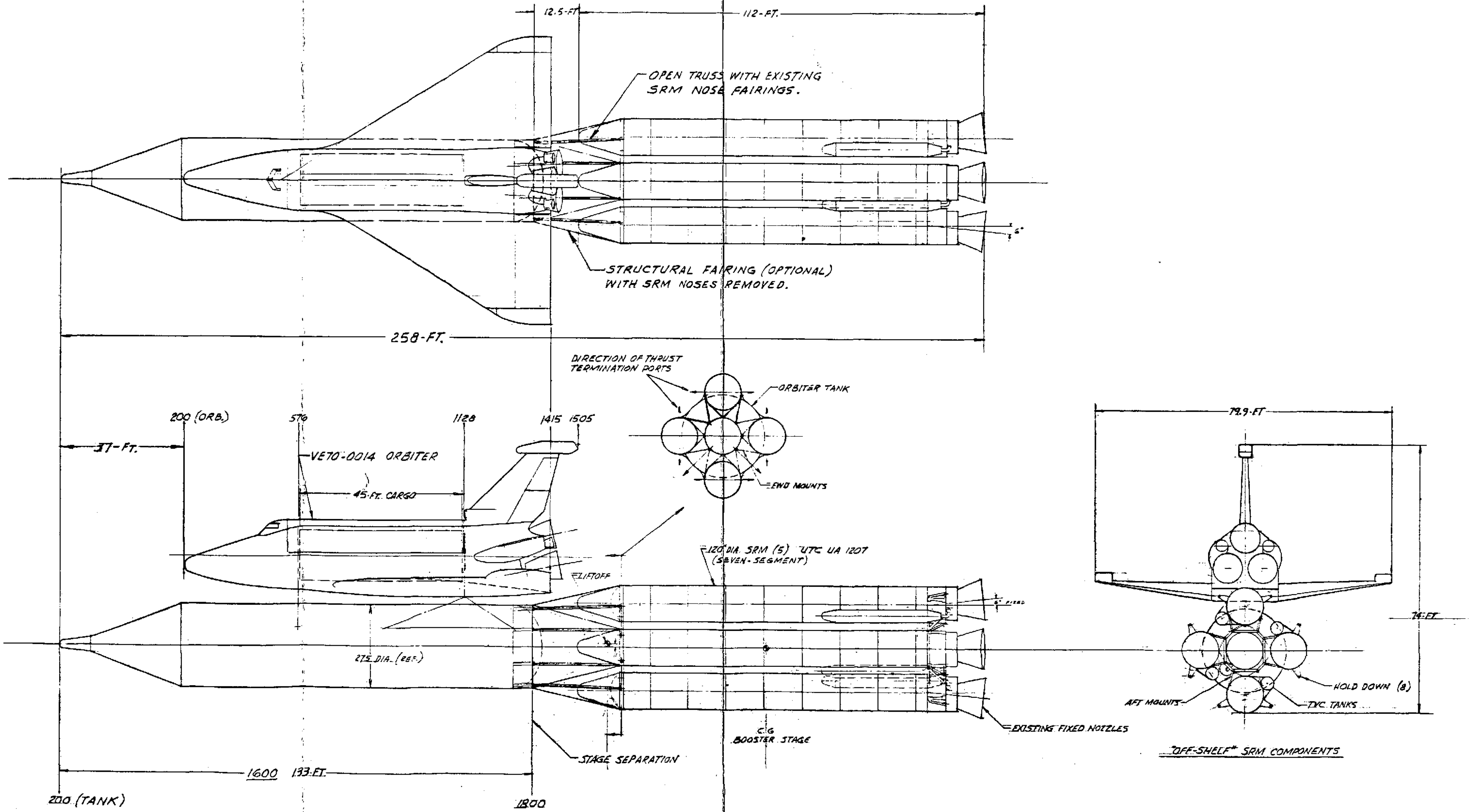


Figure 3-45. B-25 Tandem Booster 120 Inch Diameter SRM - Series Burn 45k PL East - 14 × 45 ft PL Bay

FOLDOUT FRAME 2

FOLDOUT FRAME 1

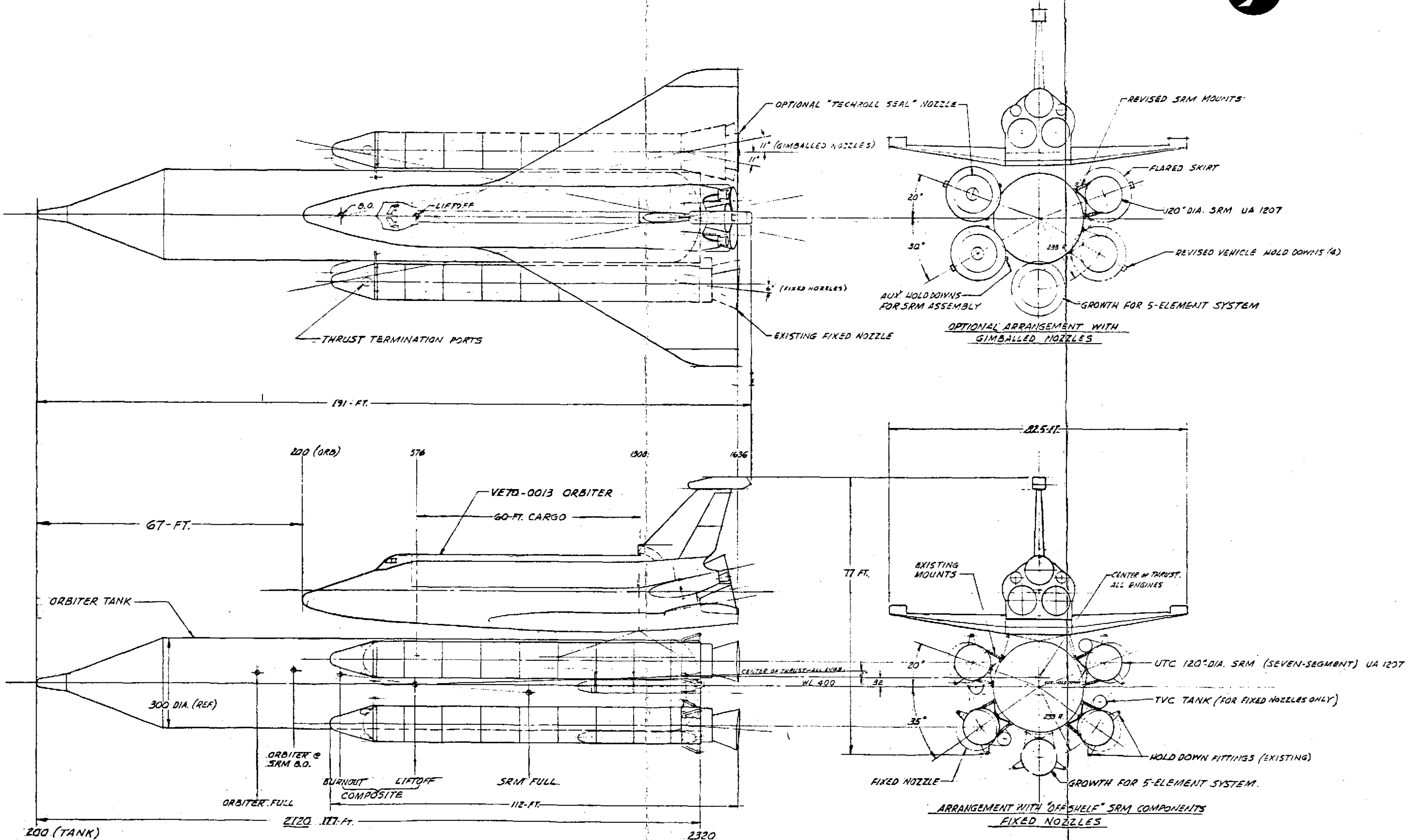


Figure 3-46. B-26 Parallel Booster 120 Inch Diameter SRM - Parallel Burn 40k PL Polar - 15 × 60 ft PL Bay

FOLDOUT FRAME 1

FOLDOUT FRAME 2

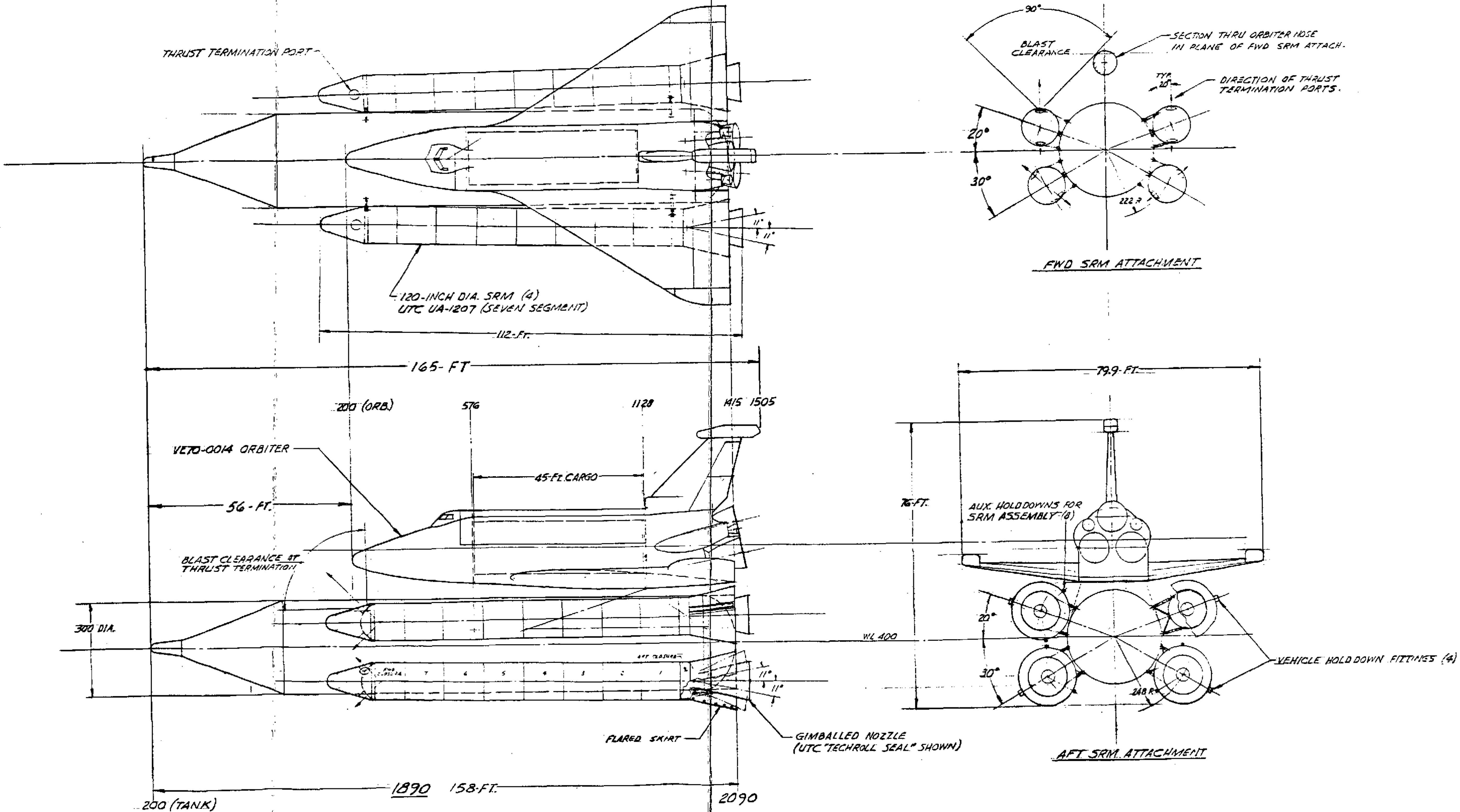


Figure 3-47. B-29 Parallel Booster 120 Inch Diameter SRM - Parallel Burn 45k PL East - 14 × 45 ft PL Bay

FOLDOUT FRAME 1

FOLDOUT FRAME 2

4.0 COMPARISON OF ISSUES

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4.1 ASSESSMENT OF BOOSTER ISSUES

The booster basic issues, area of concern, and assessments are defined by Table 4-1 for series pressure-fed boosters, Table 4-2 for series pump-fed boosters, and Table 4-3 for parallel solid-rocket motor (156 in.). These items are considered to be the important issues for each booster with the key issues outlined in the blocks. The assessments provide the approaches to be taken, current technologies available, and areas requiring further development.

4.2 APPROACH TO MINIMIZE RISK

The approach to minimize the risks attendant to the booster issues previously identified are defined by Table 4-4 for series pressure-fed booster, Table 4-5 for series pump-fed booster, Table 4-6 for parallel solid-rocket motor (156 inch).

The solutions described for each booster define state-of-the-art technologies, conservative performance estimate utilization, element testing, and model testing to avoid major program impacts. In the solid-rocket-motor (156 inch) booster program the solutions also require early development testing for starting sequence, thrust termination, and malfunction detection.

4.3 COST IMPACT OF PROGRAM ASSUMPTIONS

Comparison of cost due to requirements imposed on the pressure-fed booster and those imposed on the pump-fed booster are shown in Table 4-7. The proposed modification of the pressure-fed booster requirements and associated cost are provided for program consideration. The proposed modifications to requirements will align the pressure-fed booster development to be minimum type program matching the capabilities of the pump-fed booster.

Table 4-1. Assessment of Series Pressure-Fed Booster Issues

BOOSTER ISSUES	*AREAS OF CONCERN*	*ASSESSMENT*
(1) PRESSURE-FED ENGINES		Weight Estimate Spread
• Weight	• Confidence in weight estimates	11,952 (14,678) 16,483 Selected
• Isp	• Impact on performance	• 0.91 theoretical Isp is accepted practice
• Combustion	• Stability	• Successful firings on smaller engines. Characteristics of larger engines uncertain
• Pressurization System	• High flow rate heat exchangers (N_2H_4/LN_2)	• New development • Design criteria available
(2) ENTRY		
• Stability & Cont.	• Ability to damp separation disturbances	• SOA aerodynamics (no active control system) • Separation disturbances uncertain

Table 4-1. Assessment of Series Pressure-Fed Booster Issues (Cont)

BOOSTER ISSUES	AREAS OF CONCERN	ASSESSMENT
(3) RECOVERY		
• Ballistic Coefficient	• Terminal conditions for recovery sensitive to W/C_DA	• SOA aerodynamics • Degree of potential weight growth
• Chute Deploymnt	• Deployment & staged reefing of clustered, large-diameter chutes at subsonic speed ($M \leq 0.7$)	• Individual chute design — SOA • Multiple chute deployment demonstrated on lower speed systems.
• Water Impact	• Initial impact loads • Slapdown loads	• Scale-model tests being conducted • No comparable full-scale operation
(4) RETRIEVAL & REFURBISHMENT		
• Turnaround & Spares	• Number of vehicles, spares & maintenance personnel required	• Extensive aircraft, ship & submarine data bank • Must extrapolate to PFB environment.

Table 4-2. Assessment of Series Pump-Fed Booster (F-1 Engine) Issues

BOOSTER ISSUES	*AREAS OF CONCERN*	*ASSESSMENT*
1 PUMP-FED ENGINE		
• F-1 Reusability	• Ability of proven F-1 to take impact loads & repeated use	• F-1 engine designed & qualified for specified loads, duration • F-1 test history indicates multiple reuse feasible • F-1 not designed for impact loads, maintainability
2 ENTRY		
• Stability & Control	• Ability to damp separation disturbances	• SOA aerodynamics • Separation disturbances uncertain

Table 4-2. Assessment of Series Pump-Fed Booster (F-1 Engine) Issues (Cont)

ASSESSMENT	*BOOSTER ISSUES*	*AREAS OF CONCERN*
(3) RECOVERY		
• Ballistic Coefficient	• Terminal conditions for recovery sensitive to W/C_DA	• SOA aerodynamics • Degree of potential weight growth
• Chute Deployment	• Deployment & staged reefing of clustered, large-diameter chutes at subsonic speed $M \leq 0.5$	• Individual chute design – SOA • Multiple-chute deployment demonstrated on lower speed systems
• Retro System Operation	• Final vehicle orientation with respect to water at impact	• Avionics for orientation system – SOA • Effects of tolerances & single failures must be accounted for in design
• Water Impact	• Initial impact loads	• Scale-model tests being conducted • Correlation of data difficult • No comparable full-scale operation
(4) RETRIEVAL & REFURBISHMENT		
• Retrieval	• Effect of retrieval on component life/structure	• Establishment of retrieval environmental criteria • Evaluation of qualified Saturn S-IC components
• Turnaround/spares	• No. of vehicles, spares & maintenance personnel req.	• Extensive aircraft, ship & submarine data bank • Experience with S-IC checkout, static firings • Extrapolation to new environment & use

Table 4-3. Parallel, Solid-Rocket-Motor Booster (156 in.) Issues

BOOSTER ISSUES	*AREAS OF CONCERN*	*ASSESSMENT*
1 SRM		
• Simultaneous Ignition	• Asymmetrical conditions during start sequence	• TIIIC ignites two large solids
• Hold-down requirement	• Malfunction detection with adequate reaction time • Effects of "on pad" thrust termination	• New development — presents test difficulties
• Environment	• Effects of air pollution & acoustic noise on surrounding areas	• Environment acceptable — to Federal Standards
• TVC	• Lack of operational gimbal experience in large SRM	• SOA designs exist. Can be sized to booster application

Table 4-3. Parallel, Solid-Rocket-Motor Booster (156 in.) Issues (Cont)

ASSESSMENT	*BOOSTER ISSUES*	*AREAS OF CONCERN*
(2) ABORT		
• SRM Separation	• Ability of parallel staged SRMs to clear orbiter	• New development – difficulties due to thrust termination, asymmetrical thrust decay of 2 SRMs & booster/orbiter aero & dynamics
• Thrust Termination	• Burning of solid propellant continues • Ability to balance thrust rapidly without damaging orbiter.	• Booster/orbiter configuration arrangement driven by SRM abort concept • New development TT port to avoid plume or projectile damage to orbiter • New-development MDS with adequate reaction time
(3) SEPARATION		
• Separation	• Ability of parallel SRM to stage from orbiter	• New development – expect difficulties due to asymmetrical thrust decay of 2 SRMs.

Table 4-4. Approach to Minimize Risk Series Pressure-Fed Booster

1 PFE	
• Weight	• Select midpoint of current estimates
	• Include 10% factor in engine weight
• Isp	• Minimum guaranteed Isp to be used
	• Tank volume based on minimum Isp
• Combustion Stability	• Early development testing of
	✓ Injector
	✓ Single engine firing
• Pressurization system	• Modular design for confident scale-up & redundancy
	• Early testing of system elements
2 ENTRY	
• Stability & Control	• Select staging conditions (q = 73) and fins for aerodamping
	• Straight-forward ballistic entry used
	✓ Predictable aerodynamics
	✓ Early wind tunnel verification tests

Table 4-4. Approach to Minimize Risk Series Pressure-Fed Booster (Cont)

(3) RECOVERY	
• Ballistic Coefficient	• Early wind tunnel verification tests • Design for drag growth ✓ Increased drag flap area/deflection
• Parachute deployment	• Design for subsonic chutes only • Early test program ✓ Scale model ✓ Full-scale – single chute/cluster of 3/cluster of 6 reefed
• Water Impact	• Scale-model tests of rebound attenuators • Early large scale-model testing • Continue with design alternatives (soft landing with retros)
(4) RETRIEVAL & REFURBISHMENT	
• Turnaround & Spares	• Early verification of impact design criteria • Rugged design for impact & sea environment • Design for maintainability

Table 4-5. Approach to Minimize Series Pump-Fed Booster (F-1 Engine) Risk

(1) PUMP FED ENGINE	
• F-1 Reusability	• Support engine against inertia loads at impact & retrieval • Modify selected F-1 components
(2) ENTRY	
• Stability & Control	• Provide reaction control system • Straight-forward ballistic entry used ✓ Predictable aerodynamics ✓ Early wind tunnel verification tests

Table 4-5. Approach to Minimize Series Pump-Fed Booster (F-1 Engine) Risk (Cont)

③ **RECOVERY**	
• Ballistic Coefficient	• Early wind tunnel verification tests
	• Design for drag growth
	✓ Increased drag flap area/deflection
• Parachute Deployment	• Design for subsonic chutes only
	• Early test program
	✓ Scale model
	✓ Full-scale – Single chute/cluster of 3/cluster of 6 reefed
• Retro System Operation	• Minimize spread of impact attitudes & velocities & account for in design
• Water Impact	• Scale-model tests of impact attenuators
	• Early large-scale model testing
④ **RETRIEVAL & REFURBISHMENT**	
• Retrieval	• Early verification of design criteria
• Turnaround & Spares	• Consider retrieval alternatives (sea pickup/barge return)
	• Design structure for impact & sea environment
	• Design for maintainability
	• Modify selected S-IC components for extended life, maintainability.

Table 4-6. Approach to Minimize Parallel Solid Rocket Motor Booster (156 in.) Risk

1 SRM 2 ABORT 3 SEPARATION	• Early testing necessary to develop start sequence, termination sequence (normal & abort) & malfunction detection system • Performance characteristics of SRMs must be fully analyzed for effects on booster/orbiter configuration arrangement & environment.

Table 4-7. Cost Impact of Program Assumptions

	BASELINE PRESSURE-FED BOOSTER	*MINIMUM-DEVELOPMENT PUMP-FED BOOSTER*	*MINIMUM-DEVELOPMENT PRESSURE-FED BOOSTER*
DDT&E PROGRAM ASSUMPTIONS	• Reusable Engine	• Current expendable F-1 engine	• Do not demonstrate engine life (-$30M)
	• Designed for 150 fps impact	• Must be slowed to ~20-fps impact	• Reduce structure weight & adopt retro philosophy (-$30M)
	• 2 flight vehicles	• 1 flight vehicle	• No change
	• 1.8 ground test vehicles	• 0.5 ground test vehicle	• 1.0 ground test vehicle (-$50M)
	• Operational avionics with redundancy & data recording ✓	• Same	• No change
		(Minimum Avionics Δ$ -50 to -100M)	✓
	• Material selection — sea water compatibility	• Aluminum vehicle, limited marine compatibility	• Limit use of titanium & Inconel except for tanks (-$30M)
	• Design for low refurbishment	• No effort to effect low refurbishment design	• No change
DDT&E COST ($ B)	1.34	0.98	1.20