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FINAL SUBMITTAL

Phase B Final Report

Expendable Second Stage Reusable Space Shuttle Booster

Volume II. Technical Summary

Book 3. Booster Vehicle Modifications and Ground Systems Definition

Contract NAS9-10960, Exhibit B
DRL MSFC-DRL-221, DRL Line Item 6
DRD MA-078-U2
SD 71-140-2
25 June 1971

Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

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EXPENDABLE SECOND STAGE
REUSABLE SPACE SHUTTLE BOOSTER

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Approved by

B. Hello
Vice President and General Manager
Space Shuttle Program

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EXPENDABLE
SECOND STAGE MISSION
SII

FOREWORD

The Space Shuttle Phase B studies are directed toward the definition of an economical space transportation system. In addition to the missions which can be satisfied with the shuttle payload capability, the National Aeronautics and Space Administration has missions planned that require space vehicles to place payloads in excess of 100, 000 pounds in earth orbit. To satisfy this requirement, a cost-effective multimission space shuttle system with large lift capability is needed. Such a system would utilize a reusable shuttle booster and an expendable second stage. The expendable second stage would be complementary to the space shuttle system and impose minimum impact on the reusable booster.

To evaluate the expendable second stage concept, a two-phase study was authorized by NASA. Phase A efforts, which ended in December 1970, concentrated on performance, configuration, and basic aerodynamic considerations. Basic trade studies were carried out on a relatively large number of configurations. At the conclusion of Phase A, the contractor proposed a single configuration. Phase B commenced on 1 February 1971, based on the recommended system. Whereas a large number of payload configurations were considered in the initial phase, Phase B was begun with specific emphasis placed on three representative payload configurations. The entire Phase B activity has been directed toward handling the three representative payload configurations in the most acceptable manner with the selected expendable second stage, and toward the design of the subsystems of the expendable second stage. Results of this activity are reported in this 12-volume Phase B final report. This is Volume II, Technical Summary.

Volume I	Executive Summary	SD 71-140-1
Volume II	Technical Summary	SD 71-140-2
Volume III	Wind Tunnel Test Data	SD 71-140-3
Volume IV	Detail Mass Properties Data	SD 71-140-4
Volume V	Operations and Resources	SD 71-140-5
Volume VI	Interface Control Drawings	SD 71-140-6
Volume VII	Preliminary Design Drawings	SD 71-140-7
Volume VIII	Preliminary CEI Specification - Part 1	SD 71-140-8
Volume IX	Preliminary System Specification	SD 71-140-9
Volume X	Technology Requirements	SD 71-140-10
Volume XI	Cost and Schedule Estimates	SD 71-140-11
Volume XII	Design Data Book	SD 71-140-12

Volume II, Technical Summary, is divided into three books:

Book 1	Expendable Second Stage/Reusable Booster System Definition
Book 2	Expendable Second Stage Vehicle Definition
Book 3	Booster Vehicle Modifications and Ground Systems Definition.

This book is intended to be used together with the other books of Volume II. Book 1 contains basic data on mission/system requirements, performance, trajectories, aerodynamics, stability and control, loads, heating, and acoustic environment. Book 2 is devoted to the definition of the selected expendable second stage, its subsystems, and overall ESS operation. Book 3 covers the definition of the ESS/booster separation system, modifications required on the reusable booster for ESS/payload flight, and the ground systems needed to operate the ESS complementary with the space shuttle.

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TABLES

1.0 BOOSTER PHYSICAL CHARACTERISTICS

1.1 GENERAL ARRANGEMENT

The analyses conducted in this study and discussed in subsection 2.0 of this section were based on the shuttle booster as defined for the 270-day data reportand described in report SD 71-114-2, Volume II, Book 3, dated 26 March 1971 and titled "Booster Vehicle Definition." The external shape, major component arrangement and the overall dimensions of this booster are shown in Figure 1-1. This drawing also shows the major booster weight and dimensional characteristics. The lines describing the detailed shape of the booster body, wing, vertical tail, canard, fillets, and fairings are shown in Figure 1-2. More specific details of the booster general arrangement are shown in Figure 1-3. This drawing of the basic shuttle configuration is central to the entire ESS study effort and is the one used for detailed structural, thermal, control, and subsystem evaluation. It partially overlaps the information shown in Figures 1-1 and 1-2, but in addition, controls items such as booster/orbiter location relationships, center of gravity and booster gimbal angles. The limited modifications that must be made to the shuttle booster, as currently defined, to accommodate the ESS missions are described below.

During the study, detailed investigations were made of the effects of the ascent trajectories, stage separation, and the entry trajectories on the load and thermal environment encountered by the booster when used for ESS missions. These investigations were made for a spectrum of three payloads: the RNS, the space station, and the space tug. As a result of these investigations the following conclusions were drawn:

1. The thermal environment encountered by the booster during the ESS mission with each of the three payloads defined above is no more severe than the environment encountered by the booster during a shuttle mission. The thermal protection system as defined for the booster when used for shuttle missions therefore is satisfactory for ESS missions.

2. The loads imposed on the booster by the ESS and its various payloads in a few specific places exceed those imposed by the shuttle orbiter at various points along the exit trajectory. This requires a nominal "beef-up" of several bulkheads and adjacent skins.

This type of change must be incorporated in the shuttle booster, since a field modification for conversion between shuttle and ESS missions is not practical. Incorporation of this change imposes a nominal penalty, due to added structure weight, on the shuttle. A definition of the loads is provided in Book 1, and the structure revisions are defined in Subsection 2.0 of this section.

3. The mating/separation system utilizes the same booster-thrusted separation linkage concept as used for shuttle. The ESS, however, requires the use of recoverable and reusable mating/separation elements which are to be installed only for carriage of the ESS. The modified booster and separation system are shown in Figure 1-4. The details of the required vehicle modifications are described in Subsection 2.0.

4. The remainder of the vehicle subsystems remain unaffected. There are, however, software changes to be made to reflect trajectory and separation sequencing revisions.

1.2 BOOSTER MASS PROPERTIES

Sequence mass properties are presented in Tables 1-1, 1-2, and 1-3 for the mated configuration with the space station, nuclear stage, and space tug payloads, respectively. A summary weight statement is shown in Table 1-4. The weights as shown provide the booster with the capability of withstanding the 95 percentile peak ground winds, as defined for shuttle, while on the pad in a mated configuration for an ESS mission with any of the above three payloads. A reduction to approximately 85 percentile peak ground winds would eliminate the need for structural penalties to the booster for ground conditions. The weights also reflect the assumption that the primary structure of the shuttle booster has been modified so that it has the capability, after the completion of a shuttle mission, of being adapted for an ESS mission and delivering either the RNS, the space station, or the space tug payloads. The effect on weights of designing for a specific payload or applying wind restrictions to avoid ground wind penalties is shown in the following table.

For additional mass property data see Volume IV, Paragraph 5.0

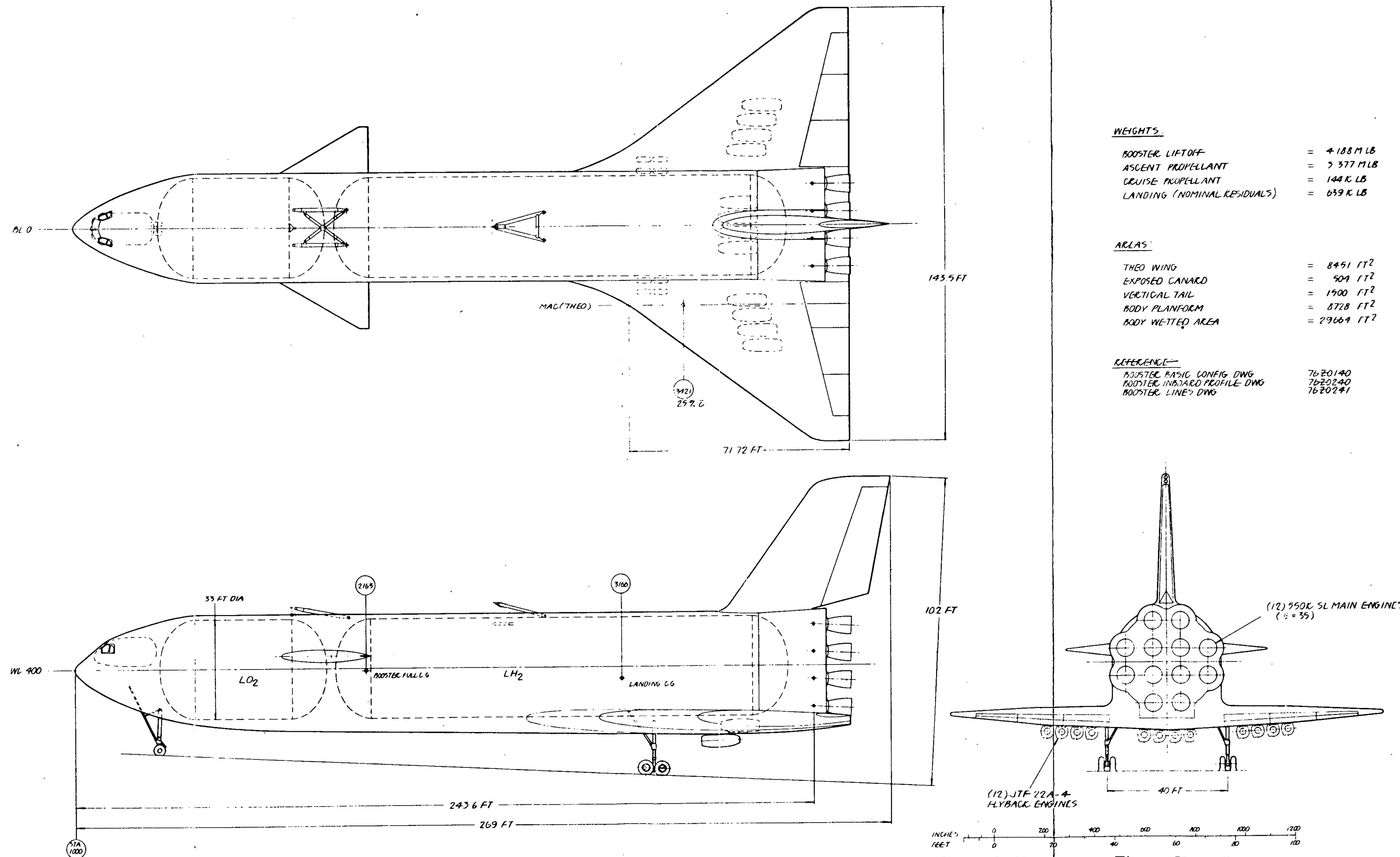

Figure 1-1. B-9U Booster Three-View Drawing

FOLDOUT FRAME 1

FOLDOUT FRAME 2

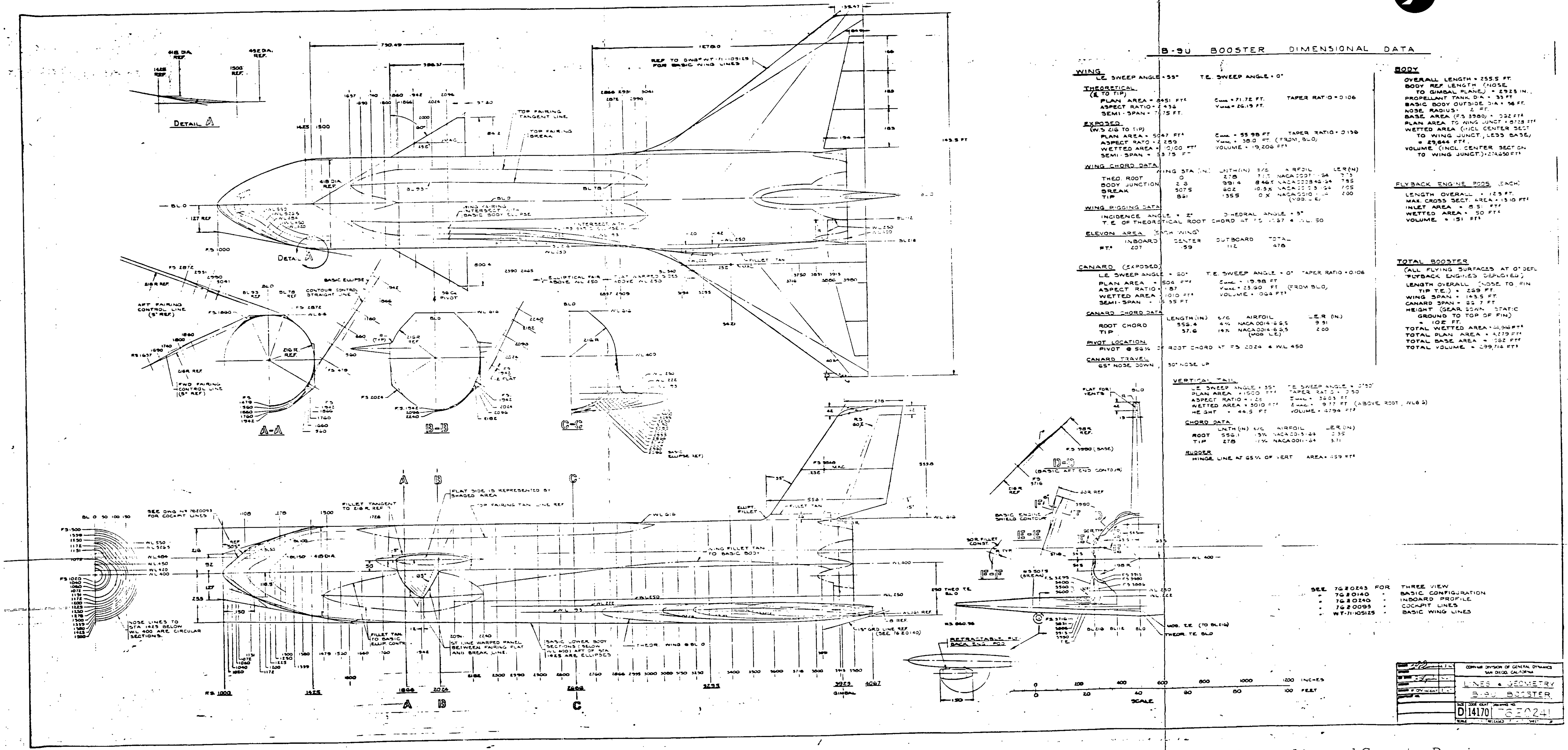

Figure 1-2. B-9U Booster Lines and Geometry Drawing

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 2

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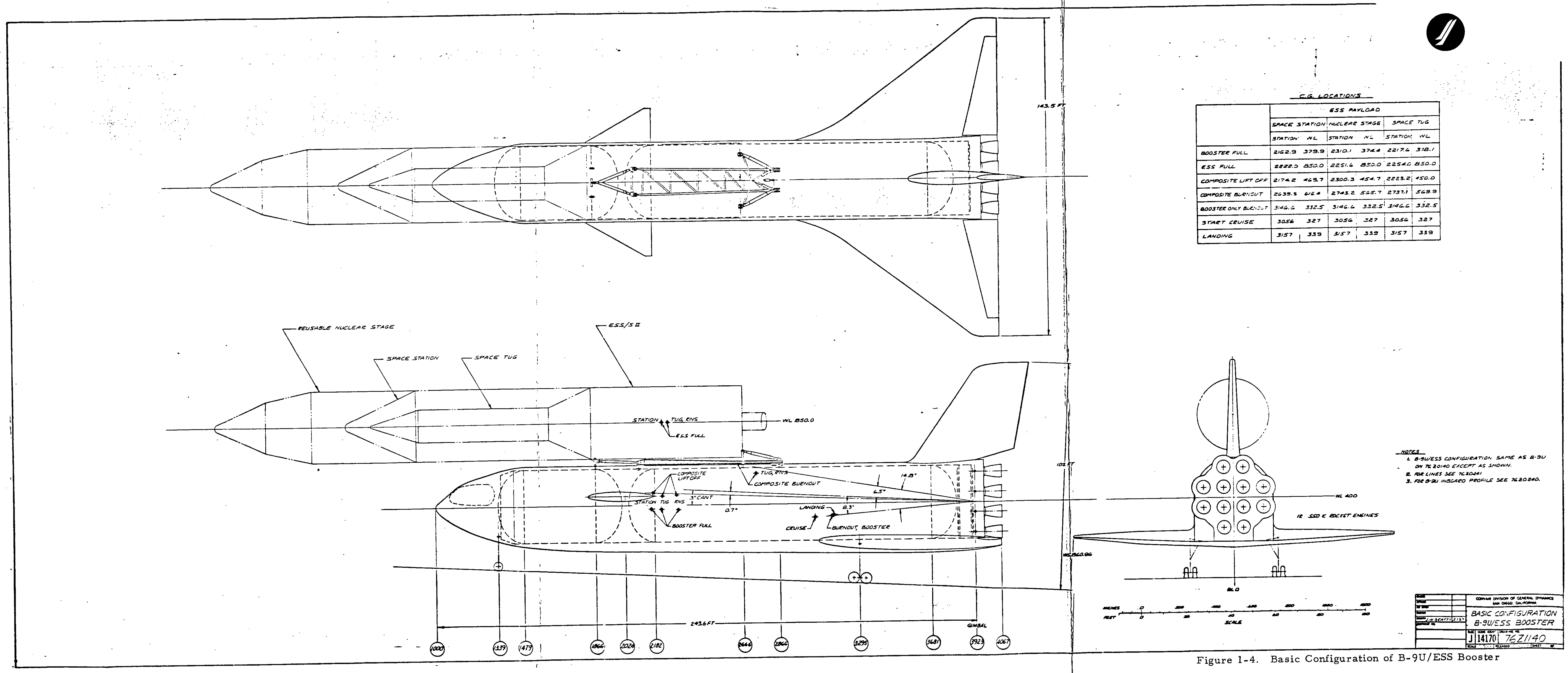


C.G. LOCATIONS

	ESS PAYLOAD					
	SPACE STATION		NUCLEAR STAGE		SPACE TUG	
	STATION	WL	STATION	WL	STATION	WL
BOOSTER FULL	2162.9	379.9	2310.1	374.4	2217.6	378.1
ESS FULL	2222.5	850.0	2251.6	850.0	2254.0	850.0
COMPOSITE LIFT OFF	2174.2	469.7	2300.3	454.7	2223.2	450.0
COMPOSITE BURNOUT	2639.3	616.4	2743.2	565.7	2737.1	569.9
BOOSTER ONLY BURNOUT	3146.6	332.5	3146.6	332.5	3146.6	332.5
START CRUISE	3056	327	3056	327	3056	327
LANDING	3157	339	3157	339	3157	339

Figure 1-4. Basic Configuration of B-9U/ESS Booster

ESS	Added Wt. (lb) Ground Conditions	Flight Conditions	Total
RNS	39	1,225	1,264
Space station	1,892	1,260	3,152
Space tug	0	879	879
All of above payloads	1,892	1,289	3,181

Table 1-1. Sequence Mass Properties Statement

CONFIGURATION B-9U BOOSTER + ESS/MDAC SS						BY			DATE	PAGE OF	
			CENTER OF GRAVITY INCHES			MOMENT OF INERTIA SLUG FT^2 X 10–			PRODUCT OF INERTIA SLUG FT^2 X 10–		
NO.	MISSION EVENT	WEIGHT LB.	X	Y	Z	I_{x-x}	I_{y-y}	I_{z-z}	I_{xy}	I_{xz}	I_{yz}
	Liftoff	5195464	2161	0.0	471.3	50.82	636.74	598.93	0.0	8.30	0.0
	Booster Ascent Prop	-1412842									
	Max q Flight Condition	3782622	2341	0.0	498.0	48.70	493.08	457.41	0.0	-10.12	0.0
	Booster Ascent Prop	-612441									
	Max G Flight Condition	3170181	2427	0.0	516.9	47.18	430.57	396.40	0.0	-19.41	0.0
	Booster Ascent Prop	-1351264									
	Booster Thrust Decay	- 5760									
	Booster Burnout	1813157	2604	0.0	616.8	37.25	273.82	249.57	0.0	-40.76	0.0
	ESS Separation	-992000									
	Booster Vent Residuals	- 17571									
	Booster ACS Prop	- 1500									
	Booster Start Cruise	802086	3049	0.0	332.0	9.99	129.50	130.70	0.0	-3.24	0.0
	Booster APU Prop	- 3231									
	Cruise Fuel (JP)	-143786									
	Booster Landing(Gear Down)	655069	3146	0.0	344.0	9.63	103.90	105.30	0.0	-7.66	0.0

NOTES:

Table 1-2. Sequence Mass Properties Statement

CONFIGURATION B-9U BOOSTER + ESS/RNS						BY		DATE		PAGE OF	
NO.	MISSION EVENT	WEIGHT LB.	CENTER OF GRAVITY INCHES			MOMENT OF INERTIA SLUG FT^2 X 10–			PRODUCT OF INERTIA SLUG FT^2 X 10–		
			X	Y	Z	$I_{x\text{-}x}$	$I_{y\text{-}y}$	$I_{z\text{-}z}$	I_{xy}	I_{xz}	I_{yz}
	Liftoff	4222117	2242	0.0	451.4	39.02	563.34	537.14	0.0	-1.18	0.0
	Booster Ascent Prop	-1151550									
	Max q Flight Condition	3070567	2413	0.0	470.8	38.11	446.14	420.85	0.0	-1.30	0.0
	Booster Ascent Prop	-511800									
	Max G Flight Condition	2558767	2503	0.0	485.0	37.5	390.46	365.84	0.0	-25.27	0.0
	Booster Ascent Prop	-1080150									
	Booster Thrust Decay	- 5760									
	Booster Burnout	1472857	2694	0.0	562.9	32.11	257.51	238.20	0.0	-34.03	0.0
	ESS Separation	-651700									
	Booster Vent Residuals	- 17571									
	Booster ACS Prop	- 1500									
	Booster Start Cruise	802086	3049	0.0	332.0	9.99	129.50	130.70	0.0	-3.24	0.0
	Booster APU Prop	- 3231									
	Cruise Fuel (JP)	-143786									
	Booster Landing(Gear Down)	655069	3146	0.0	344.0	9.63	103.90	105.30	0.0	-2.66	0.0

NOTES:

Table 1-3. Sequence Mass Properties Statement

CONFIGURATION
B-9U BOOSTER + ESS/NR TUG

BY | DATE | PAGE OF

NO.	MISSION EVENT	WEIGHT LB.	CENTER OF GRAVITY INCHES			MOMENT OF INERTIA SLUG FT² X 10–			PRODUCT OF INERTIA SLUG FT² X 10–		
			X	Y	Z	I_{x-x}	I_{y-y}	I_{z-z}	I_{xy}	I_{xz}	I_{yz}
	Liftoff	4517437	2219	0.0	458.4	41.97	569.71	539.84	0.0	1.80	0.0
	Booster Ascent Prop	-1093026									
	Max q Flight Condition	3424411	2372	0.0	477.0	40.91	458.70	429.88	0.0	-10.48	0.0
	Booster Ascent Prop	-956399									
	Max G Flight Condition	2468012	2535	0.0	506.9	39.21	354.56	327.44	0.0	-23.74	0.0
	Booster Ascent Prop	-886210									
	Booster Thrust Decay	- 5760									
	Booster Burnout	1576042	2673	0.0	581.7	33.18	245.06	223.95	0.0	-35.0	0.0
	ESS Separation	-754885									
	Booster Vent Residuals	-17571									
	Booster	- 1500									
	Booster Start Cruise	802086	3049	0.0	332.0	9.99	129.50	130.70	0.0	-3.24	0.0
	Booster APU Prop	- 3231									
	Cruise Fuel (JP)	-143786									
	Booster Landing(Gear Down)	655069	3146	0.0	344.0	9.63	103.90	105.30	0.0	-2.66	0.0

NOTES:

Table 1-4. Booster Weight Statement (Launch Condition)

CONFIGURATION		BY		DATE			
CODE	SYSTEM	A	B	C	D	E	F
1.0	WING GROUP	61990	61990	61990	61990		
2.0	TAIL GROUP	19230	19230	19230	19230		
3.0	BODY GROUP	177301	182772	182772	182772		
4.0	INDUCED ENVIR PROTECT	82644	82644	82644	82644		
5.0	LANDING, DOCKING	27361	27361	27361	27361		
6.0	PROPULSION, ASCENT	130186	130186	130186	130186		
7.0	PROPULSION, CRUISE	50413	50413	50413	50413		
8.0	PROPULSION, AUXILIARY	10557	10557	10557	10557		
9.0	PRIME POWER	1801	1801	1801	1801		
10.0	ELECTRICAL CONV & DIST	1438	1438	1438	1438		
11.0	HYDRAULIC CONV & DIST	1862	1862	1862	1862		
12.0	SURFACE CONTROLS	7889	7889	7889	7889		
13.0	AVIONICS	5468	5468	5468	5468		
14.0	ENVIRONMENTAL CONTROL	1650	1650	1650	1650		
15.0	PERSONNEL PROVISION	1600	1600	1600	1600		
16.0	RANGE SAFETY						
17.0	BALLAST						
18.0	GROWTH	46486	46486	46486	46486		
19.0	ESS PLATFORM	-	9770	9770	9770		
	SUBTOTAL (DRY WT)	627876	643117	643117	643117		
20.0	PERSONNEL	476	476	476	476		
21.0	CARGO						
22.0	ORDNANCE						
23.0	RESIDUAL FLUIDS	11476	11476	11476	11476		
24.0							
	SUBTOTAL (INERT WT)	639828	655069	655069	655069		
25.0	RESERVE FLUIDS						
26.0	INFLIGHT LOSSES	20802	20802	20802	20802		
27.0	PROPELLANT-ASCENT	3382307	3382307	2941395	2749260		
28.0	PROPELLANT-CRUISE	143786	143786	143786	143786		
29.0	PROPELLANT-MANEUV/ACS	1500	1500	1500	1500		
30.0							
	TOTAL WEIGHT - LB	4188223	4203464	3762552	3570417		

DESIGNATIONS:

ITEM
- A *Reusable Orbiter
- B Space Station
- C Space Tug
- D Nuclear Stage
- E
- F

NOTES & SKETCHES

*Ref. SD 70-403-8, "Mass Properties Status Report," dated 1 May 1971.

2.0 BOOSTER SUBSYSTEM MODIFICATIONS

2.1 STRUCTURAL SUBSYSTEMS GROUP

The structural arrangement of the ESS booster, including the payload support platform, is shown in Figure 2-1. Except as defined in this section, the structure of the ESS booster is identical to the shuttle booster as presented in the Phase B Final Report, Vol. II, Book 3, Section 6.1 dated 26 March 1971.

The ESS structural loads are presented in Book 2 Paragraph 2.2.2.4 of this report. The critical structural components are the ESS support bulkheads at Stations 1866, 2096, 2666 and 2866, the aft part of the hydrogen tank, and the thrust section. Analysis shows that ESS loads exceed shuttle loads for some conditions and the influence on the structure in terms of modification and weight is presented here. All of the modifications discussed are required in the basic structure and must be permanently incorporated during initial airframe fabrication.

2.1.1 Space Station Payload

Critical loads are on the Station 1866 and 2866 bulkheads.

At Station 1866 for the maximum βq condition, the bulkhead receives an ESS side load of 224,000 pounds compared with 121,000 pounds from the shuttle. The higher load requires strengthening of the side load distribution structure in the upper one-third segment of the bulkhead as shown in Figure 2-2. The second stage attachment fitting and bulkhead cap areas, shear webs and web stiffeners of the shuttle structure are increased in size, adding 325 pounds of weight. The modification is confined to a reasonably local area because the general bulkhead and bulkhead-supporting body structure are designed for the significantly more critical maximum thrust condition of the shuttle.

The Station 2866 bulkhead receives a vertical load of 760,000 pounds from the space station, compared to the shuttle design load of 204,000 pounds. Higher ESS loads on this bulkhead result from the requirement that ESS be supported longitudinally from the aft end. The longitudinal support link introduces a vertical load into the Station 2866 bulkhead that for the shuttle is introduced into the intertank body structure at Station 2096. The ESS load requires a general strengthening of the bulkhead that adds 735 pounds to the shuttle weight. The tank skin adjacent to the bulkhead is

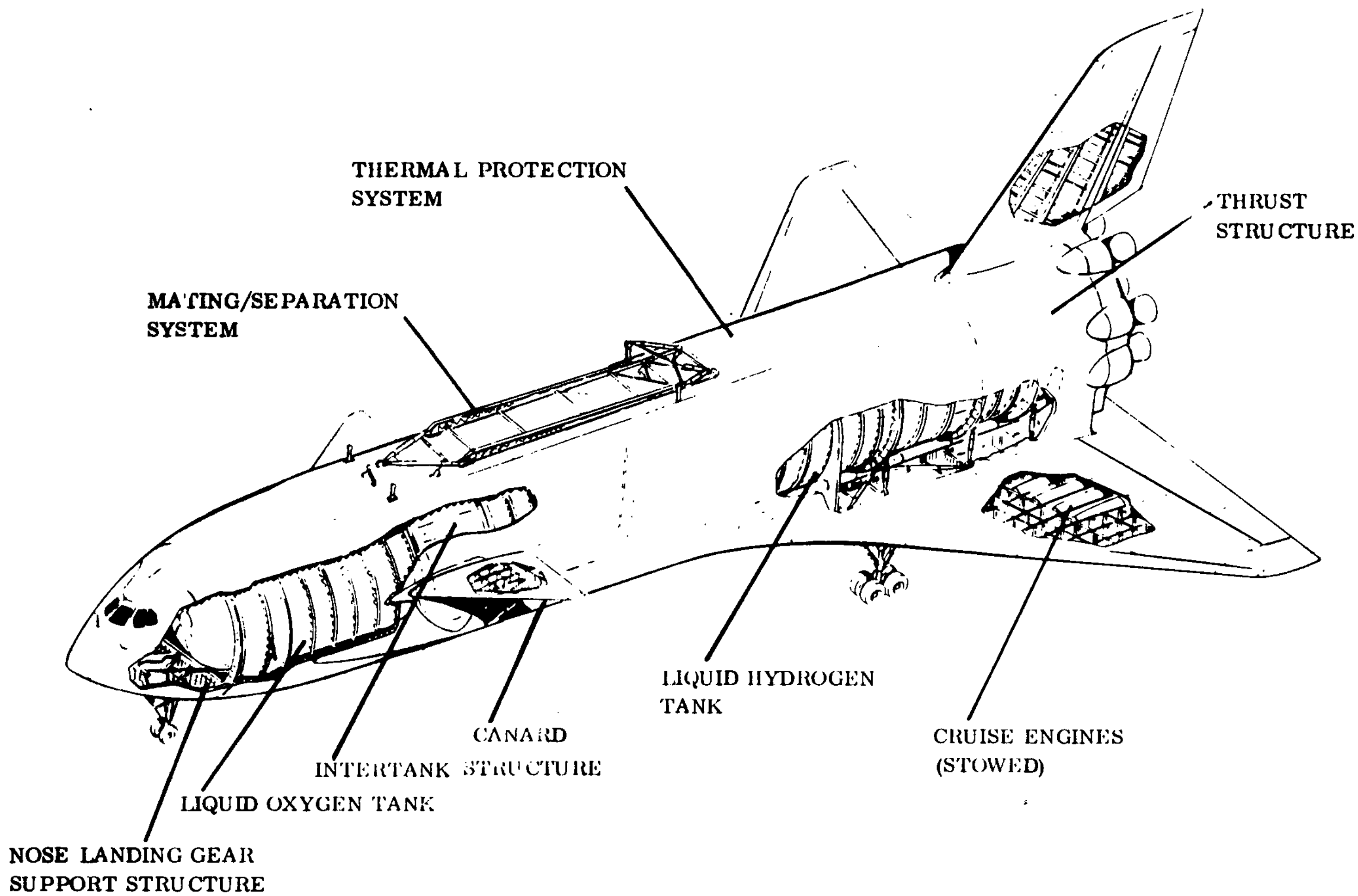


Figure 2-1. ESS Booster Structural Arrangement

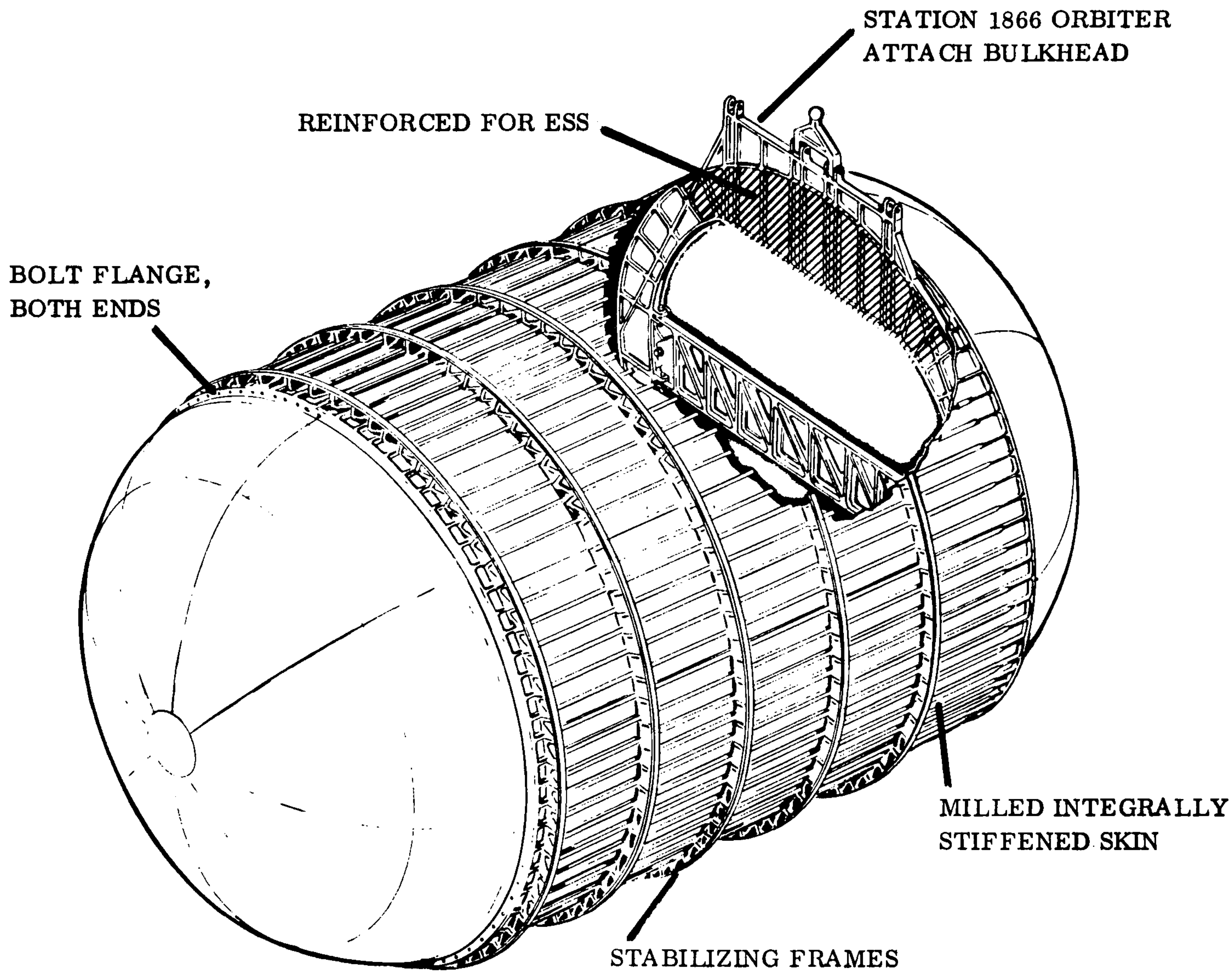


Figure 2-2. Liquid Oxygen Tank

increased in thickness to accommodate the distribution of increased shear load from the bulkhead into the body airframe, adding 200 pounds.

The aft segment of the LH_2 tank receives compression loads from ESS along the top and sides during conditions of maximum one-hour ground wind that exceed the shuttle design loads. At Station 3681 along the top centerline, the maximum ultimate compression load for the shuttle is 7325 pounds per inch and the comparable load for the ESS space station is 8596 pounds per inch. The tank skin, stiffeners, and frames in this area, as shown in Figure 2-3, require increased material thicknesses, adding 527 pounds to the shuttle tank weight.

The thrust structure also receives compression loads from ESS that exceed the shuttle loads. At Station 3921 along the top centerline the maximum ultimate compression for the shuttle is 8627 pounds per inch and for the ESS Space Station is 9393 pounds per inch. The critical condition is for ground wind while the vehicle is on the launch site so the hold-down fittings are affected as well as the adjacent skin, stiffener, and frame structure (Figure 2-4). These elements require increased thicknesses adding 1365 pounds to the shuttle weight.

A summary of the modification weights for the space station payload is presented in Figure 2-5. The total added weight is 3152 pounds.

2.1.2 Reusable Nuclear Shuttle Payload

The Station 1866 and 2866 bulkheads also receive critical loads from this payload.

At Station 1866 the ESS side load is 247,000 pounds, compared with 121,000 pounds for the shuttle. The bulkhead modification is the same as described for the Space Station. The weight increase is 354 pounds.

The Station 2866 bulkhead receives a vertical load of 618,000 pounds for ESS, compared with 204,000 pounds from shuttle. The required bulkhead modification increases weight by 685 pounds and strengthening of the adjacent skin adds 186 pounds.

The hydrogen tank is critically loaded for a local section along the side. The weight of tank structure required to accommodate the higher loads is 39 pounds.

A summary of the modification weights for the RNS payload is presented in Figure 2-6. The total added weight is 1264 pounds.

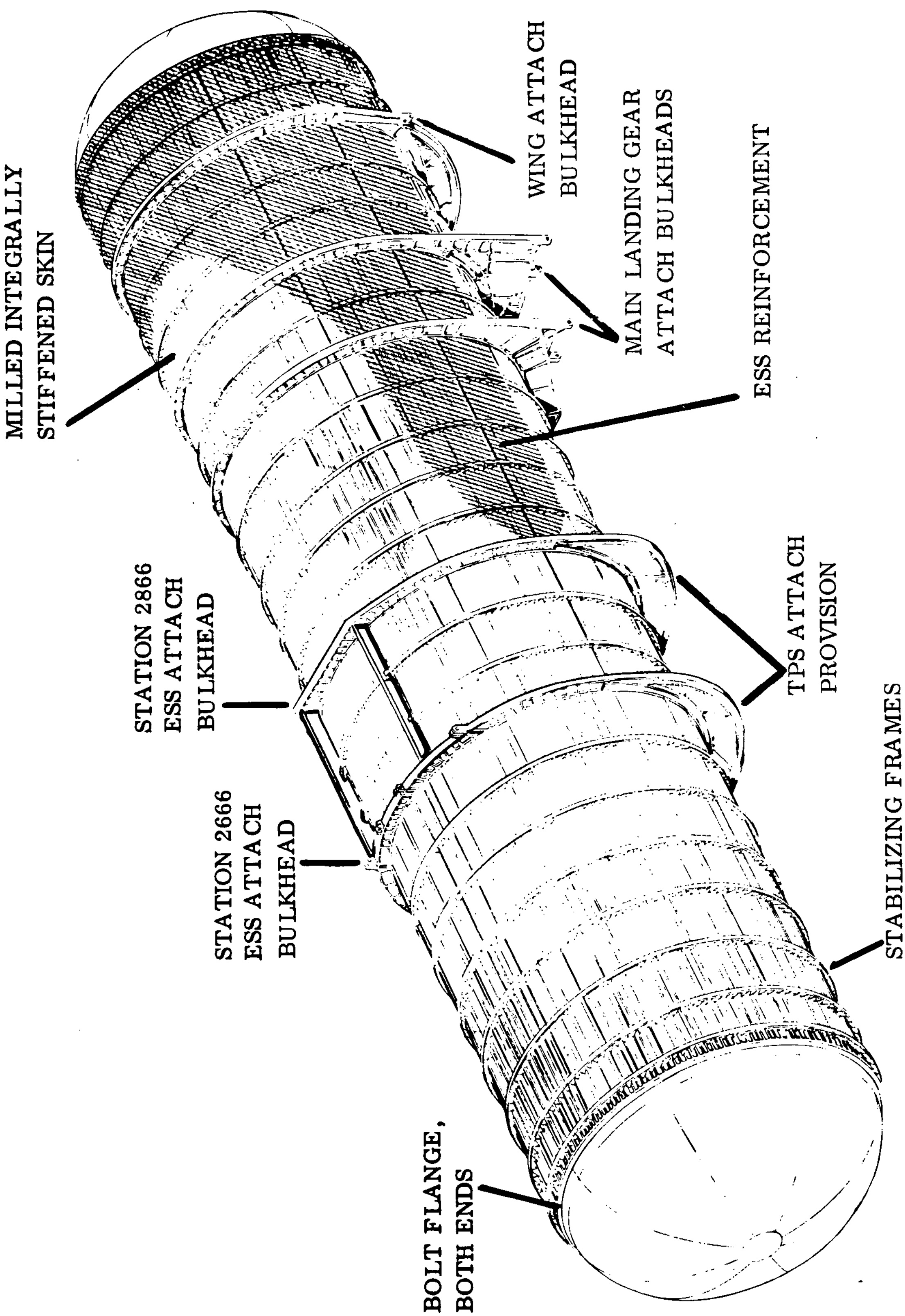


Figure 2-3. Liquid Hydrogen Tank

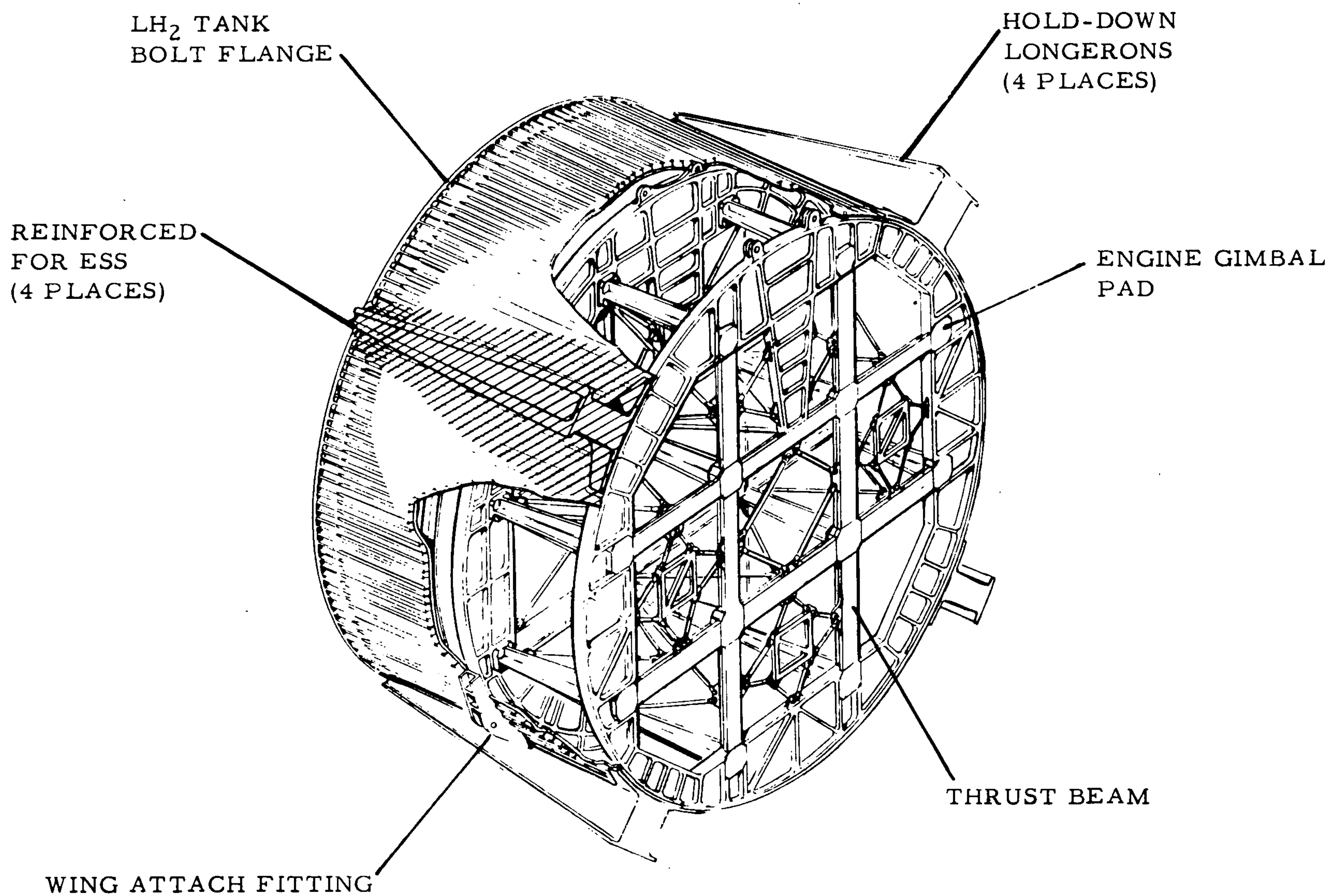
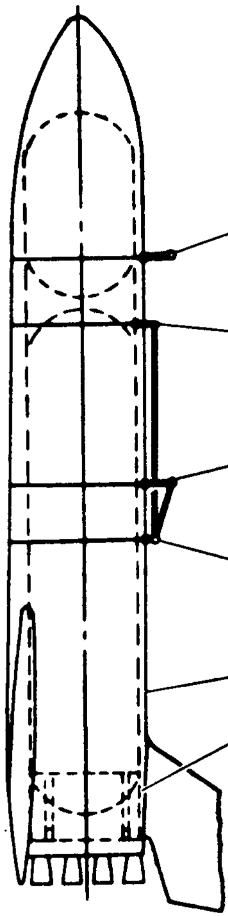
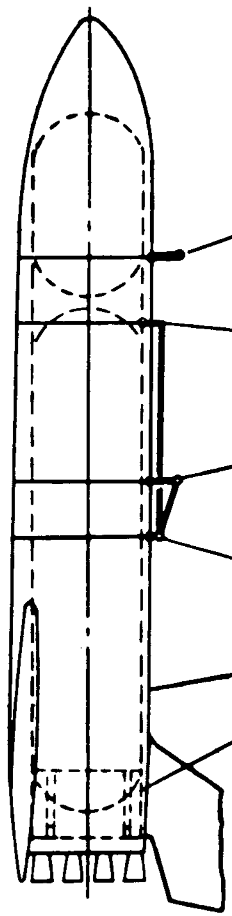


Figure 2-4. Thrust Structure



AFFECTED COMPONENT	CRITICAL CONDITION	ADDED WEIGHT (LBS)	
		GROUND CONDITIONS	FLIGHT CONDITIONS
STA. 1866 BULK'D	MAX βq	0	325
STA. 2096 BULK'D	-	0	0
STA. 2666 BULK'D	-	0	0
STA 2866 BULK'D ADJACENT SKIN	MAX THRUST	0 0	735 200
LH_2 TANK THRUST STRUCT.	1 HR. GROUND WIND	527 1,365	0 0
	TOTALS	1,892	1,260
		3152	

Figure 2-5. ESS/Space Station Effect on Structure Weight



AFFECTED COMPONENT	CRITICAL CONDITION	ADDED WEIGHT (LBS)	
		GROUND CONDITIONS	FLIGHT CONDITIONS
STA 1866 BULK'D	MAX. βq	0	354
STA 2096 BULK'D	—	0	0
STA 2666 BULK'D	—	0	0
STA 2866 BULK'D ADJACENT SKIN	MAX. THRUST	0 0	685 186
LH_2 TANK THRUST STRUCT.	1 HR GR'D W'D —	39 0	0 0
	TOTALS	39	1225
		1264	

Figure 2-6. ESS/Nuclear Stage Effect on Structure Weight

2.1.3 Space Tug Payload

Critical loads are applied to the payload support bulkheads at Stations 1866 and 2096.

At Station 1866 the ESS side load is 125,000 pounds, compared with 121,000 pounds for shuttle. The weight increase to accommodate the slightly higher load is negligible.

At Station 2866 the ESS vertical load is 638,000 pounds, compared with 204,000 pounds for shuttle. The weight increase for the higher load amounts to 692 pounds on the bulkhead and 187 pounds on the adjacent skin. The primary body loads for the space tug payload are within the shuttle load envelopes.

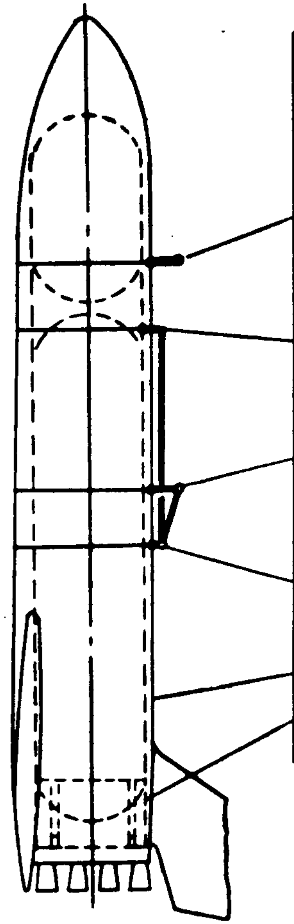
A summary of the Space Tug/ESS modification weights is presented in Figure 2-7. The added weight is 879 pounds.

2.1.4 Composite Booster

A booster that can accommodate all three ESS payloads requires a Station 1866 bulkhead designed for the RNS and a Station 2866 bulkhead, hydrogen tank, and thrust section designed for the Space Station payload. The total added weight of the composite booster is 3181 pounds as summarized in Table 2-1.

The weight analysis is summarized to show the influence of ground wind conditions and flight conditions. Loads analysis show that with nominal reduction in one-hour ground wind design velocity, the basic shuttle hydrogen tank and thrust section can support the ESS payloads without modification or added weight. The maximum weight increase with restricted ground winds is that required for flight conditions — 1289 pounds for a composite booster.

The shuttle thermal protection system, Figure 2-8, can withstand the aeroheating of the ESS missions without change, but requires structural modification to accommodate the installation of the ESS payload support platform. Four access doors are needed in the shuttle TPS upper surface to provide for penetration of the platform support fittings. During conversion from a shuttle to an ESS configuration, the doors are removed, the platform installed, and ESS doors reinstalled that close the openings and seal around the platform supports.



AFFECTED COMPONENT	CRITICAL CONDITION	ADDED WEIGHT (LBS) GROUND CONDITIONS	ADDED WEIGHT (LBS) FLIGHT CONDITIONS
STA 1866 BULK'D	MAX. βq	0	0
STA 2096 BULK'D	—	0	0
STA 2666 BULK'D	—	0	0
STA 2866 BULK'D ADJACENT SKIN	MAX. THRUST	0 0	692 187
LH_2 TANK THRUST STRUCT.	—	0	0
	TOTALS	0	879
		879	

Figure 2-7. ESS/Space Tug Effect on Structure Weight

Table 2-1. Summary of ESS Weight Increases, Booster Structure

ESS	ADDED WEIGHT (lb.)		
	GROUND CONDITIONS	FLIGHT CONDITIONS	TOTAL
NUCLEAR STAGE	39	1,225	1,264
SPACE STATION	1,892	1,260	3,152
SPACE TUG	0	879	879
COMPOSITE BOOSTER	1,892	1,289	3,181

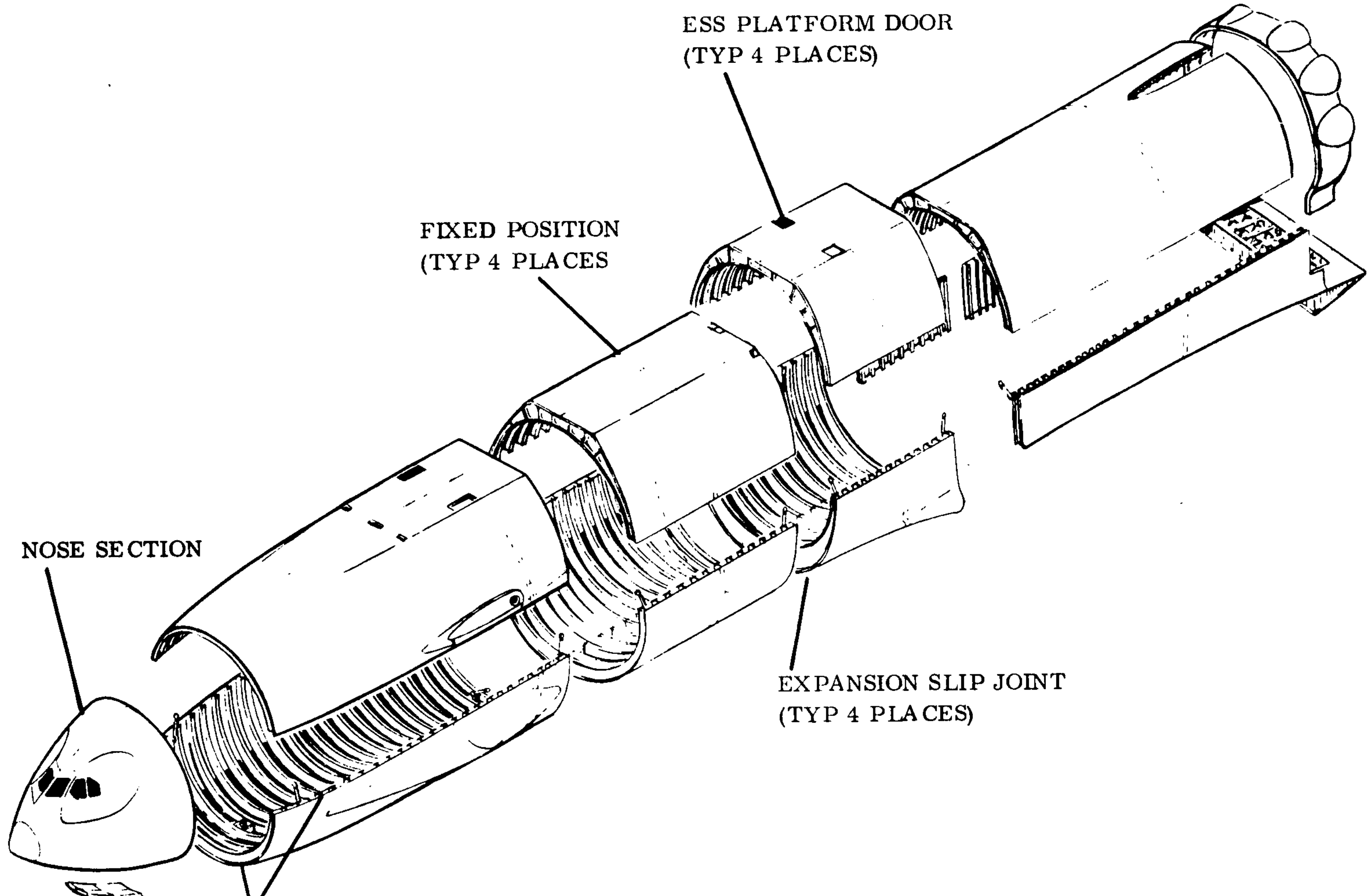


Figure 2-8. Body TPS Shell Structure

2.2 PROPULSION SYSTEMS

2.2.1 Main Propulsion

The booster main propulsion system provides thrust to the integrated vehicle from launch through ESS vehicle separation. The system as defined for shuttle is used for ESS and its various payloads without modification to any of the components. The system consists of twelve 550,000-pound thrust (sea level) high chamber pressure engines with a 35:1 area ratio operating at a mixture ratio of 6:1. Fail operational capability with loss of one engine and fail safe capability with the loss of two engines are obtained through operation of functioning engines at emergency power level (109 percent nominal). Auxiliary systems supporting the main rocket engines include propellant feed, propellant level sensing, loading, and tank pressurization and vent. These systems also are used without modification when the shuttle booster is used for an ESS mission.

During normal operations the engines are started simultaneously and brought up to 50 percent thrust. Each engine is held at 50 percent for an operating checkout. After engine operation is verified, the wind load hold-down links are released and their position verified. Approximately 500 milliseconds after the engine with the slowest thrust rise reaches 50 percent thrust, checkout and release is completed. The engine's thrust is then increased to 100 percent with liftoff occurring at a thrust to weight ratio (T/W) of 1.0. The actual thrust level at liftoff will vary as a function of the weight of the payload being delivered by the ESS.

On shuttle the engines are operated at 100 percent power (109 percent with one engine out) until 3.0 g vehicle acceleration is attained. All engines then are throttled to maintain 3 g acceleration. Throttling is initiated approximately 160 seconds after launch. When used with ESS the engines are throttled to 50 percent at burnout to keep the acceleration at burnout to a minimum. The actual time that throttling occurs and the maximum acceleration level for each payload is as shown.

ESS Payload	Time From Liftoff to Start of Throttling (sec)	Maximum g Level
Space station	130	2.06
RNS	160	2.48
Space tug	160	2.47

Throttling continues until a signal is received from the LO_2 or LH_2 depletion sensing systems. Following this signal the ESS engines are started, the vehicle separated, and the booster engines cut off. The engines are shut down simultaneously at a time in the separation sequence that insures vehicle separation and avoids propellant starvation to the engine.

The total engine operating time from liftoff to burnout compares with shuttle as follows:

	Shuttle	Space Station	RNS	Space Tug
Operating time (sec)	215	249	216	239

2.2.2 Auxiliary Propulsion System

The APS as defined for shuttle provides propulsive thrust to perform maneuvers and maintain booster control during atmospheric entry. This condition exists from booster/orbiter staging to transition to aerodynamic control flight mode. The propulsive thrust is generated by gaseous hydrogen and oxygen attitude control engines. Maintaining attitude control during main engine operation is not required. The system produces a total of 636,000 lb-sec of impulse and provides minimum vehicle accelerations of 0.3 deg/sec^2 in pitch, yaw, and roll from separation to (+) 100 seconds and 1.1 deg/sec^2-in yaw from (+) 100 seconds to approximately (+) 270 seconds.

The LH_2 storage tank capacity is approximately 3000 pounds and the LO_2 storage tank capacity is approximately 3200 pounds. Thirty thrusters at 2100 pounds thrust each are used to satisfy system control requirements. The APS system as defined for shuttle is capable of satisfying the ESS mission requirements without modification.

2.2.3 Airbreathing Engine System

The ABES provides propulsive thrust to power the booster from an entry point back to the base where it lands. Twelve P&WA JTF22A-4 engines are used. None of the changes made to the booster to accommodate the ESS affect this installation and the engine thrust characteristics are satisfactory.

2.2.4 Power Systems

Shuttle uses four auxiliary power units (APU) to provide for generation of hydraulic and electrical power during prelaunch checkout, boost phase, entry, flyback and post-landing phases. The system capability is as follows:

1. Electrical Generator Drive. The APU's provide to each of four electrical generators a shaft power of 32 hp nominal, 47 hp maximum continuous, and 63.5 hp for a maximum of 5.0 seconds.

2. Hydraulic Pump Drive. The APU's provide to each of four hydraulic pumps a shaft power in accordance with Figure 2-9. The total hydraulic power provided after launch is 906 hp-hr. Safe performance levels are achievable after two APU failures.

For the booster, as modified for the ESS, the power requirements during cruise, entry, and landing are the same as for shuttle. During the boost and entry phases of flight the booster is flying at lower dynamic pressures than encountered on the shuttle mission. Since this results in reduced power requirements, the power systems as defined for shuttle were considered satisfactory without further analysis.

2.3 AVIONICS

Replacing the orbiter with the ESS will result in very minor hardware changes in the avionics equipment or its interconnections. Significant changes must be made in the software that is sensitive to the mated vehicle configuration.

2.3.1 Hardware

The general design of the booster and orbiter is such that each vehicle is essentially autonomous. A provision is made for transferring computer data and crew voice between vehicles. The data link will allow the booster vehicle to monitor critical data from the ESS for safety reasons. Commands also can be sent to the ESS, utilizing the existing capability. The voice link between the two vehicles would not be required when the ESS is used.

2.3.2 Software

The software programs that are mated vehicle configuration dependent and require changes when the ESS is used are shown below. Also included are the maximum and minimum number of words that require changing for each booster vehicle:

Software Categories	Max Words	Min Words
1. Abort logic	1000	500
2. Processing for display	3000	1500
3. Performance monitoring	3000	1500
4. Guidance	6000	3000
5. Flight control	2500	1200

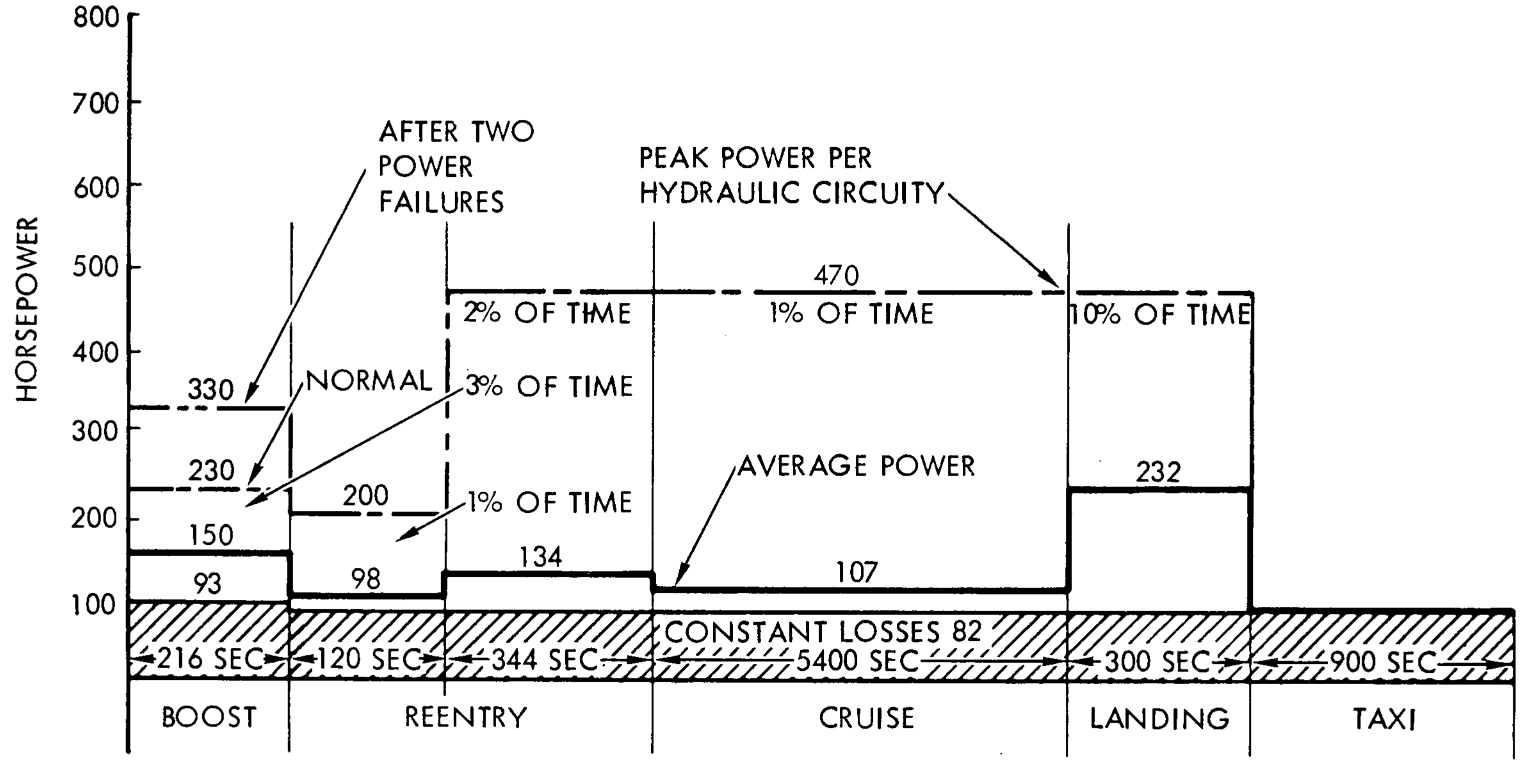


Figure 2-9. Booster Hydraulic Power Versus Time for Each of Four Hydraulic Circuits

3.0 BOOSTER/ESS SEPARATION SUBSYSTEM

The baseline orbiter/shuttle mating/separation subsystem is defined in SD-71-114-2, Phase B Final Report, Volume II, Book 3, paragraph 6.1.5, dated 26 March 1971. This section describes the separation system for the booster mated with an expendable second stage (ESS) consisting of a modified S-II and its various payloads. The primary differences (described in detail later in this section) between the orbiter/shuttle and the booster/ESS mating/separation subsystem are due to the following factors:

1. Differences in primary load paths. These dictated the use of a structural adapter as described later in this section.

2. Differences in mass properties and trajectories required changing of booster thrust scheduling at the staging points.

3.1 REQUIREMENTS

The booster/ESS mating/separation subsystem is designed for the following capabilities:

1. The mating/separation subsystem shall be capable of withstanding all loads imposed during ground operations and mated flight.

2. The subsystem shall provide safe separation during normal staging with one or two ESS engines operating and with two ESS engines operating and two booster engines inoperative.

3. The separation mechanism shall have FO/FO capability. For purposes of interpreting the redundancy requirements, the primary load paths through the links, joints, pivots and bearings of the stage interconnect structure and separation subsystem are considered primary structure.

4. Operation of the separation subsystem shall not produce any debris (including explosive residue) which could damage the booster or ESS.

5. The subsystem shall provide independent separation control from both ESS and booster, which does not rely on crew management.

3.2 DESCRIPTION

The ESS is separated from the booster in a manner similar to separation of the orbiter from the booster. Booster thrust is used to accelerate the ESS transversely from the booster. Forces for the transverse separation are transmitted by the rotating links located at the fore and aft linkage attach points on the fixed platform shown schematically on Figures 3-1 and 3-2. The fixed platform is supported by the same structural hard points provided for the orbiter/booster mating/separation subsystem—that is, fittings located on the two major forward bulkheads and the two major aft bulkheads. Forces are transmitted to the ESS through linkage attach points provided. Design loads corresponding to three ESS configurations are shown on Figures 3-3, 3-4, and 3-5.

3.2.1 Structural Adapter

The booster, as used for shuttle operations, reacts longitudinal loads at the forward booster/orbiter mating structure as shown in Figure 3-6. If this arrangement were used for the ESS, a major redesign of the ESS forward skirt and hydrogen tank structure would be required. If the shuttle separation linkage and structural arrangement were redesigned so that longitudinal loads were to be reacted by the aft linkage and structure as shown on the bottom of Figure 3-6, an extensive redesign of the booster hydrogen tank structure would be required. Since the study objectives specify that the impacts on the ESS and booster structure be minimized, a structural adapter was provided, as shown schematically in Figures 3-1 through 3-5. This adapter is pinned to the same hard points of the booster which are designed to react the longitudinal loads induced by the orbiter on the booster. Longitudinal loads are transmitted to the adapter by the aft diagonal links and transferred by the platform to the aforementioned hard points. This arrangement provides maximum structural compatibility between the ESS and the booster and minimizes the structural impact on each. This arrangement, however, induces a vertical load component at the aft booster bulkhead as shown. The effect of this force component on the aft bulkhead is described under structural subsystems, Subsection 2.2.

The structural arrangement of the adapter is shown on Figure 3-7. The adapter, denoted "Fixed Platform," consists of two longitudinal trusses, machined fittings, and suitably placed cross members. The platform is configured to transmit the vertical, lateral and longitudinal loads induced by the ESS during ground operations and mated flight. The estimated weight of the platform—shown on Table 3-1 is based on the use of 718 Inconel in all principal load carrying members. Insulation is applied locally to minimize

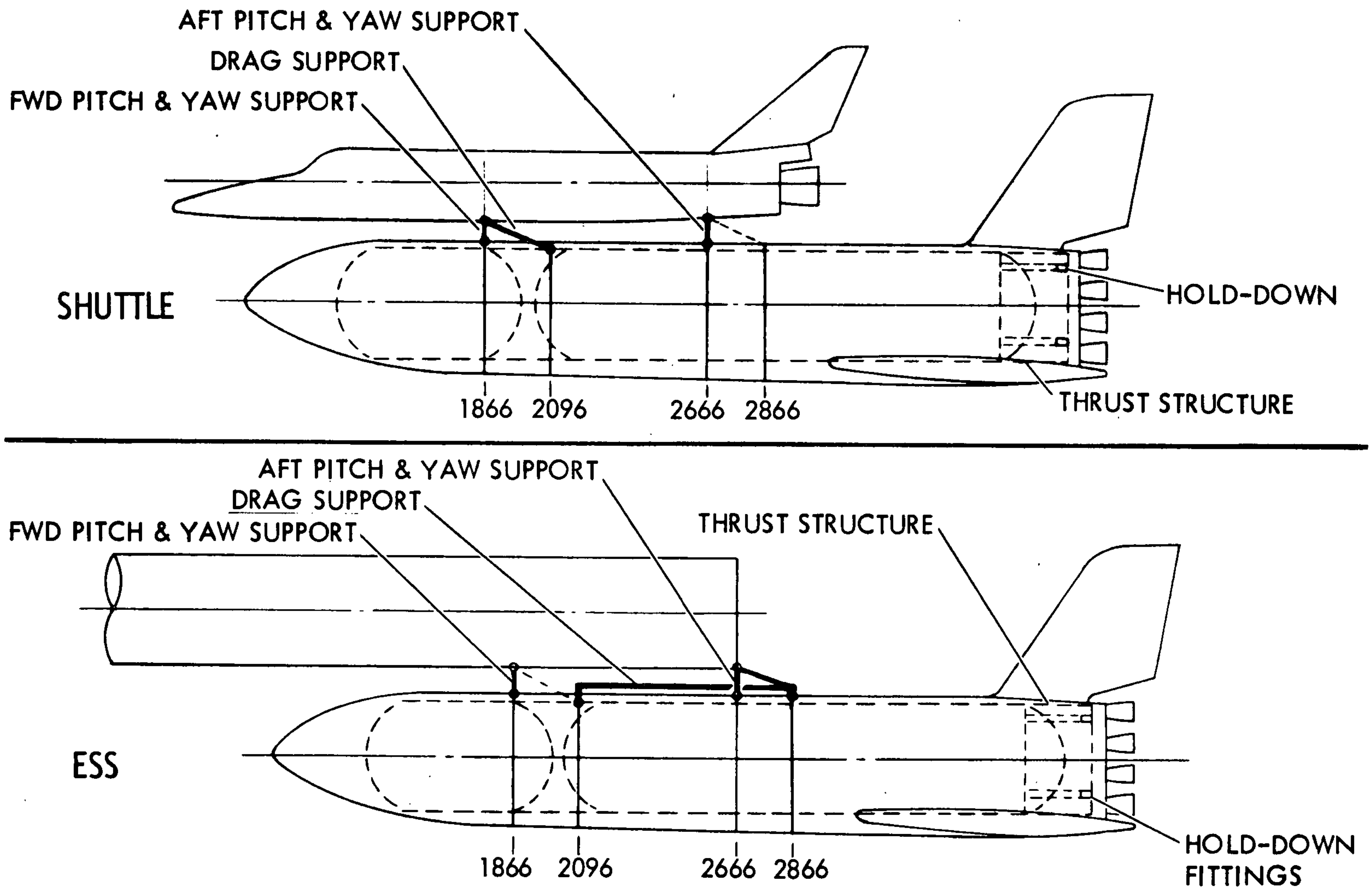


Figure 3-1. Mating/Separation System Structure Schematic

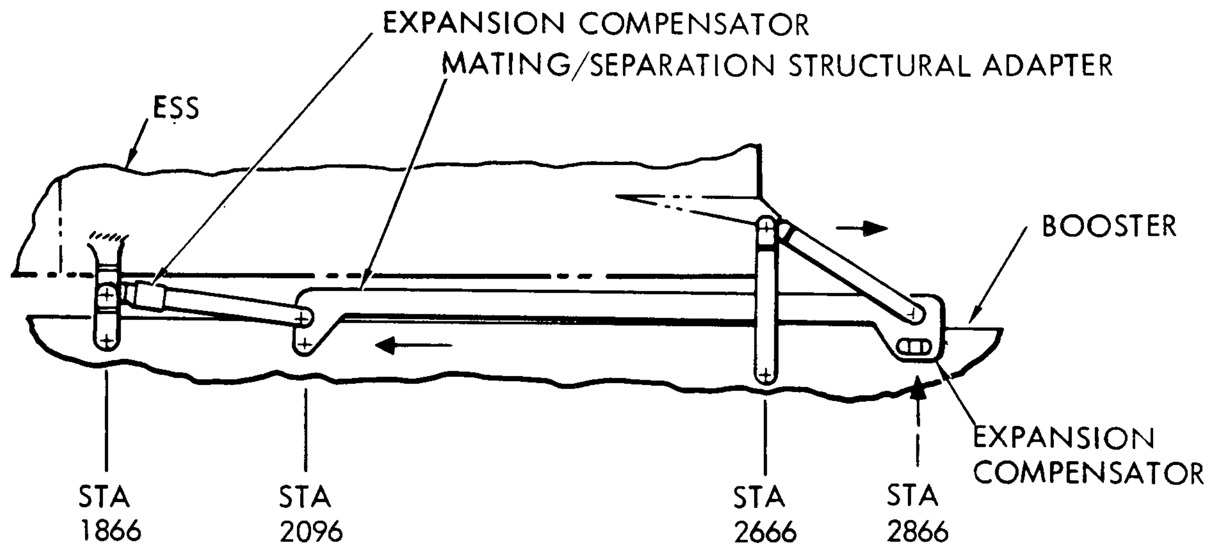
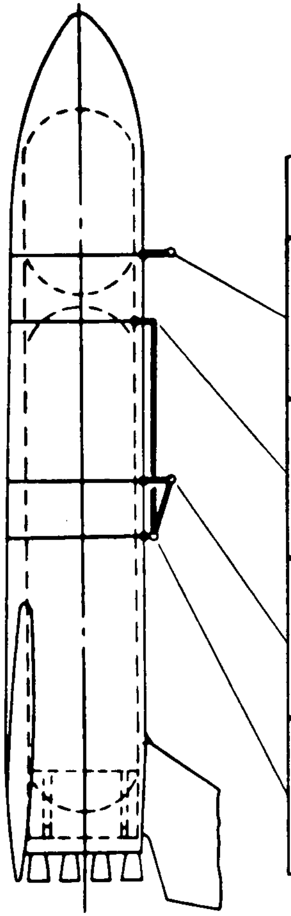
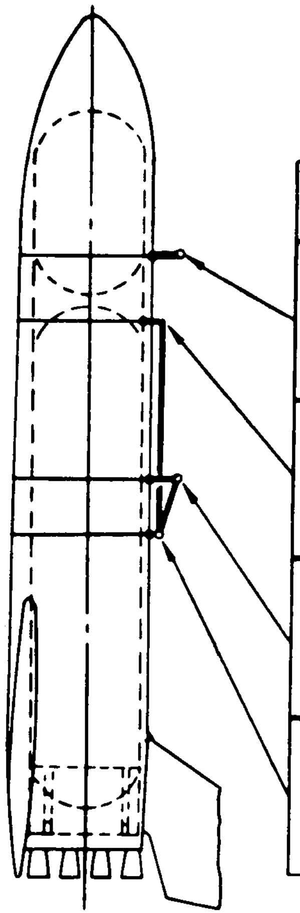


Figure 3-2. Booster/ESS Mating/Separation System, Structural Adapter Schematic (Fixed Platform)



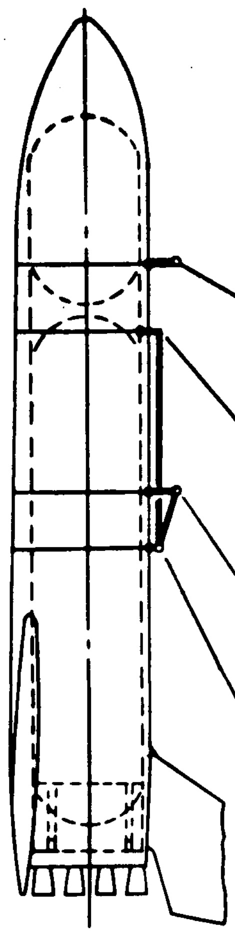
STATION	LOADS — KIPS (LIMIT) SHUTTLE COND.			ESS		
	COND.	VERT.	HORIZ.	VERT.	HORIZ.	COND.
1866	MAX. THRUST	778	0	409	0	MAX αq
	2 WEEK GR. WIND	85.7	121	161	$\boxed{247}$	MAX βq
2096	MAX. THRUST	584	2824	-59	1818	MAX. THRUST
	—	—	—	—	—	—
2666	MAX αq	842	0	184	0	MAX αq
	MAX βq	120	225	-294	182	MAX βq
2866	SEPARA-TION	204	390	$\boxed{618}$	0	MAX. THRUST
	—	—	—	—	—	—

Figure 3-3. ESS/Nuclear Stage Effect on Bulkheads



STATION	LOADS — KIPS (LIMIT): SHUTTLE COND.	SHUTTLE VERT.	SHUTTLE HORIZ.	ESS VERT.	ESS HORIZ.	ESS COND.
1866	MAX. THRUST	778	0	486	0	MAX. THRUST
	2-WK. GR. WIND	85.7	121	306	$\boxed{224}$	MAX βq
2096	MAX. THRUST	584	2,824	-72.4	2,240	MAX. THRUST
	—	—	—	—	—	—
2666	MAX αq	842	0	-350	0	MAX αq
	MAX βq	120	225	-164	158	MAX βq
2866	SEPARATION	204	390	$\boxed{760}$	0	MAX. THRUST
	—	—	—	—	—	—

Figure 3-4. ESS/Space Station Effect on Bulkheads



STATION	SHUTTLE COND.	SHUTTLE VERT.	SHUTTLE HORIZ.	ESS VERT.	ESS HORIZ.	ESS COND.
1866	MAX. THRUST	778	0	424	0	2.47 G MAX. TH.
	2 WEEK GR. WIND	85.7	121	302	$\boxed{125}$	MAX βq
2096	MAX. THRUST	584	2824	-61	1874	2.47 G MAX. TH.
	—	—	—	—	—	—
2666	MAX αq	842	0	-130	0	MAX αq
	MAX βq	120	225	-34	38.8	MAX βq
2866	SEPARA-TION	204	390	$\boxed{638}$	0	2.47 G MAX. TH
	—	—	—	—	—	—

LOADS — KIPS (LIMIT)

Figure 3-5. ESS/Space Tug Effect on Bulkheads

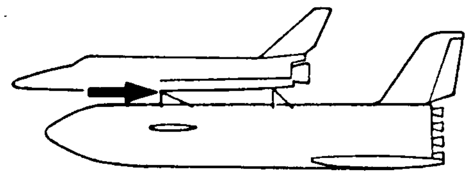
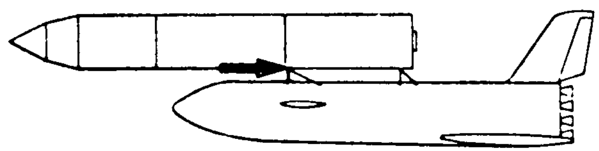
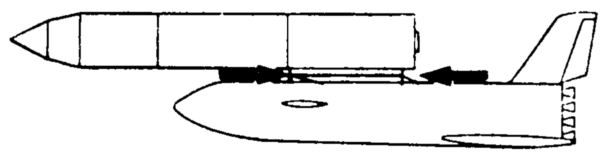
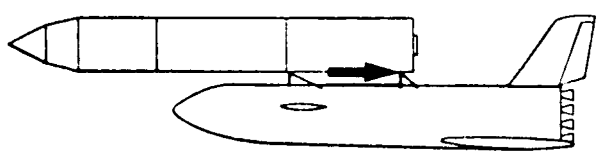
	CONFIGURATION	COMMENTS
SHUTTLE		AXIAL LOAD APPLIED AND REACTED AT FORWARD BOOST AND ORBITER ATTACHMENT FITTINGS
ESS OPTIONS		SHUTTLE APPROACH — REQUIRES REDESIGN OF ESS FORWARD SKIRT AND LH_2 TANK STRUCTURE
		ADAPTER TO TRANSFER AXIAL LOAD FROM FORWARD BOOSTER FITTINGS TO AFT SECTION OF ESS
		REACT AXIAL LOAD AT AFT BOOSTER/ESS ATTACHMENT. REQUIRES EXTENSIVE MODIFICATIONS TO BOOSTER HYDROGEN TANK STRUCTURE

Figure 3-6. Separation System, Shuttle and ESS

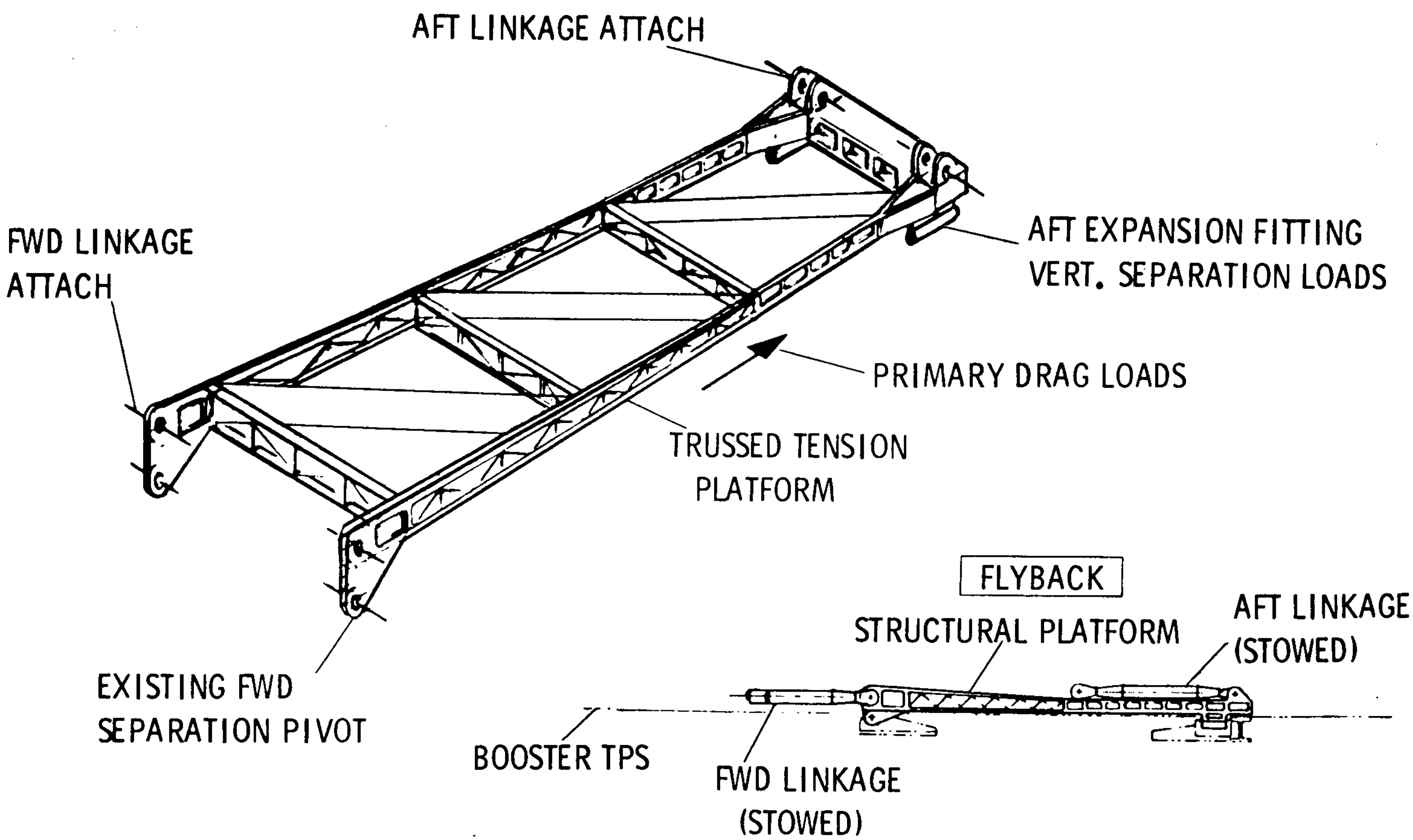


Figure 3-7. Fixed-Platform Concept, Booster/ESS Separation

Table 3-1. Separation System Summary Weight Statement

Item	Weight (lb)
Forward link set *	1963
Aft link set *	4629
Fixed platform *	9770
Total	16,362 ▲

Notes:

*Includes Insulation
▲Total weight of structural/ mechanical bolt-on items

thermal stress effects where necessary. The aft expansion fittings interface with mating bolt-on fittings attached to the hydrogen tank frame of the booster. A basic advantage of the fixed platform is that the pivot points for the rotating link are divorced from the structural hard points provided on the booster. This facilitates rotating link geometry changes and simplifies installation of the platform/linkage assembly on the booster.

3.2.2 Forward Linkage Arrangement

The forward linkage arrangement resembles the aft linkage arrangement of the baseline booster/orbiter separation system. In the rotatable "A" frame an expansion compensator, as shown on Figure 3-8, functions as on the baseline system by accommodating forward/aft structural/thermal deformations between the ESS and platform. Axial loads are not transmitted by the expansion compensator until the separation maneuver is started. The vertical links react vertical loads, and the lateral restraint, the spherical end of which nests in a socket-like fitting in the ESS, reacts side loads until the separation maneuver is effected. Vertical and lateral links attach to the existing linkage attached points on the booster.

As in the baseline system, spherical bearings are used at the pin joints to facilitate installation and to compensate for structural deflections and provide relative motion.

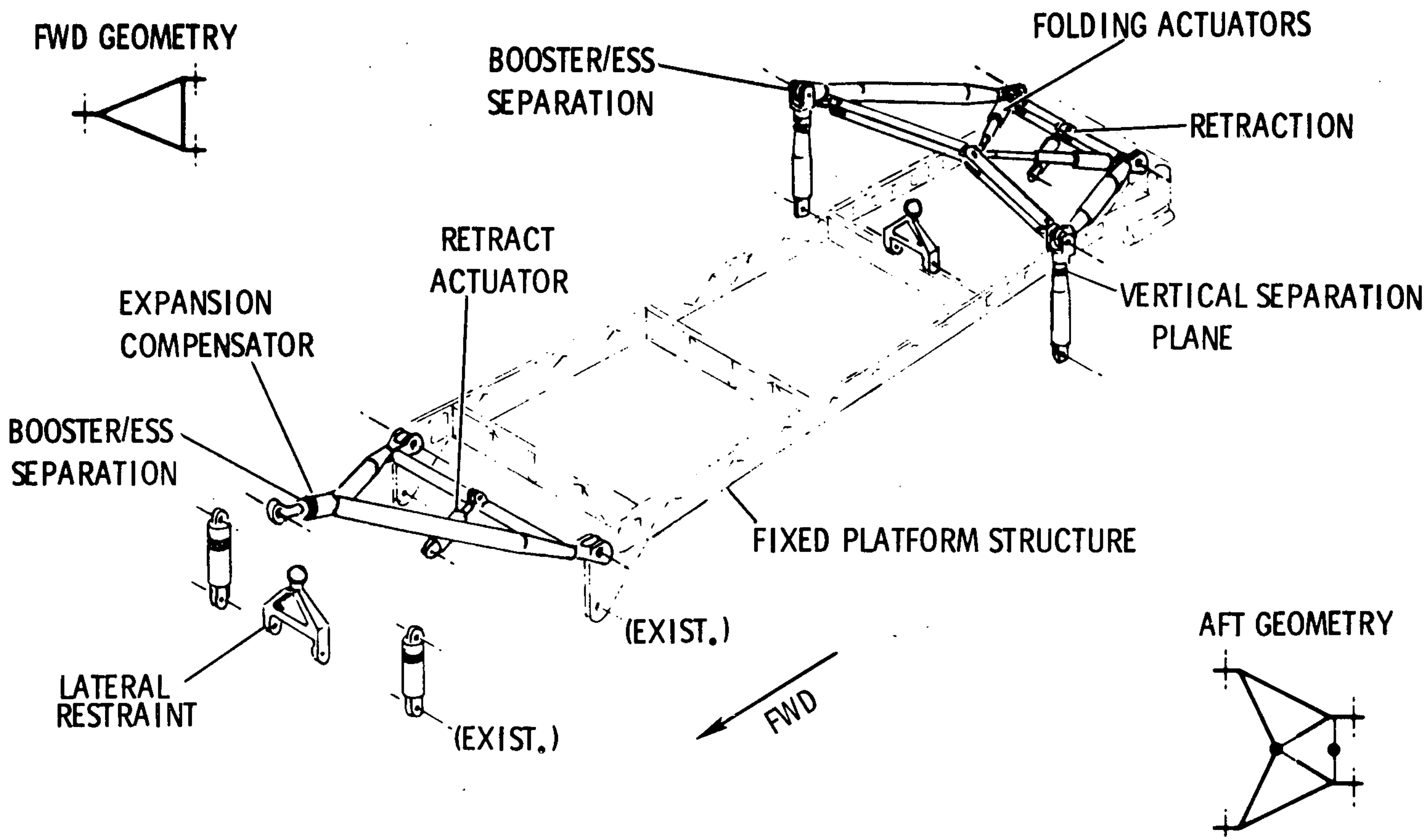


Figure 3-8. Fixed-Platform Linkage Concept, Booster/ESS Separation

A snubber/retract actuator is provided to snub and retract the rotating "A" frame link to a faired position after separation has been completed.

3.2.3 Aft Linkage Arrangement

The aft linkage arrangement, shown on Figure 3-9, consists of the vertical links which react vertical loads only, the lateral restraint member which reacts side loads only, and rotating links. The vertical and side restraint members attach to the same lugs provided for the baseline orbiter/booster separation system. The aft rotating links, however, pivot about lugs which are integral to the fixed platform. Also, as for the forward links, the aft rotating links are snubbed and retracted after separation has been completed. In addition, the aft links are made to fold inward to facilitate protection of those elements during reentry and to reduce drag during the flyback phase. Spherical bearings are provided at critical points to facilitate installation alignment and to compensate for structural deflections.

3.2.4 Pyrotechnic Devices

Explosive bolts, shown in Figure 3-9, are used for separation as they are in the baseline orbiter/booster mating/separation subsystem. The upper ends of the vertical and rotating links are equipped with the explosive bolts. Redundancy is achieved by providing dual separation planes. Independent charges and igniters are provided for each plane. In addition, redundant electrical input signals are provided for each igniter. Housings on the attach fittings provide for containment of loose pieces. A shaped charge is provided to sever the links in the event of failure of the explosive bolt.

3.2.5 Conversion

Conversion of a booster configured to carry an orbiter to a configuration suitable for carrying an ESS requires the following:

1. Remove orbiter/booster software and install ESS/booster software used in conjunction with the separation controller. Software is pecular to each ESS/booster configuration.

2. Remove all booster/orbiter-peculiar separation mechanism components and install the fixed platform separation mechanism assembly and retract/snubber actuators described in this section. Removal of access doors provided in the booster TPS is required for installation of this hardware. Refer to Figures 3-10 and 3-11 for a description of hardware to be removed.

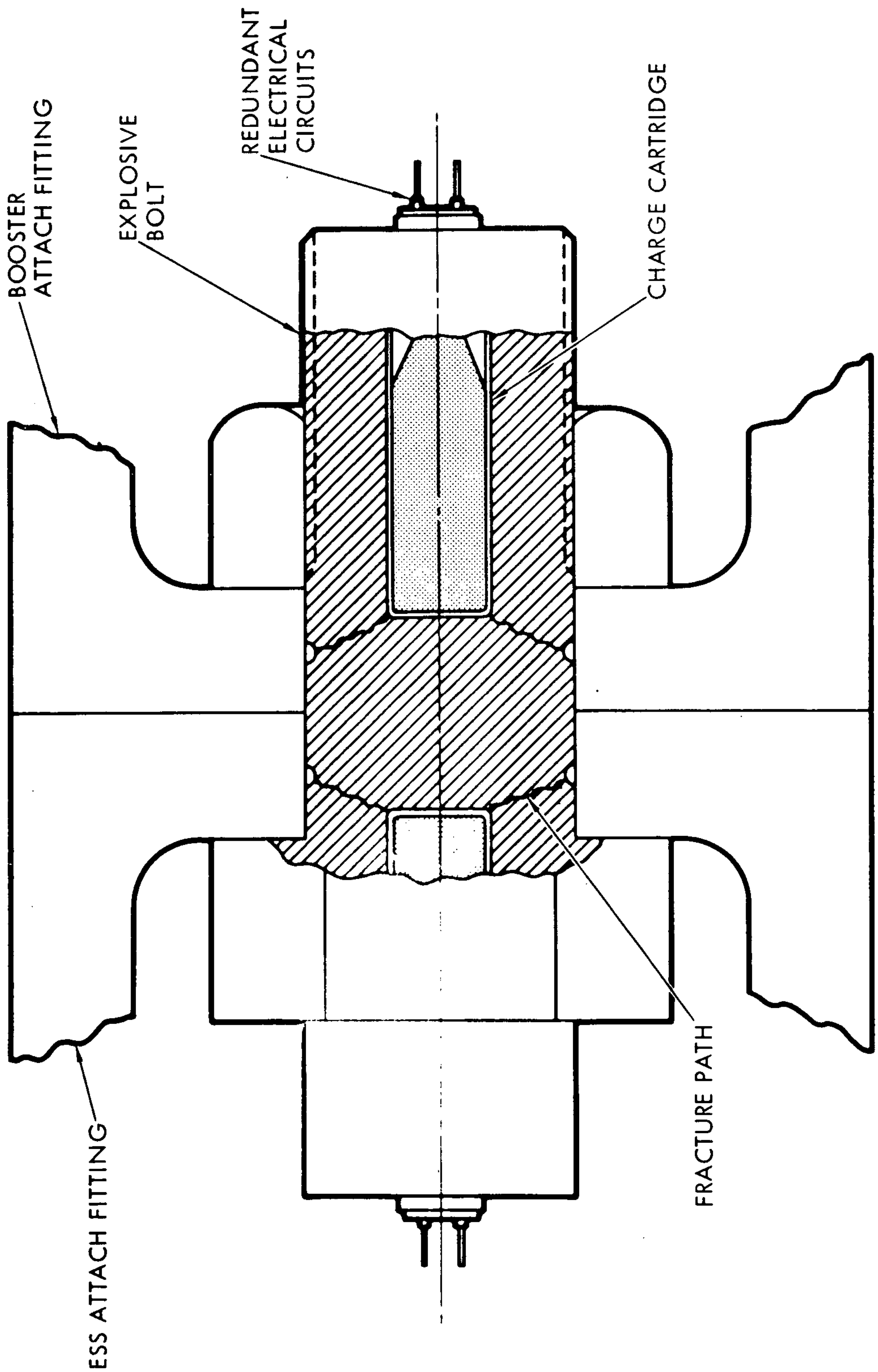


Figure 3-9. Typical Explosive Bolt Arrangement

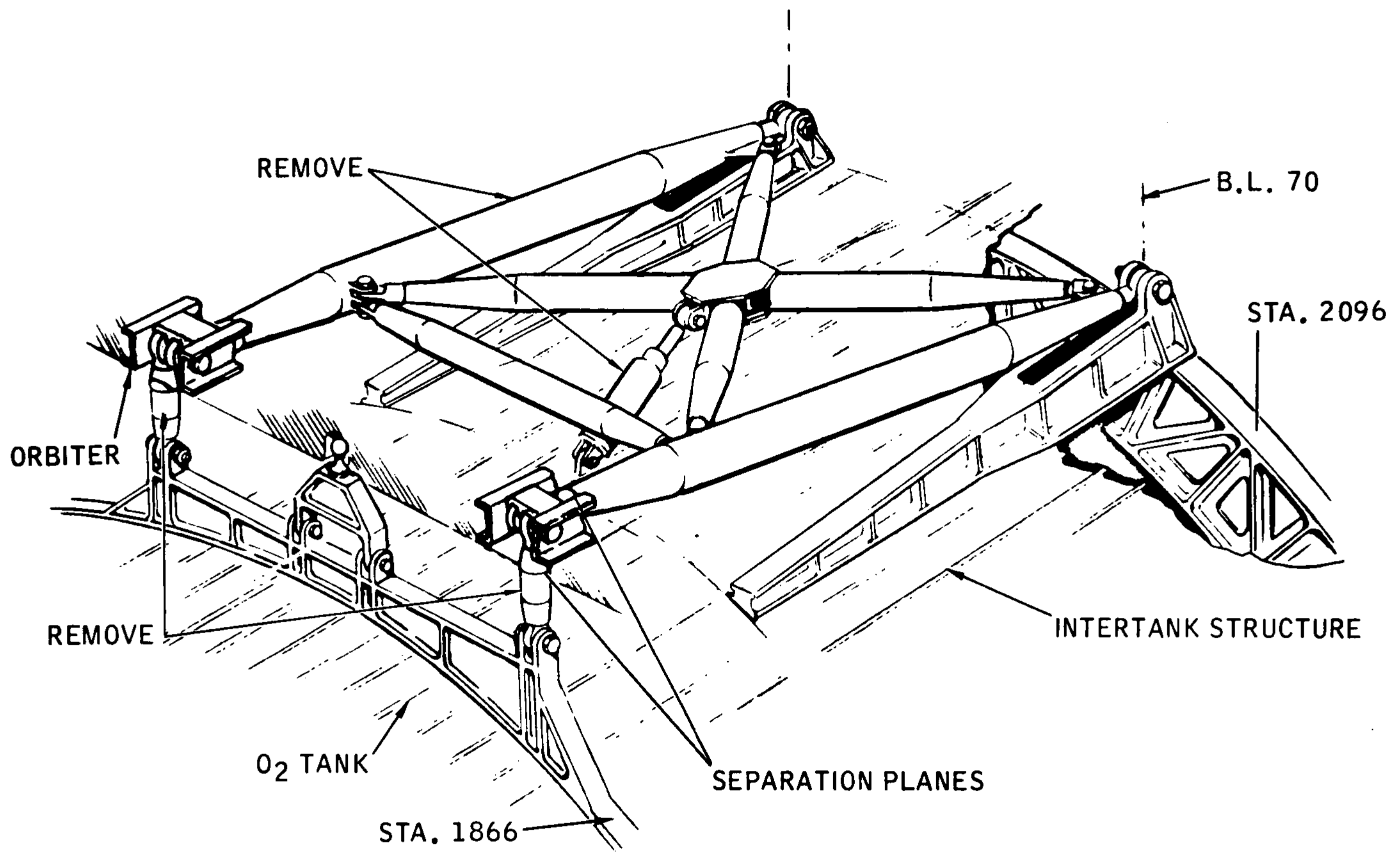


Figure 3-10. Baseline Mating/Separation System, Forward Attachment

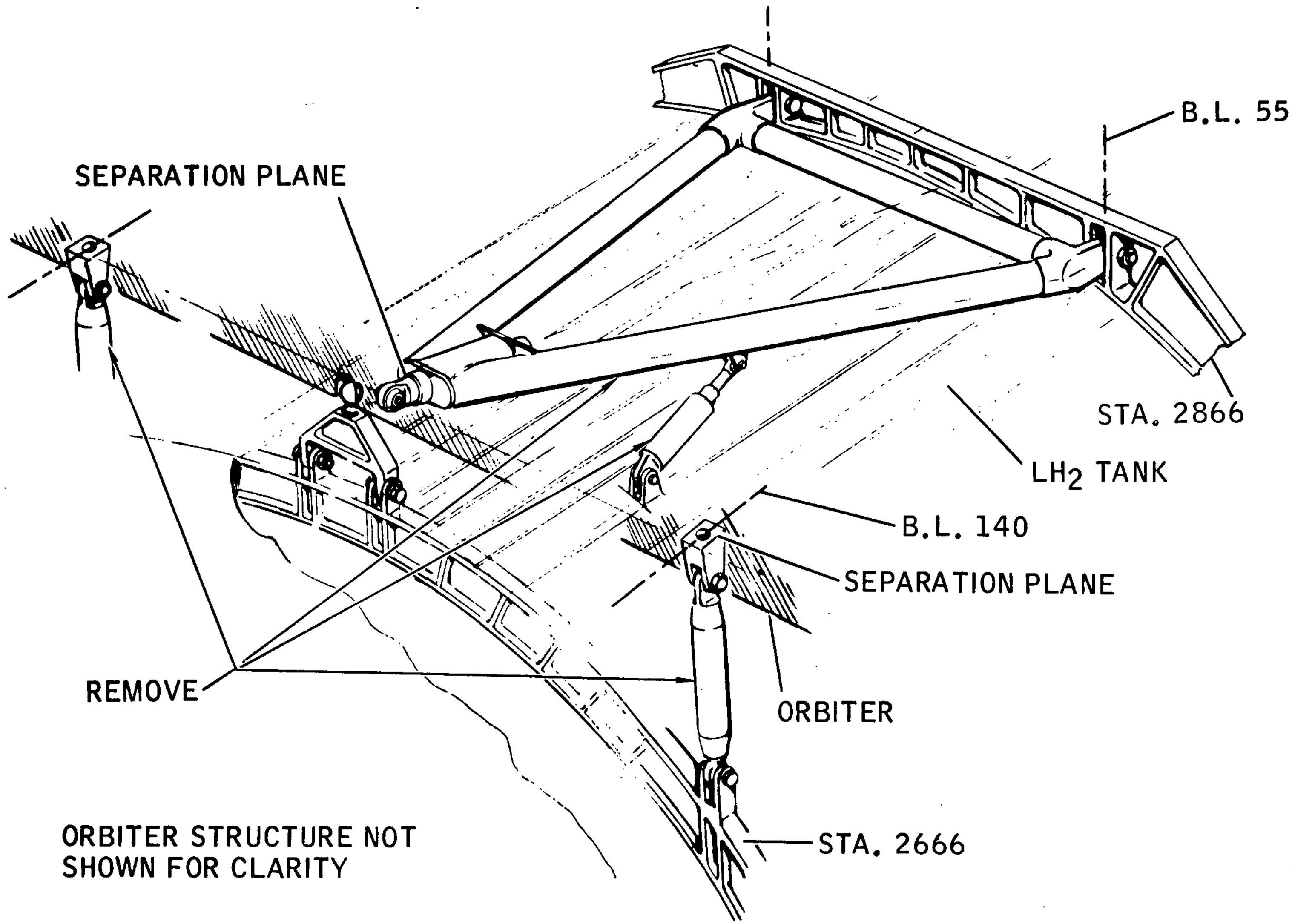


Figure 3-11. Baseline Mating/Separation System, Aft Attachment

3. Make all data links and breakwire connections as required.

4. Perform subsystem checks as required.

3.2.6 Operational Sequence

Booster and ESS thrust scheduling relative to disconnect timing is shown in Figure 3-12. A signal from the booster LO_2 depletion sensor initiates—as in the baseline system—throttling of booster engines to 50 percent thrust and concurrently the ESS engines are started. The rate of change of booster thrust as it drops to the 50 percent thrust will be small since the thrust level is limited to only slightly greater than 50 percent during the final boost phase. When the ESS engines are at 50 percent thrust, the explosive bolts in the four vertical links are fired, thus releasing vertical restraint on the ESS. At the same time the expansion compensator in the forward rotating frame is caused to lock and 0.10 second later booster engine cut-off occurs. After the vertical links are broken, the booster accelerates longitudinally relative to the ESS. When this occurs the rotating links provide the transverse ESS acceleration. After a .75 second time delay, the explosive bolts restraining the ESS to the rotating links are fired, freeing the ESS from the booster. Immediately upon ESS release the snubber/retractor actuators are activated to return and lock the rotating links to their fired positions. In addition, the aft link members are drawn inward by actuators.

The control of all sequencing functions necessary for accomplishing separation and maintaining control of both the ESS and booster is accomplished by software in the main computer. This includes thrust scheduling, release timing, link retraction, guidance, engine gimbaling, and attitude control (ACPS).

3.3 MODIFICATIONS

Modifications required to adapt the ESS to the booster are essentially of two types:

1. Built-in or fixed

2. Bolt-on, recoverable (reuseable).

This discussion deals with those removable or ESS-flight-peculiar elements. Because the booster/orbiter mating/separation subsystem and interfacing structure are designed to accept longitudinal boost phase induced loads at

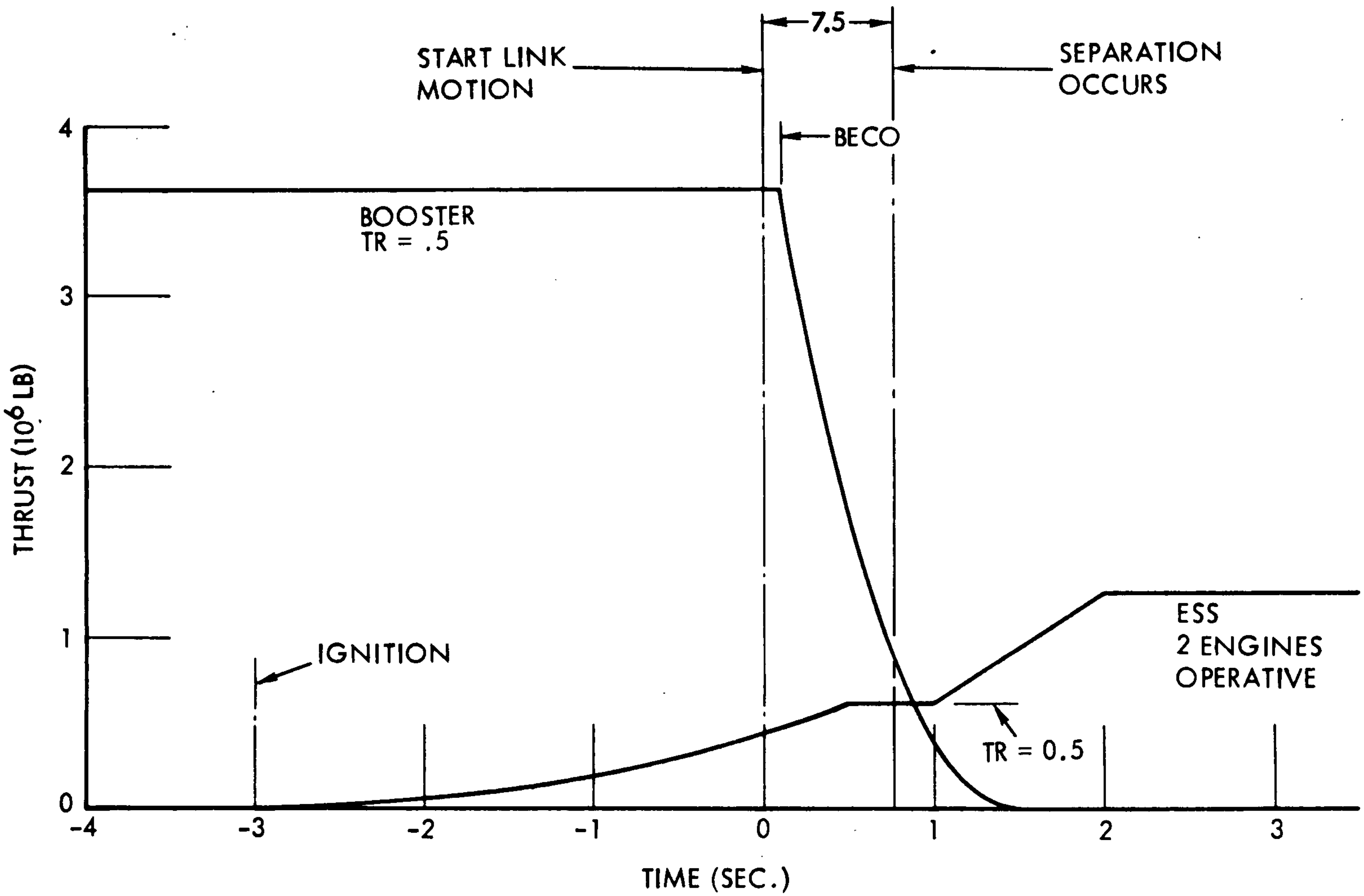


Figure 3-12. Thrust Scheduling, Normal Staging of ESS With RNS Payload

the forward link set, and because the S-II of the ESS is designed to accept thrust loads at its aft skirt structure, a method has been developed which facilitates transfer of longitudinal boost phase induced loads from the forward link attach points on the booster to the aft skirt structure of the ESS. This method also incorporates the booster-thrusted separation linkage concept utilized in the baseline. Figures 3-13, 3-14, and 3-15 depict the load transfer means as well as the separation subsystem linkage. The fixed platform serves as the aforementioned load transfer element. The vertical, lateral, and swing links function as they do in the baseline booster/orbiter separation subsystem; however, the swing link expansion compensator—located in the aft swing links of the baseline subsystem—is now located in the forward swing links of the booster/ESS linkage subsystem. Also, the aft swing linkage elements are made to retract and fold inward to facilitate protection of those elements during reentry and to reduce drag during the flyback phase.

The present booster/ESS release elements consist of pyrotechnic devices similar to those proposed for use in the baseline booster/orbiter subsystem.

Another fundamental difference exists between the baseline subsystem and the booster/ESS separation system. Separation initiation commands cannot emanate from the ESS as in the case for the baseline booster/orbiter subsystem. Initiation of the separation maneuvers is a booster command which is based upon monitored inputs from both the ESS and the orbiter. Obviously, computer software used in conjunction with the separation controller is unique for each booster/ESS integrated vehicle.

3.4 PERFORMANCE

Convair Digital Program P5255 was used, as for the shuttle orbiter/booster cluster, to solve the equations of motion of the ESS/booster separating at the normal staging point where aerodynamic effects are minimal. Output of the program included vehicle displacements, velocities, accelerations, and linkage loads. The program was used to simulate separation of the following payloads from the booster:

1. An ESS with the RNS payload
2. An ESS with the space station payload

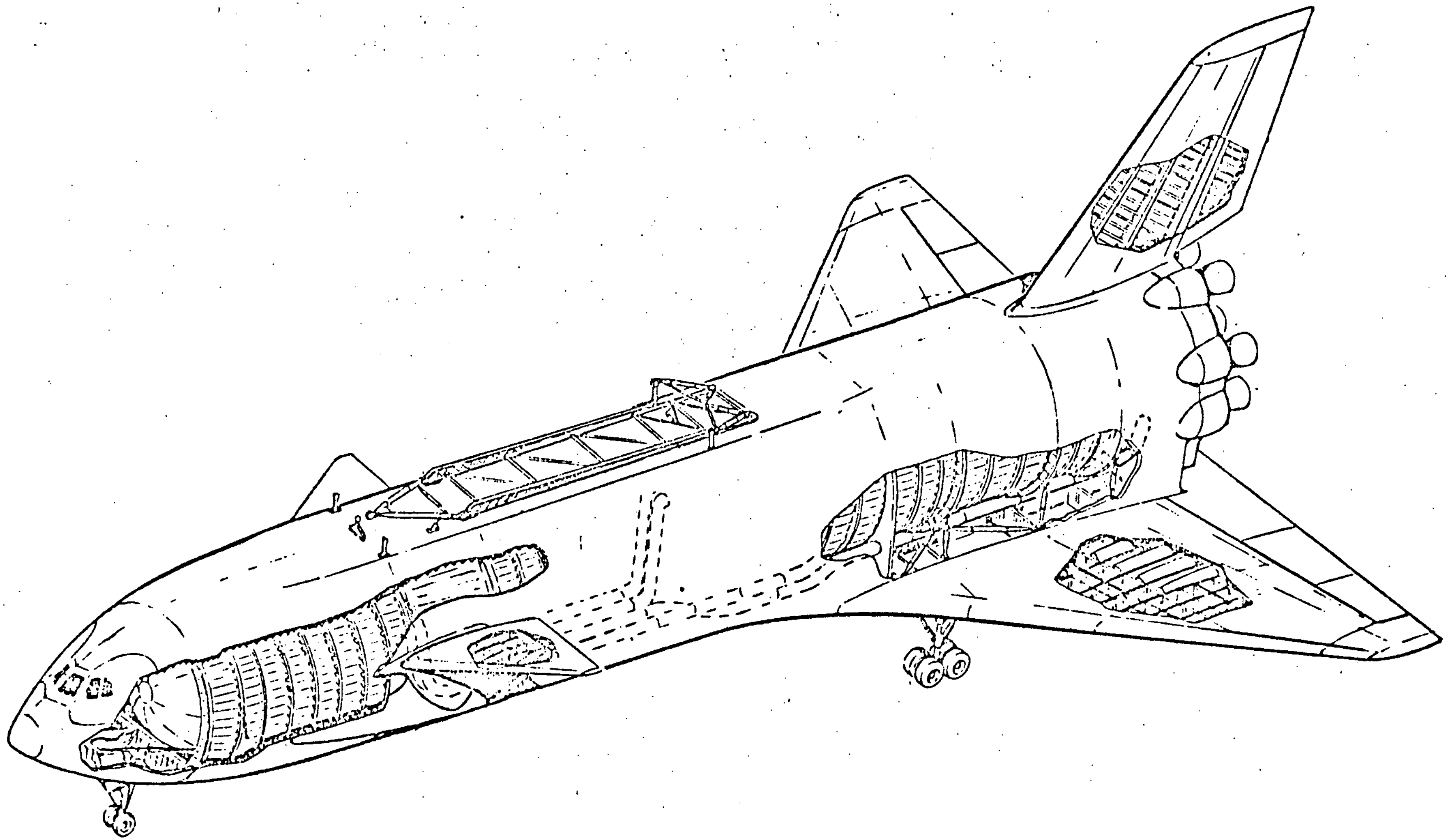


Figure 3-13. Separation System Linkage/Load Transfer Elements, General Arrangement

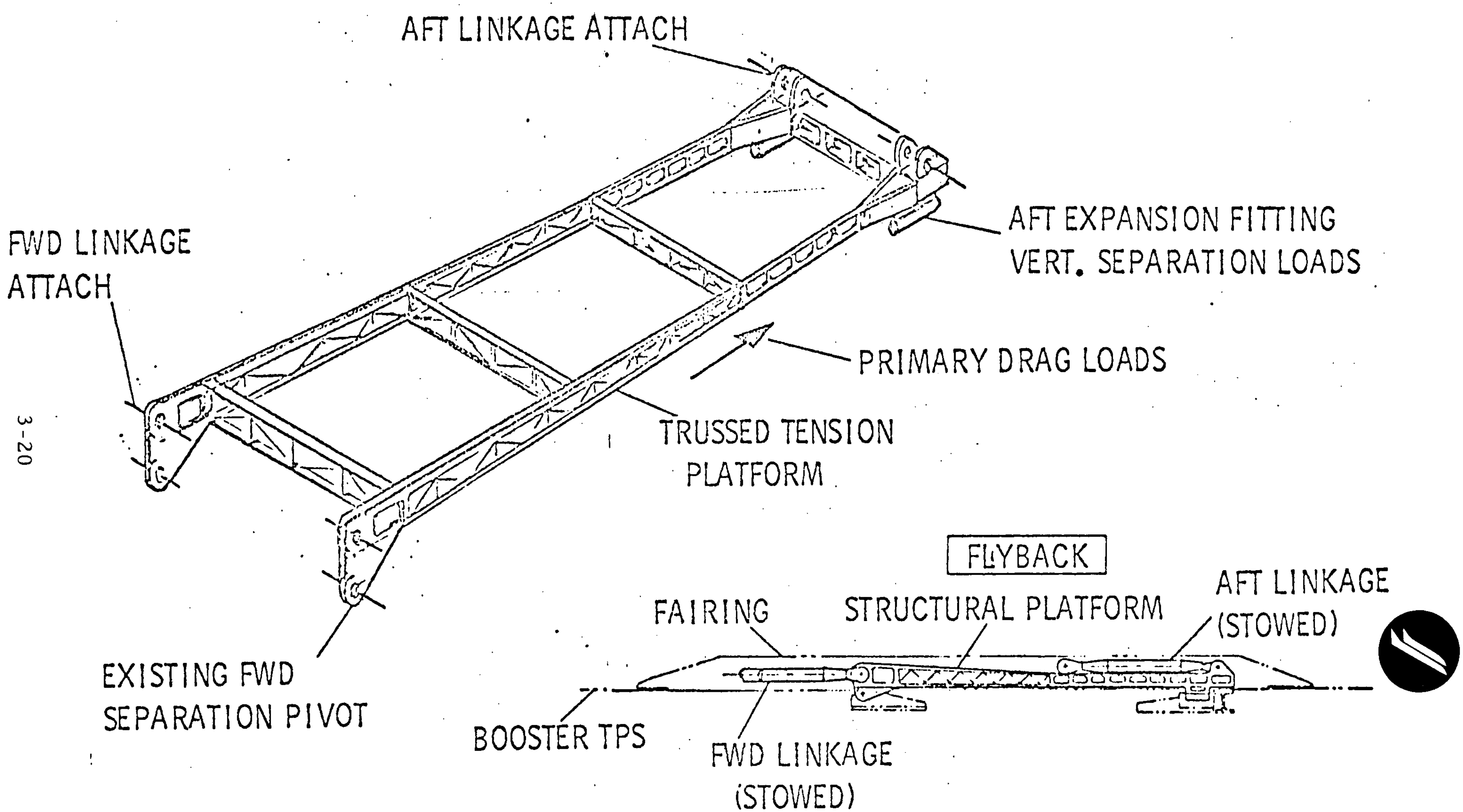


Figure 3-14. Fixed-Platform Concept, Booster/ESS Separation

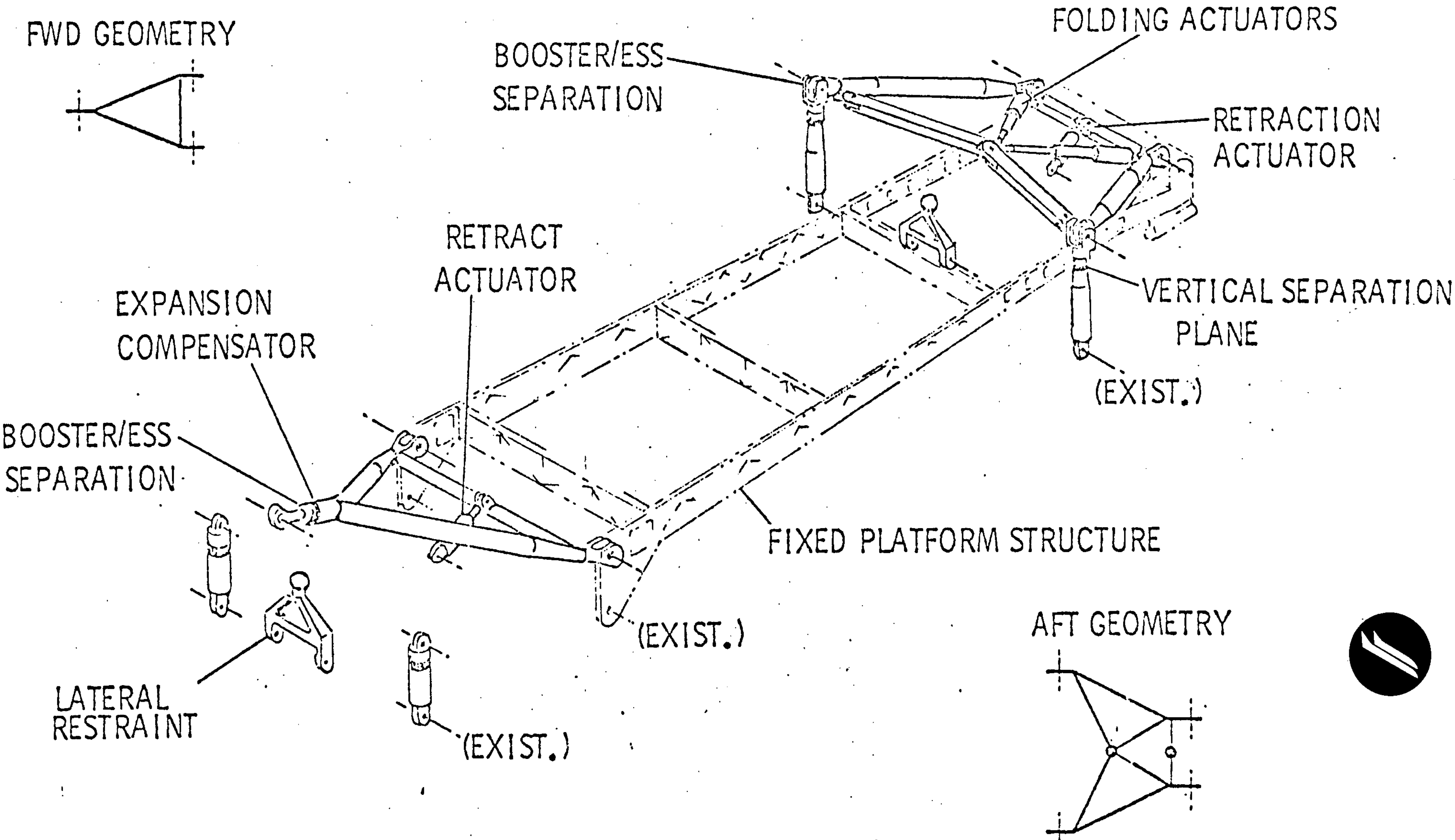


Figure 3-15. Fixed-Platform Linkage Concept, Booster/ESS Separation

Separation trajectories were not defined for the ESS/space tug case. A comparison of payload mass properties and end boost trajectory data indicated that separation simulation of this payload was not warranted since the aforementioned booster payloads bound the separation kinematics problem. Refer to Table 3-2 for a comparison of payload mass properties.

Integral to Convair Digital Program P5255 is the capability to let either "Theta Release" or "Time of Release" govern final release of the ESS from the rotating links. Theta release is the relative pitch angular difference between the ESS and the booster at the instant of ESS release from the rotating links. Theta release was made to govern release for the following graphs. However, as noted previously in the operational sequence portion of this section, Time of Release ultimately may be used to control final separation. Discussion of these two values is included in the following paragraphs.

For the ESS (RNS) payload, separation trajectories are shown in Figures 3-16 and 3-17 for two ESS engines operative and one ESS engine operative, respectively; corresponding thrust schedules are shown on Figures 3-18 and 3-19; typical link loads as a function of time are depicted by Figure 3-20. Each of the separation trajectories, illustrating relative attitudes and clearances, indicate satisfactory booster/ESS relative clearances, relative attitudes, and manageable booster and ESS inertial pitch rates subsequent to separation. As noted on the trajectory curves, stabilization of the booster may be achieved within approximately three seconds through the use of the booster attitude control propulsion system which—as the graphs indicate—was not used in the computer simulations. Also, stabilization of the ESS may be effected with ease since ESS engine thrust is available. For the one ESS engine out condition, the trajectory of Figure 3-17 and the thrust scheduling shown on Figure 3-19 indicate that a satisfactory separation may be obtained even if the thrust of one ESS engine is stabilized (allowed to dwell) at 50 percent. Normally, however, ESS engine dwell is not used when one ESS engine is inoperative. If one ESS engine is inoperative, dwell or thrust stabilization at 50 percent is automatically increased to 100 percent as shown on Figure 3-21. Elimination of the ESS engine dwell period would cause the trajectory of Figure 3-17 to improve—that is, longitudinal clearance would increase as vertical clearance diminished by a small amount.

Typical link loads versus time, as illustrated by Figure 3-20, indicate that an earlier release at approximately 0.75 second may be effected. This corresponds to the time when the load in link L1 is approximately zero.

Table 3-2. Comparison of Booster Payloads

Item	ESS (RNS)	ESS (Space Tug)	ESS (MDAC Space Station)
Stage weight (lb)	669,420	691,523	991,687
CG at ESS station (in.)	445.4	443.0	475.0
Inertia (pitch) (slug ft^2)	45.2×10^6	30.5×10^6	46.2×10^6

For the MDAC Space Station configurated ESS, separation trajectories are shown on Figures 3-22 and 3-23. Thrust schedules are shown on Figures 3-21 and 3-24. Typical load versus time histories are shown on Figure 3-25.

As in the case for the RNS-configurated ESS, separation trajectories for the ESS configured with the MDAC space station are satisfactory in all respects. The normal staging separation trajectories shown on Figure 3-22 indicates, for BECO points at 0.1 second and 0.2 second, respectively, that ESS/booster relative clearances, relative angles, and inertial pitch rates are acceptable. Also, BECO timing is not critical. Furthermore, as in the case for the ESS (RNS), stabilization of the booster by the attitide control propulsion system is well within the capabilities of that system. ACPS acceleration capability is 0.73 deg/sec/sec. As noted previously, computer simulation of the separation maneuvers did not include ACPS simulation; consequently, the increasing pitch rates of the booster result from small aerodynamic effects. Stabilization of the ESS presents no problem for reasons specified previously.

Figure 3-24 illustrates the effect of BECO timing upon release timing when Theta release, as previously noted, governs final release. When Time of Release is made to govern—which is normal for the timed separation sequence—final separation will occur at approximately 0.75 second when the load in the aft rotating link L1 is approximately zero (Figure 3-25).

For the case of one ESS engine (MDAC configuration) inoperative, the trajectory is shown on Figure 3-23 and thrust scheduling is shown on Figure 3-21. The same conclusions regarding clearances, attitudes and vehicle pitch rates apply. Figure 3-21 illustrates normal ESS engine phasing for the one ESS engine operative condition.

PITCH RATES (INERTIAL)
(DEG/SEC)

TIME (SEC.)	BOOSTER	ESS
-2	+1.65	+1.65
-1	+0.94	+0.94
0	+1.82	+1.82
1	-1.44	+0.08
2	-1.53*	+1.87
3	-1.58*	+1.71
4	-1.62*	+ .87

*BOOSTER ACPS NOT USED IN SIMULATION

BOOSTER ACPS CAPABILITY
0.73 DEG./SEC./SEC.

CONCLUSION: STABILIZATION TIME ≈ 2 SEC.

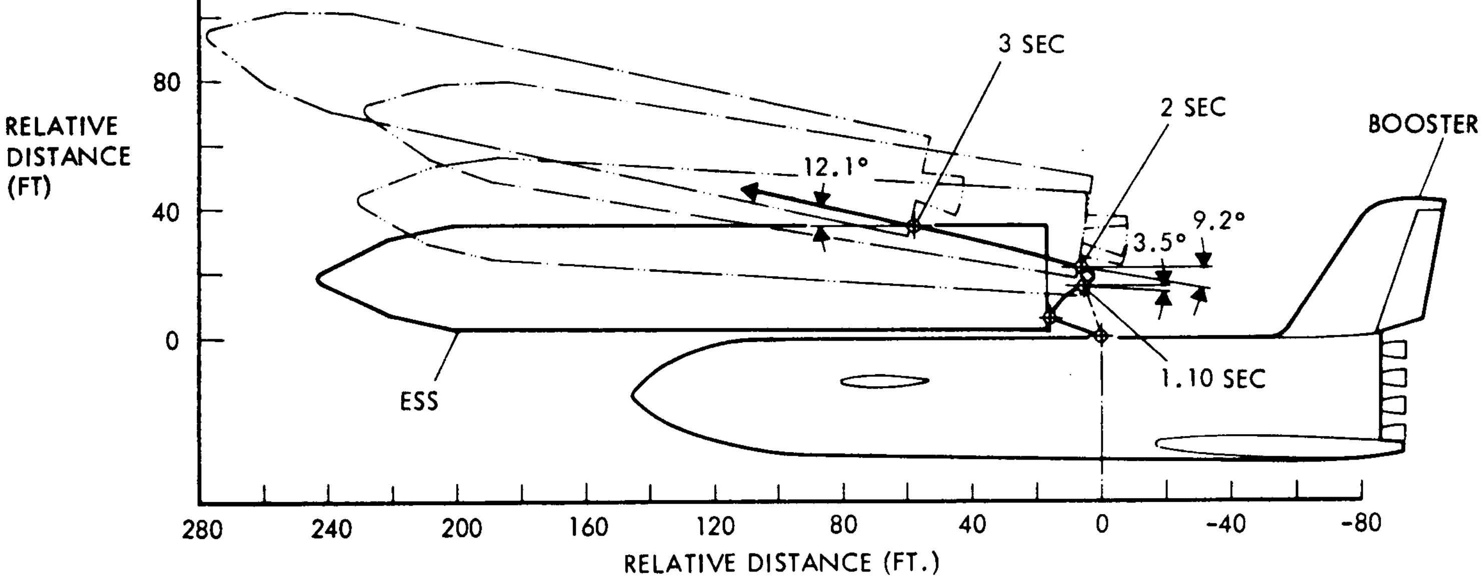


Figure 3-16. Separation Trajectory, Normal Staging of ESS With RNS Payload (Two ESS Engines Operative)

PITCH RATES (INERTIAL) DEG/SEC

TIME (SEC.)	BOOSTER	ESS
-2	+1.67	+1.67
-1	+1.06	+1.06
0	+2.08	+2.08
1	-1.93*	+0.39
2	-2.08*	+0.83
3	-2.13*	+1.57
4	-2.18*	-0.61

*BOOSTER ACPS NOT USED IN SIMULATION

BOOSTER ACPS CAPABILITY

0.73 DEG./SEC./SEC.

CONCLUSION: STABILIZATION TIME ≈ 3 SEC

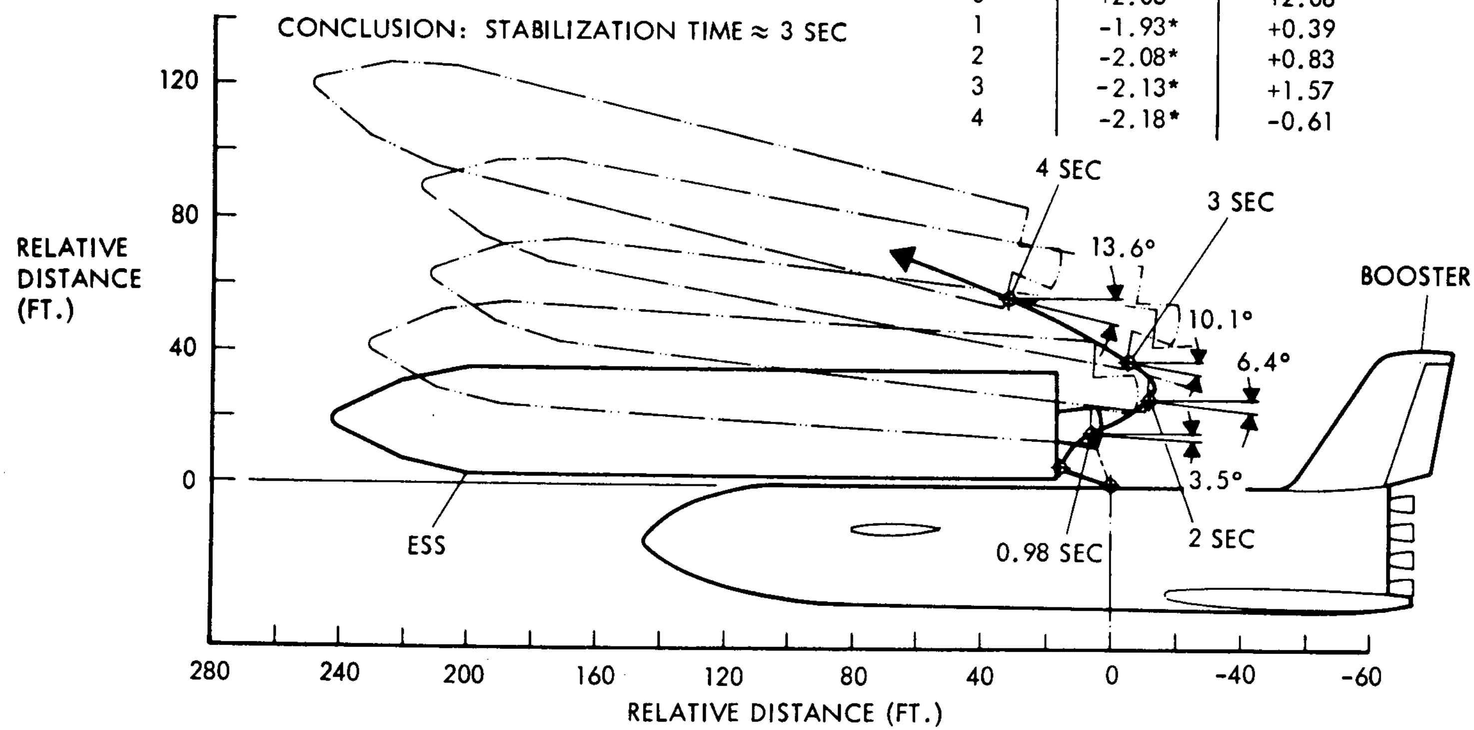


Figure 3-17. Separation Trajectory, Staging of ESS With RNS Payload (One ESS Engine Operative)

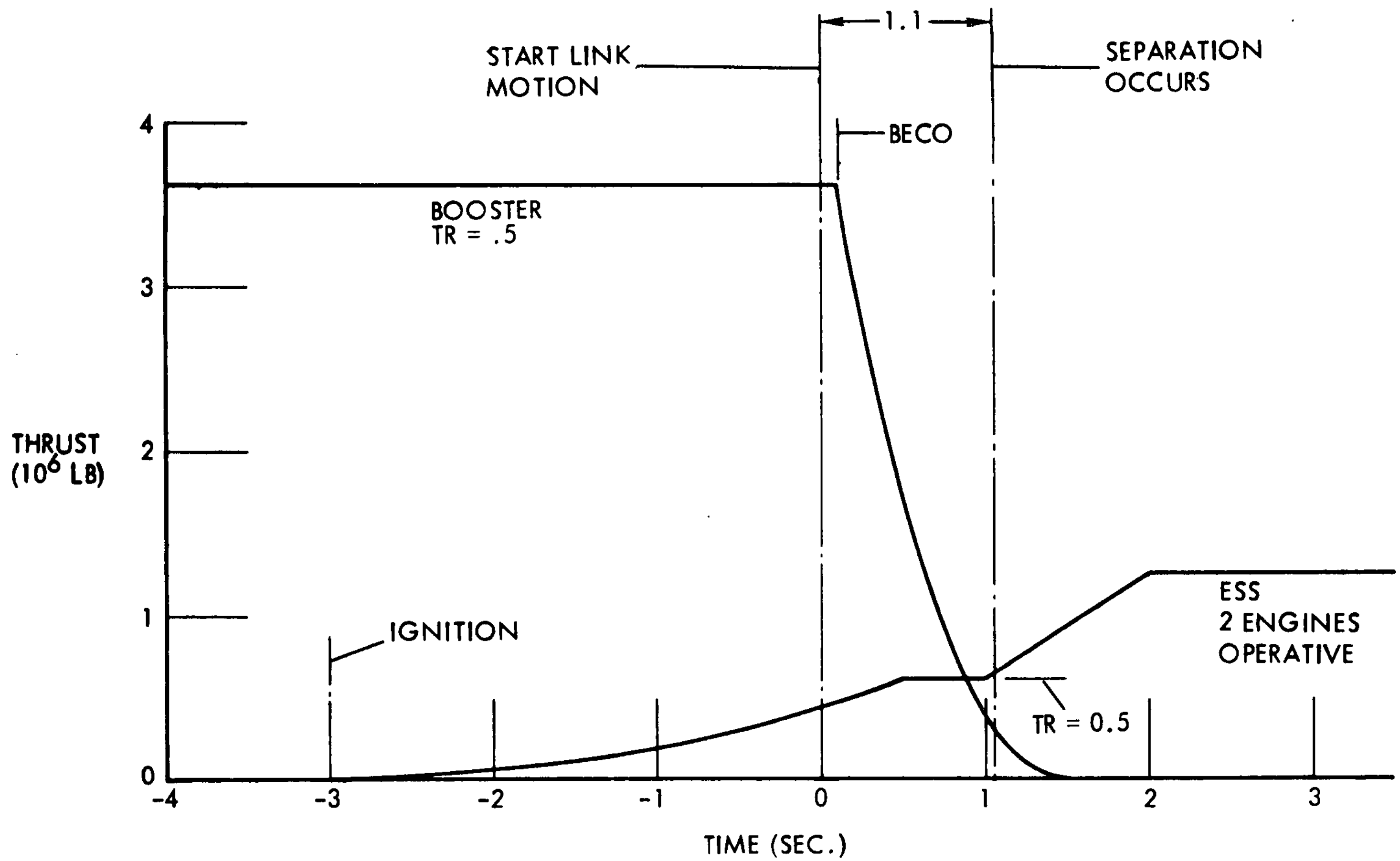


Figure 3-18. Thrust Scheduling, Normal Staging of ESS With RNS Payload (Two ESS Engines Operative)

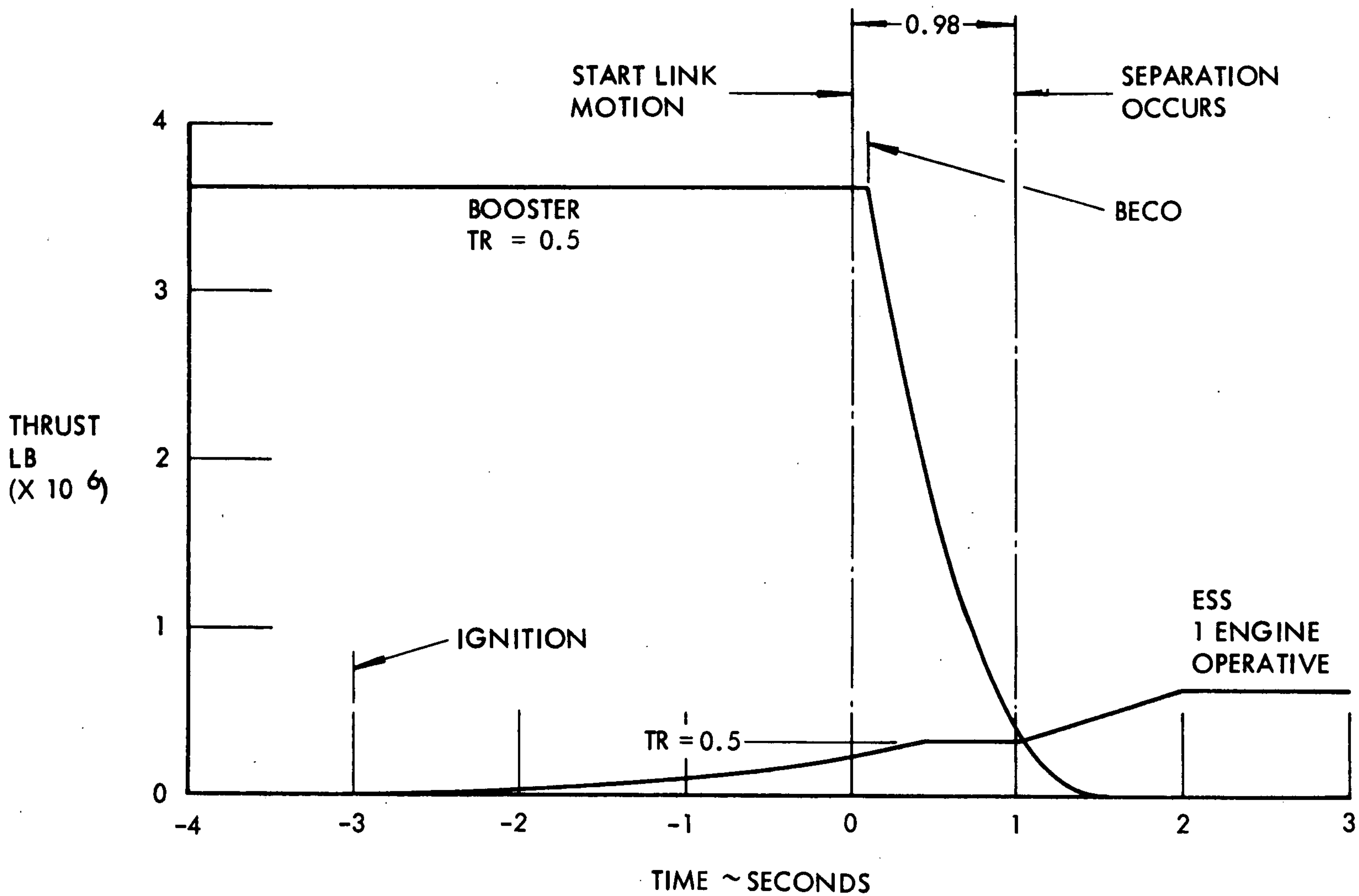


Figure 3-19. Thrust Scheduling, ESS With RNS Payload
(One Engine Operative)

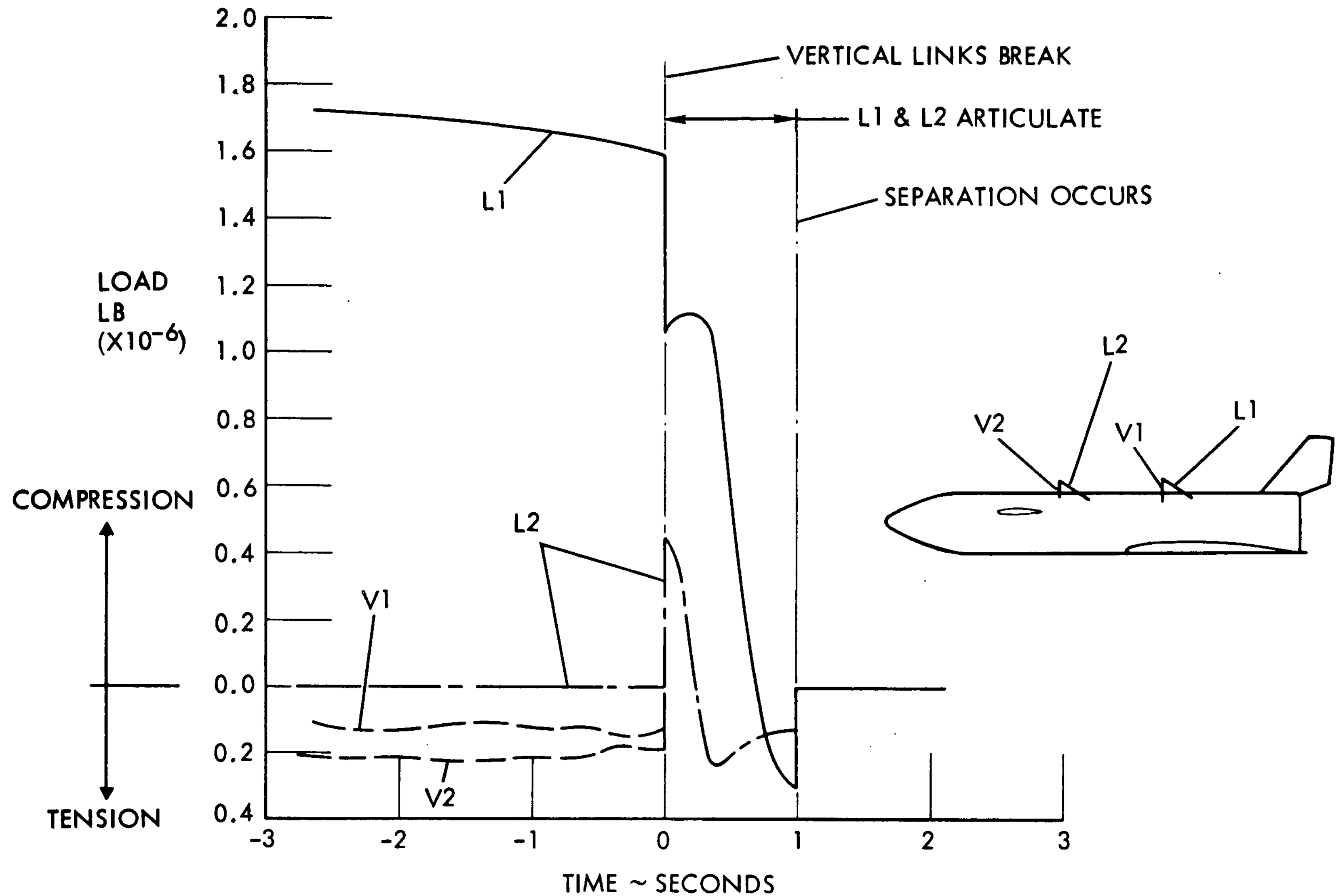


Figure 3-20. Separation System Link Loads, ESS With RNS Payload (One ESS Engine Operative)

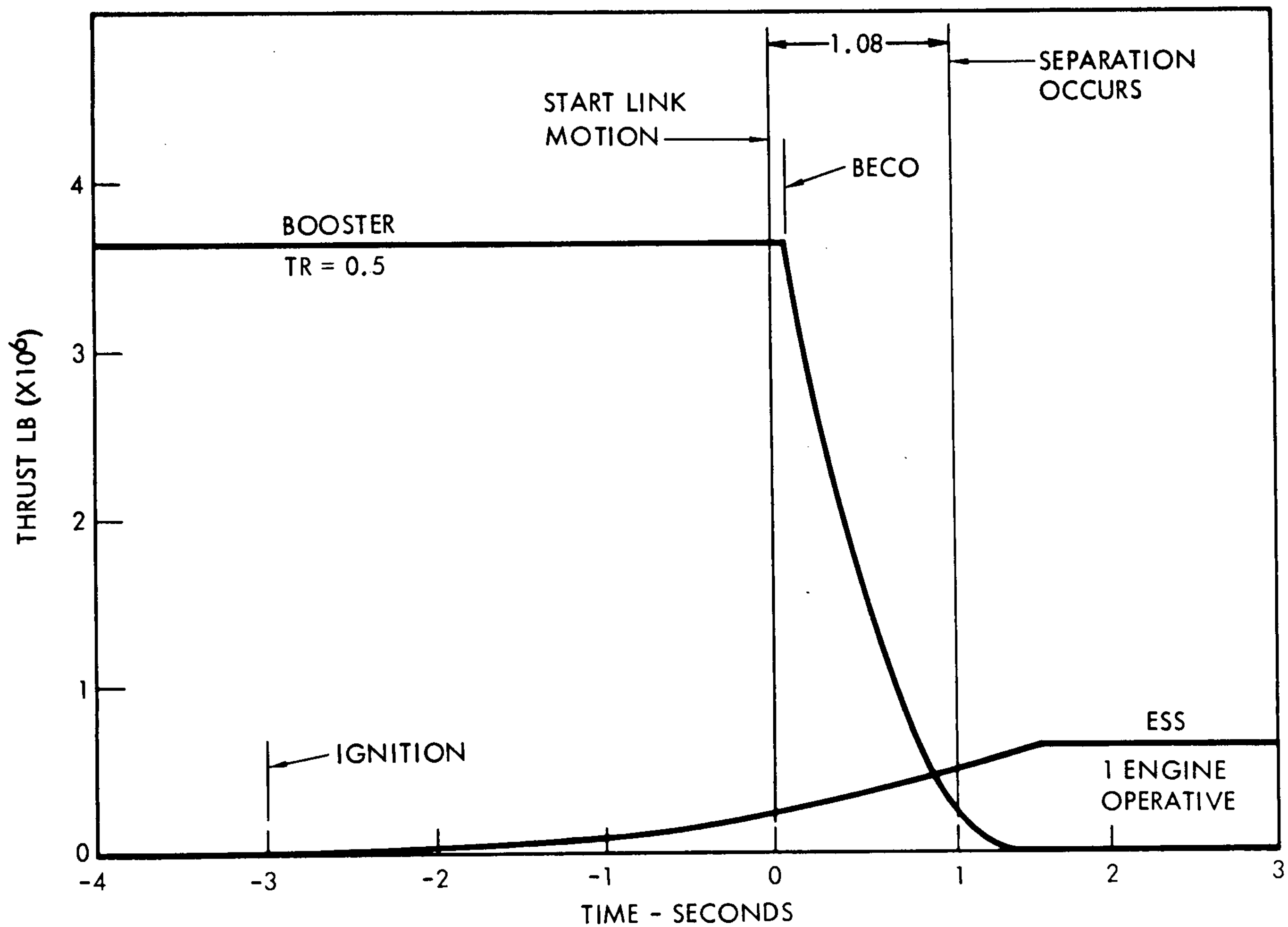


Figure 3-21. Thrust Scheduling, Staging of ESS With MDAC Space Station Payload

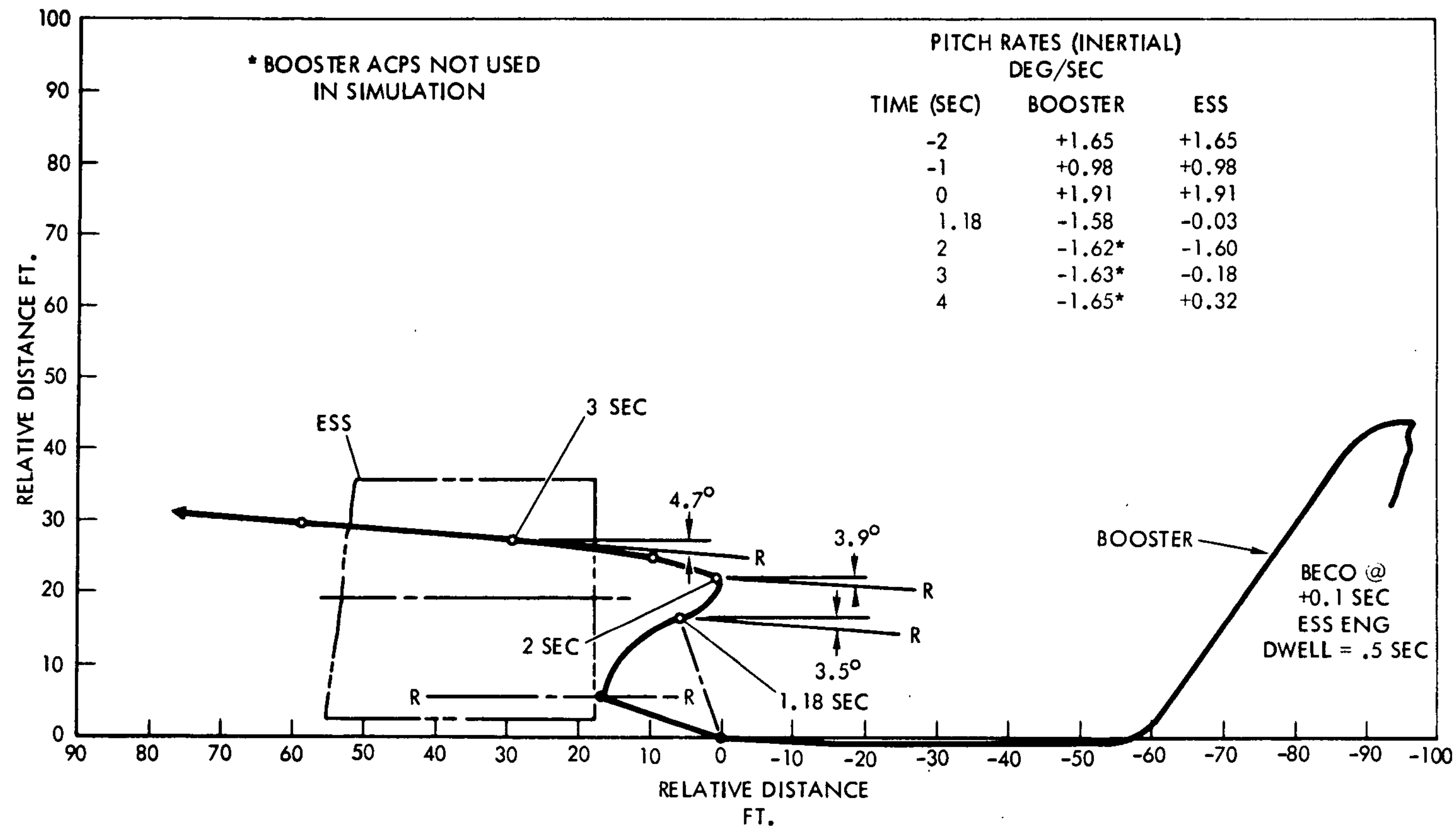


Figure 3-22. Separation Trajectory, Staging of ESS With MDAC Space Station Payload (Two ESS Engines Operative)
(Sheet 1 of 2)

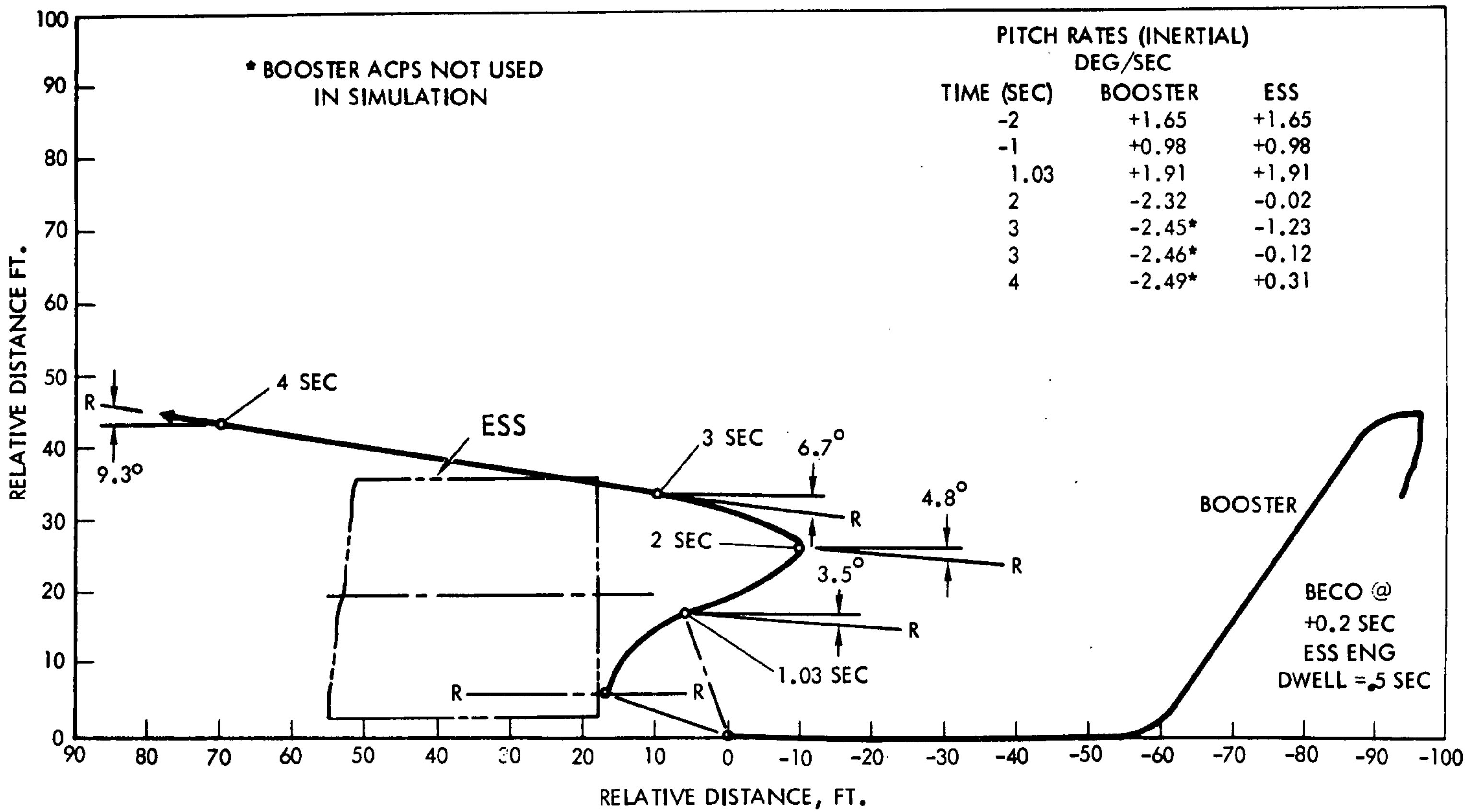


Figure 3-22. Separation Trajectory, Staging of ESS With MDAC Space Station Payload (Two ESS Engines Operative) (Sheet 2 of 2)

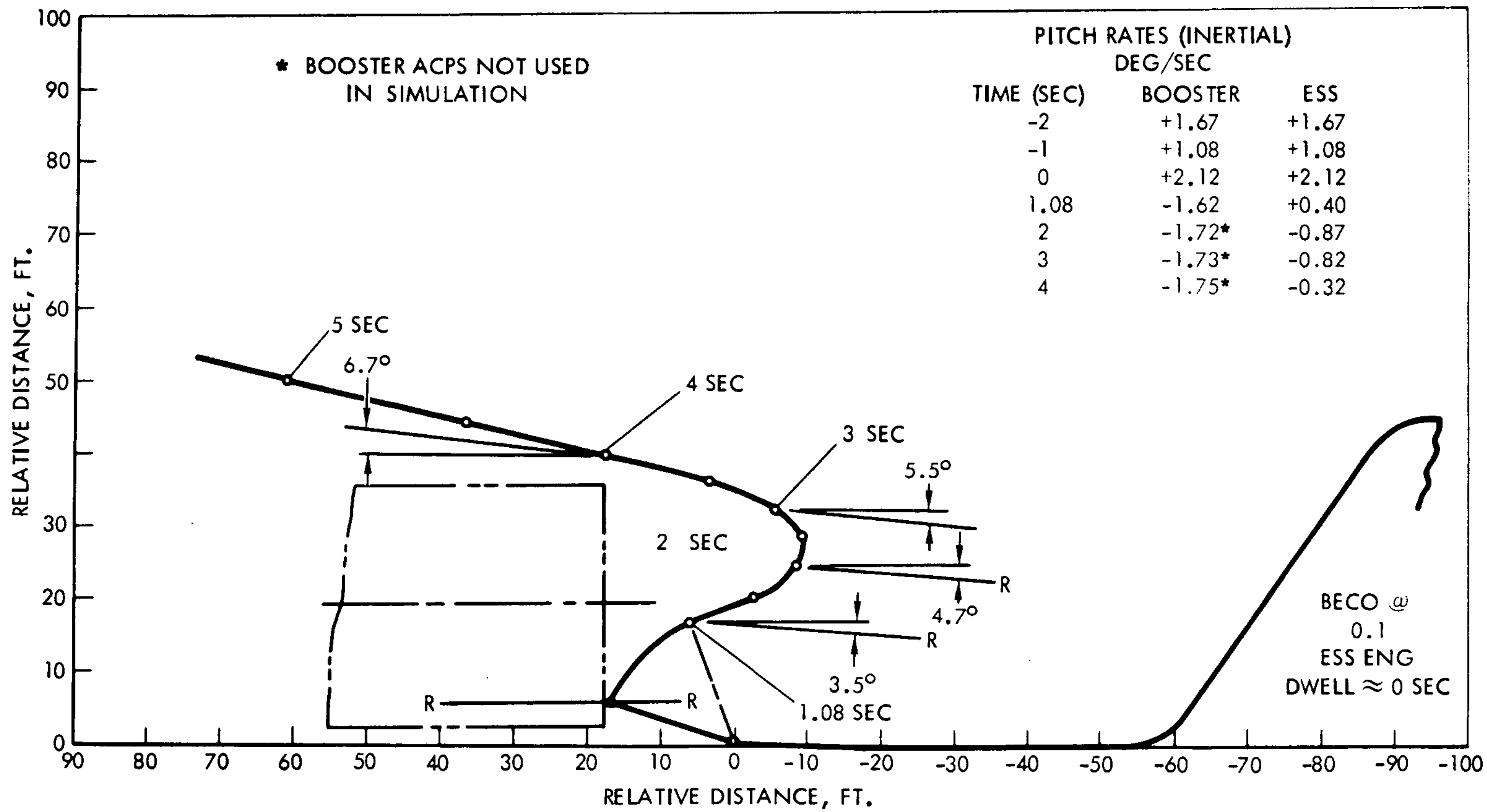


Figure 3-23. Separation Trajectory, Staging of ESS With MDAC Space Station Payload (One ESS Engine Operative)

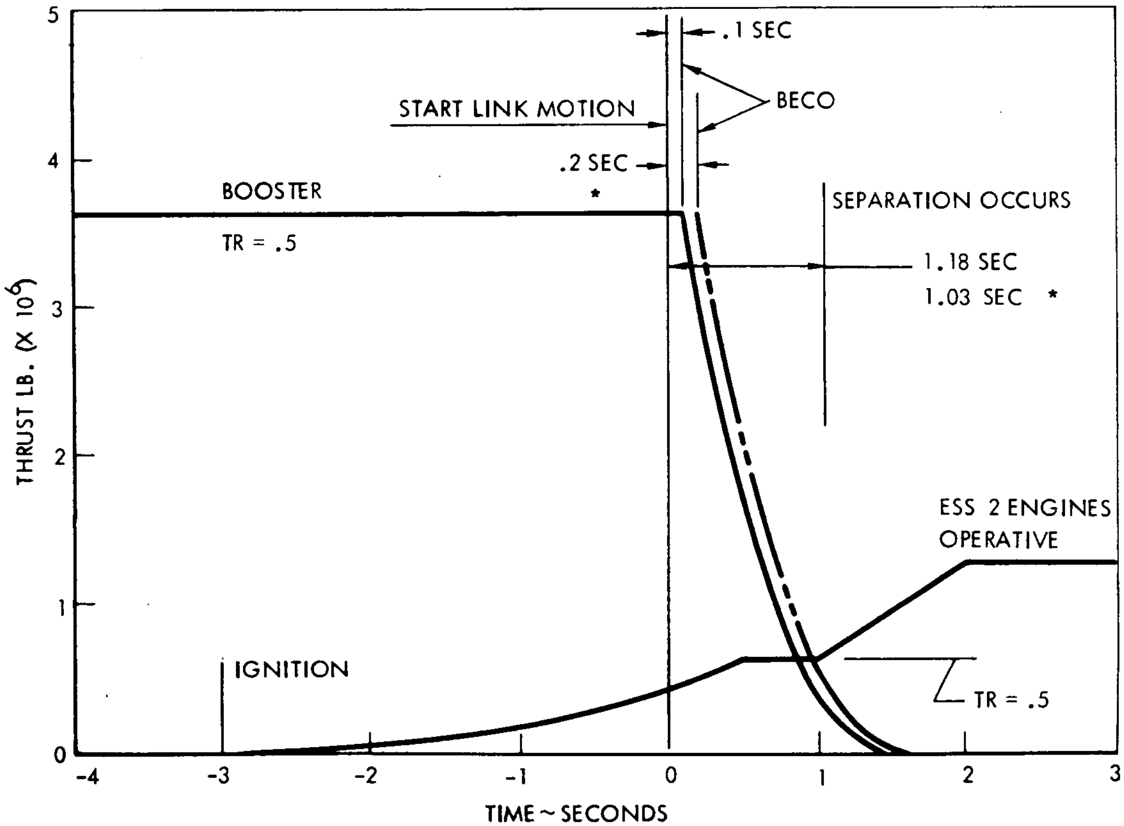


Figure 3-24. Thrust Scheduling, Normal Staging of ESS With MDAC Space Station Payload

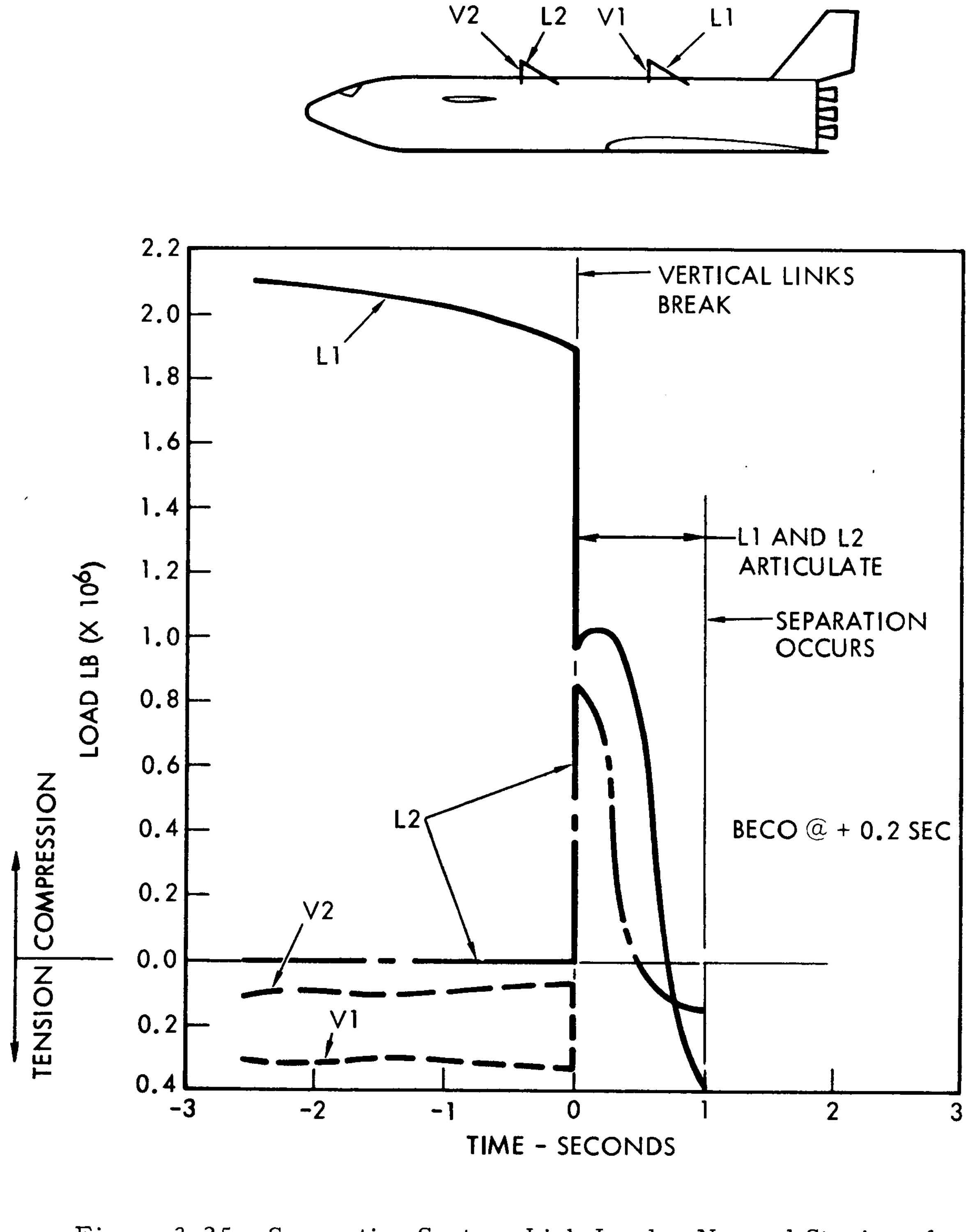


Figure 3-25. Separation System Link Loads, Normal Staging of ESS With MDAC Space Station Payload

3.5 CONCLUSIONS

For the three integrated vehicle systems considered it may be concluded that satisfactory separations can be effected for those cases when one and two ESS engines are operative. The graphs indicate that separations at normal staging points of the ESS compare favorably with those published for the baseline orbiter/booster integrated system.

The fixed platform concept used to adapt the ESS to the booster represents a satisfactory means to provide maximum structural compatibility between the ESS and the booster while minimizing adverse structural impacts on each.

4.0 BOOSTER VEHICLE MODIFICATIONS, FABRICATION, INSTALLATION, AND CHECKOUT

4.1 BOOSTER VEHICLE MODIFICATIONS

The loads induced on the booster exceed the shuttle loads for some ground and flight conditions. Because of this, certain modifications are required in the basic structure. The nature of the modifications to the basic structure requires that they be permanently incorporated during initial air-frame fabrication. Since the study requirements specify that the identical booster be used for shuttle and ESS missions, the added structure weight to accommodate ESS also will be reflected in shuttle operations.

To prepare a booster for an ESS mission, after returning from a shuttle mission, additional modifications are required. These modifications are accomplished in the maintenance area during the normal turnaround cycle and consist of:

1. Removal of the shuttle booster mating/separation subsystem linkage components

2. Removal of the four heat shield access doors

3. Installation of modified heat shield access doors

4. Installation of the ESS booster mating/separation subsystem structural adapter and linkage components

5. Changes to software programs

4.2 FABRICATION, ASSEMBLY, INSTALLATION, AND CHECKOUT

For the basic shuttle program the major booster elements are assembled and checked out at the Michoud assembly facility.

After ensuring correct interfacing, the major elements are disassembled and shipped to the final joining and flight test side. The Kennedy Space Center is used as the booster-element joining area to prepare the booster vehicle for flight test. For the ESS program the mating/separation system elements will also be delivered to Michoud for an initial fit check. After the fit check, the elements will be delivered to the Kennedy Space Center for installation on a booster, as required. Acceptance tests will be conducted on the manufactured components and assemblies using approved checkout procedures. After installation on the booster, a final functional checkout will be accomplished in accordance with approved procedures.

The mating/separation system components will be capable of being installed on any operational shuttle booster and mated to any ESS. The elements, therefore, will be designed and tooled for interchangeability.

5.0 SAFETY, RELIABILITY, AND QUALITY ASSURANCE

Report SD 71-114-2 Volume II, Book 3, "Booster Vehicle Definition," describes the activities of these disciplines and their integral role in the creation of the design during Phase B and continuing in to Phase C/D and applies to the shuttle booster and the booster when used for ESS mission. The system safety and reliability and quality assurance reviews discussed in this section were conducted to identify the possibilities of impact on operations or hardware peculiar to the ESS concept.

5.1 SYSTEM SAFETY

The system safety review was conducted to identify the safety impact of the operations and hardware peculiar to the ESS concept, which are not common to the normal booster operations with an orbiter. The review considered only the safety aspects of the concept and did not consider cost, weight, etc., which would result from any change required to achieve optimum safety of the system.

The identified areas of safety concern are:

1. The need for revised servicing connections. This imposes additional rise-off clearance problems for the booster.

2. Item 1 will be further aggravated by the increased drag area of the ESS/RNS configuration, thus exposing the system to greater drift than the orbiter configuration would experience in similar winds. This condition may require more restrictive wind parameters for operation with the ESS.

3. The ESS propellant tanks must be vented so that the vented materials will not adversely affect the booster, either by corrosive action on the booster, or by mixing with booster vented or exhausted materials with potentially explosive results.

4. The requirement to change to separate computer programs for ESS flights increases the potential for hazards induced by handling errors.

5. The structural modifications and associated kits required to adapt the booster to the ESS, and back to the booster/orbiter configuration, increase the probability of inducing damage to the booster and generating hazards (such as fuel tank puncture, etc.), during their installation and removal.

The identified safety problems confirm the need for the booster design to consider operations with the ESS and the orbiter in the initial booster design requirements and subsequent development, in order to meet the same safety standards as those established for normal shuttle operations.

5.2 RELIABILITY AND QUALITY ASSURANCE

The results of a qualitative assessment of the impact on booster reliability for the proposed design modifications incorporated for operating the booster with an expendable second stage are summarized as follows:

1. The functional reliability of the separation system structural concept does not appear to be compromised or decreased by the modifications to the load transfer links, retraction mechanism and/or the addition of the fixed platform beam structure. With the exception of the fixed platform, the coupling members and release functions are performed using a system that is very similar to the baseline system. The addition of two redundant retraction cylinders for aft link-fold will not appreciably effect system reliability.

2. Separation initiation requirements and functional success criteria were reviewed to determine effects of ESS and modifications required for booster separation control to ensure positive separation. However, no increase in failure probability is anticipated from vehicle separation control. Provisioning of the ESS with required redundant initiation control will provide for the separation control previously supplied in the baseline system by an orbiter separation controller.

3. Unlike the baseline shuttle operation of the manned orbiter, the absence of a manned second stage, with its attendant multiple redundant control systems, could result in a higher risk of vehicle collision after release. With lesser ability to correct the expendable second stage post-separation conditions, a lower mission success probability is anticipated and considered the primary area of reliability impacted from the proposed operation of the booster with an ESS.

The qualitative assessment was prepared through use of the attached FMEA's and equipment quanties comparison table to evaluate the changes respective to baseline system.

Table 5-1. Configuration Weight Summary

Configuration	MDAC SS		RNS		Tug	
Item	B-9U	ESS	B-9U	ESS	B-9U	ESS
Dry weight	643,117	96,936	643,117	96,936	643,117	96,936
Personnel	476		476		476	
Payload		176,960		83,000		107,180
Payload adapter						10,000
Residual fluids	11,476	5,965	11,476	5,965	11,476	5,965
Payload margin		5,330		9,314		9,413
Inert weight	655,069	285,191	655,069	195,215	655,069	229,494
Reserve fluids		6,659		10,480		18,487
In-flight losses	20,802	83	20,802	83	20,802	83
Propellant ascent	3,382,307	677,150	2,749,260	428,198	2,941,395	496,420
Propellant cruise	143,786		143,786		143,786	
Propellant mvr/ACS	1,500	22,917	1,500	17,724	1,500	10,401
Stage total weight	4,203,464	992,000	3,570,417	651,700	3,762,552	754,885
Spacecraft GLOW	5,195,464		4,222,117		4,517,437	

6.0 LAUNCH COMPLEX OPERATIONS AND SERVICES

6.1 INTRODUCTION

ESS requirements were analyzed in relation to the shuttle launch complex operations and services to determine the preferred launch pad servicing and operational concept. An overview of the turnaround cycle (shown in Figure 6-1) defines the basic elements considered in the booster/ESS ground operations study.

A separate trade study was conducted to determine the preferred launch pad servicing concept for the booster/ESS. From the study, a variety of servicing concepts were considered and it was concluded that a new launch pad-mounted service tower offered the best alternative. The new service tower was selected because it offered minimum development risk, maximum compatibility with shuttle operations, and intermediate cost.

The booster basically follows the shuttle functional flow for the ESS phase of operations. Booster storage, maintenance, and checkout operations are conducted in the new hangar addition to the VAB, and erection and mating are accomplished in the existing VAB high-bay as in shuttle operations.

The ESS is stored, serviced, and handled in the same low-bay area of the VAB as in present Saturn operations. The vertical lift of the ESS will be made from the VAB transfer aisle with the mating to the booster being accomplished in Cell 3 of the VAB. The mated booster/ESS will be transported on a mobile launcher along the crawler-way to either Launch Pad 39A or 39B.

Vertical launch operations will follow the standard shuttle procedures. Horizontal recovery and safing of the booster will be conducted in the same manner as conceived for the shuttle.

ESS operations are conducted in the normal two-week turnaround and have minimum impact on shuttle operations.

6.2 LAUNCH PAD SERVICING TRADE STUDY

This trade study evolved from the requirement to provide access, propellant, electrical, and other services to the ESS on the launch pad. Location of the swing arms and/or rise-off disconnects to provide the required services posed the major problem to be resolved by the study.

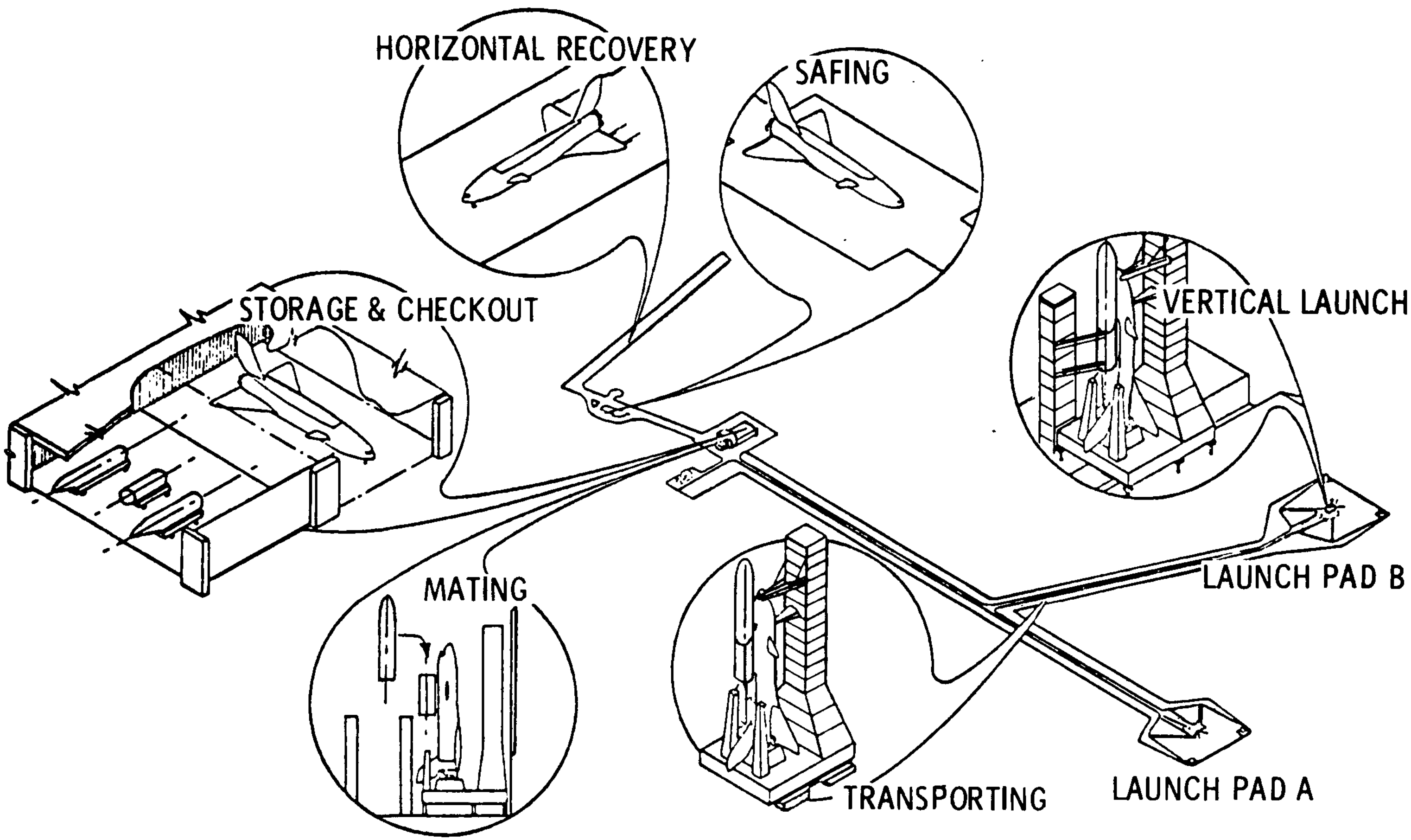


Figure 6-1. Operational Ground Turnaround

Two basic concepts were evaluated: (1) shuttle baseline (booster belly toward the mobile launcher tower) and (2) booster belly away from the tower. The shuttle baseline offered four alternatives and the best possible solutions to the problem.

6.2.1 Description of Alternatives

The following alternatives, using the shuttle baseline booster/launcher relationship, were evaluated:

1. Addition of two swing arms to the mobile launcher tower to interface with existing ESS umbilical disconnects.

2. Extension and adaption of one existing orbiter rise-off disconnect pylon. This would require redesign of the ESS to relocate all service connections to the aft end of the ESS.

3. Addition of a pad-located service tower with two swing arms to interface with existing ESS umbilical disconnects.

4. Addition of a launcher-located service tower with two swing arms. An additional alternative was offered by deviating from the shuttle baseline booster/launcher relationship (or establishing a new baseline):

5. Relocate booster on launcher with belly away from the tower and add two swing arms to the launcher tower.

Two of the alternatives (Items 4 and 5) were discarded as not feasible in the initial phase of the study. Preliminary analysis established that a launcher-mounted service tower with swing arms (alternative 4) would require a tower approximately 235 feet high and 20- by 20-feet in width and breadth; adequate space is not available on the mobile launcher. Additionally, tower height and proximity to the booster and ESS would be such that serious clearance problems at launch would be introduced.

Reorientation of the booster on the launcher to booster belly away from the tower was also discarded because of the extensive impact on the established baseline (booster belly toward the tower). It did not appear feasible to attempt to modify the shuttle baseline to accommodate the relatively small number of ESS launches.

Each of the remaining three alternatives (LUT swing arms, LUT-mounted rise-off disconnect pylon, and new pad-located service tower with swing arms) were subjected to additional analysis. Highlights of this evaluation follows.

6.2.2 LUT Swing Arms (Figure 6-2)

Facility Modification Requirements

At least one mobile launcher would require modification by the addition of two swing arms to the tower. One arm, located approximately at tower level 207, would provide access to the ESS forward section and payload. The second arm, located approximately at tower level 147, would provide access to the aft end of the ESS as well as LH_2 and LO_2 fill lines. Both arms would contain electrical cables and utilize existing stage umbilical carrier plates and disconnects.

The required swing arms would be approximately 90 feet long. To permit operation of the swing arms in the VAB, it is required that they be articulated in some manner. To maintain existing booster to tower clearances, it is also required that the new swing arms are no closer to the booster than the face of the tower when they are retracted.

Some modification of the launcher would also be required to provide the proper interface between the added swing arms and the launcher fluid, gas, and electrical supply systems.

Impact on the Baseline Facility

The mobile launcher tower would require considerable modification; however, the additional service arms required for the ESS could be designed to stow in such a manner that they would not compromise the use of the launcher for baseline shuttle operations.

There would be minor impact on the VAB and MSS in that access platforms must be provided for use during mating and prelaunch operations.

Operational Impact

Scheduling ESS operations into baseline shuttle operations on a non-interference basis might be a problem as only one mobile launcher would be available for ESS launch operations and only one mating bay would be available for ESS/shuttle mating operations. However, proper planning should avoid any schedule conflicts with only two ESS missions per year.

Swing arms must be retracted after first motion to clear the canard and wings. To meet this requirement, very complex equipment must function in an extremely short time span. It is doubtful that this requirement could be met. Therefore, the swing arms probably would have to be retracted prior to liftoff to provide the required clearance. This eliminates backout capability in the event of pad abort.

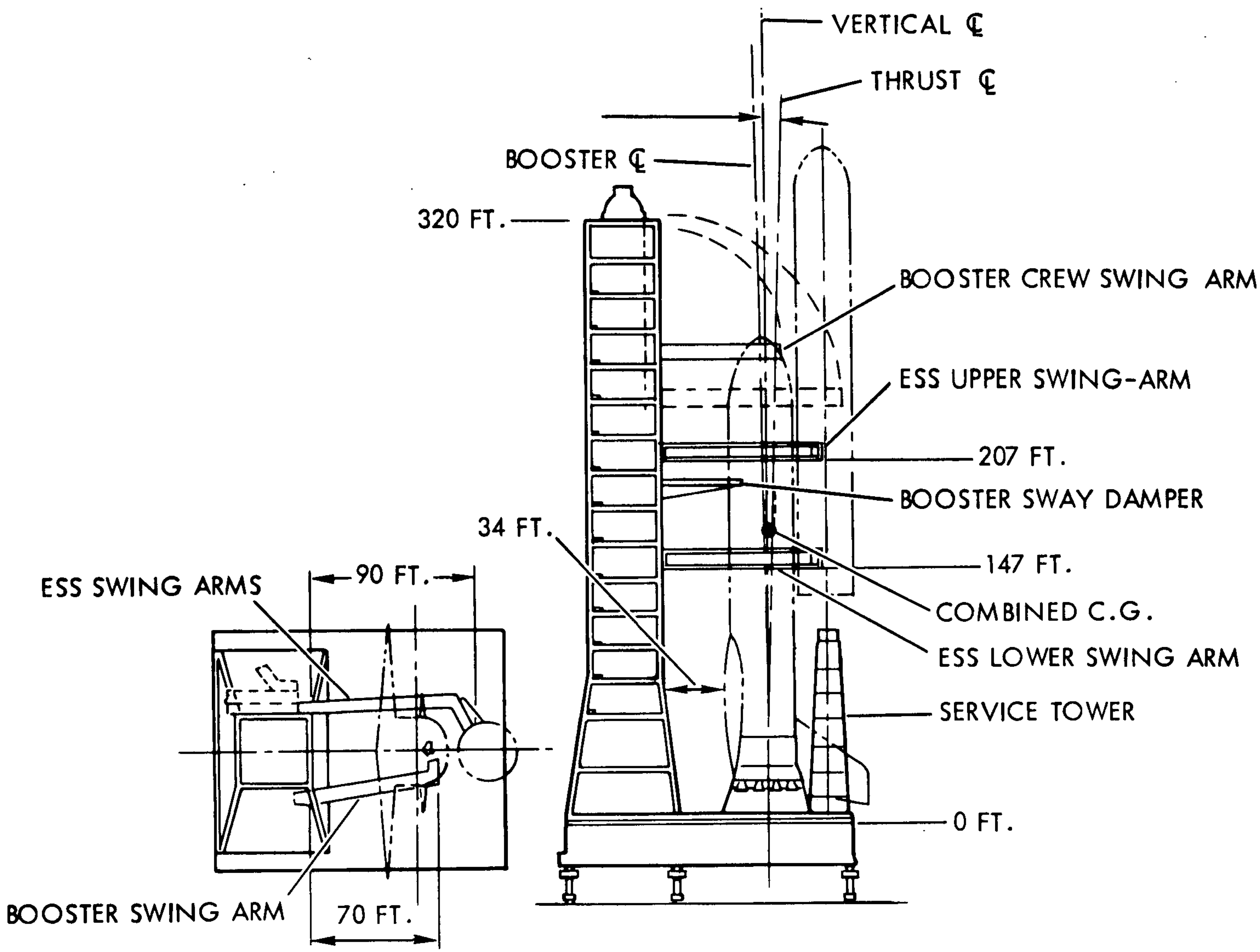


Figure 6-2. LUT Swing Arms

6.2.3 LUT Mounted Rise-Off Disconnect Pylon (Figure 6-3)

Facility Modification Requirements

One orbiter service pylon would require modification to adapt it to both the orbiter swing arm and the new ESS swing arm, which is approximately ten feet taller. To provide clearance at liftoff, the new swing arm would be required to swing horizontally and rotate vertically away from the ESS. The ESS swing-arm would provide LH_2 and LO_2 fill lines and the required electrical cables. The pylon would require dual interface connections for the structural and servicing requirements of both the orbiter swing-arm and the ESS swing-arm.

Impact on the Baseline Facility

The mobile launcher pylon would require modification to adapt it for both the ESS and the orbiter swing arms. Rework of the pylons would be required prior to and following each ESS launch.

Operational Impact

There would be a schedule requirement to allocate a pylon swing-arm exchange period for the removal of the orbiter swing-arm and the installation and connection of all interfaces to the ESS swing-arm. The impact on the VAB would be minimal, with the only requirement being several wall-mounted access platforms.

6.2.4 New Pad-Located Service Tower With Swing Arms (Figure 6-4)

Facility Modification Requirements, Launch Pad

A new service tower could be located on the pad near the southwest corner of the mobile launcher. The tower would be approximately 230 feet high (measured from the top of the pad) and 28 by 28 feet at the base and top. The tower would provide all the services required by the ESS. Tower swing arms would furnish access to the forward and aft ends of the ESS as well as propellant, fluid, gas, and electrical services.

Impact on the Baseline Facility

The service tower would become a permanent part of the launch pad facility; therefore, a one-time modification of the pad would be required. The tower, when installed, must not interfere with normal shuttle operation and must be located clear of all existing equipment on the pad. Impact on the total baseline facility would be negligible as little or no LUT or VAB rework would be required.

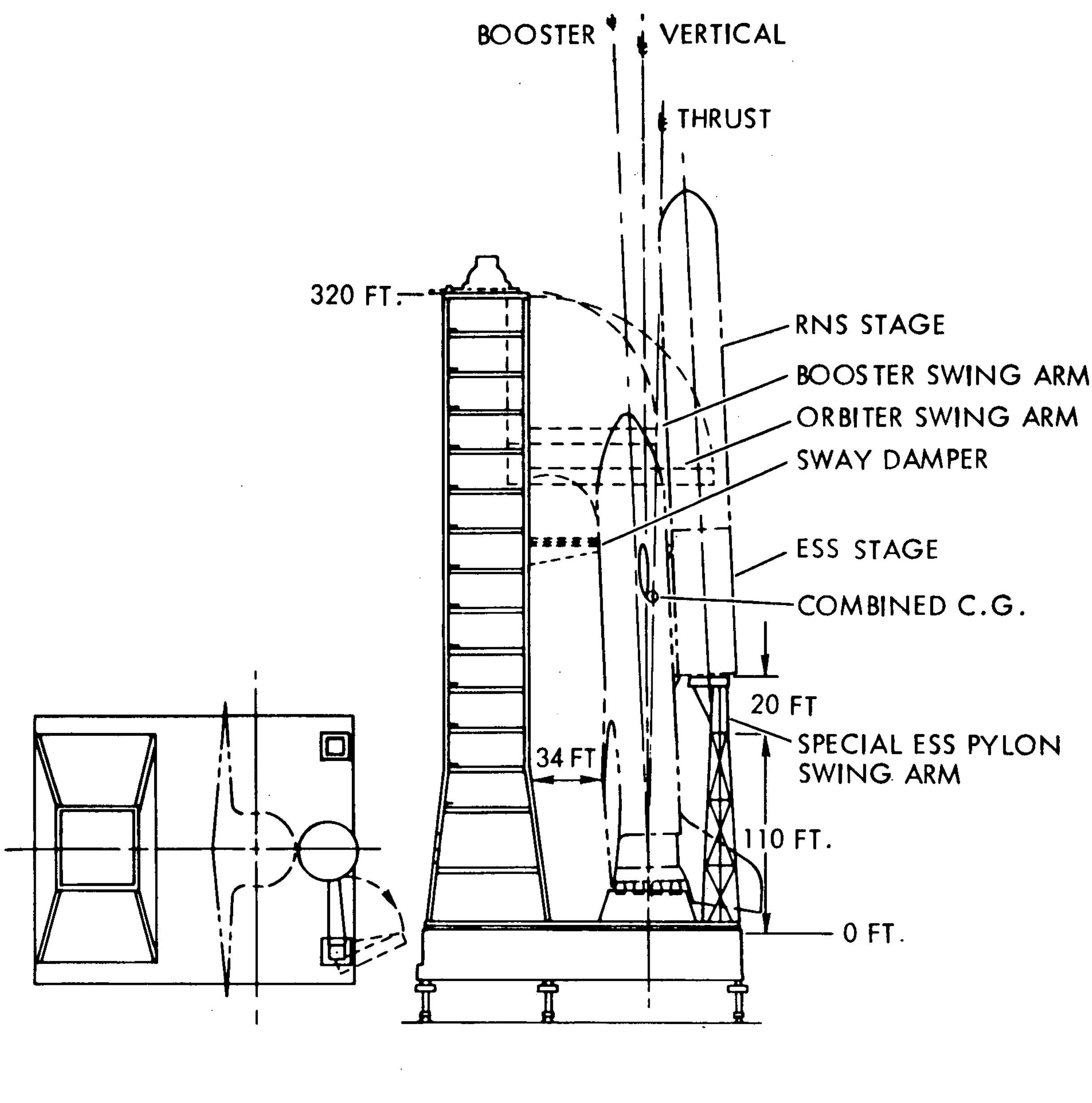


Figure 6-3. LUT Mounted Rise-Off Disconnect Pylon

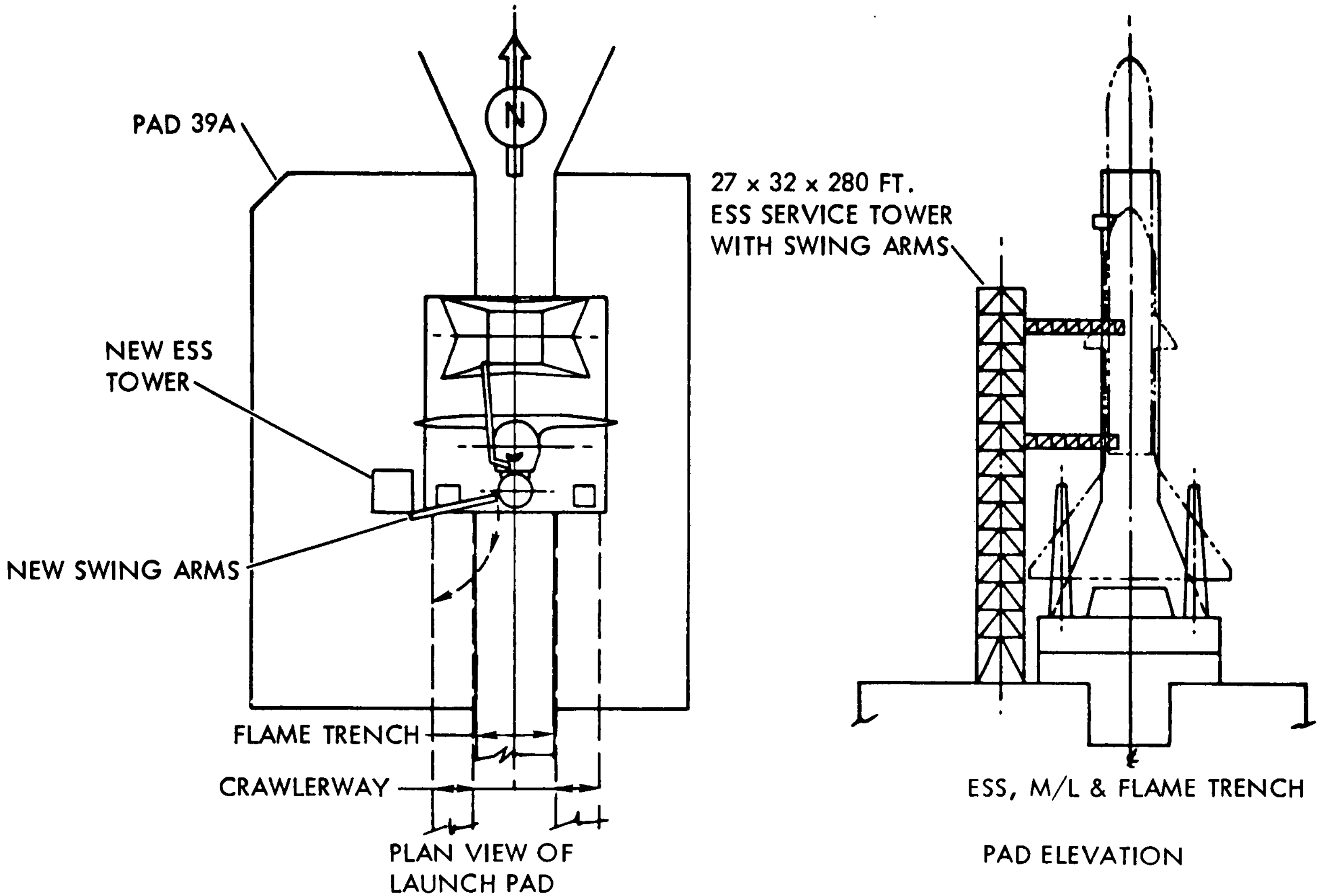


Figure 6-4. New Pad-Located Service Tower With Swing Arms

Operational Impact

The only impact would be scheduling ESS ground operations to fit into baseline shuttle operations on a noninterference basis.

6.2.5 Concept Evaluation

The three servicing concepts studied were evaluated on the basis of cost, added environment exposure, development risk, safety, liftoff clearance, and compatibility with the shuttle baseline. The results of this evaluation are presented in Table 6-1.

Cost

Table 6-2 provides a cost breakdown for each of the concepts studied.

Environment Exposure

The pad service tower concept requires an additional day of pad exposure since ESS checkout must be accomplished at the pad subsequent to service tower swing-arm connection.

Development Risk

The LUT swing-arm concept presents the highest development risk potential because of the length of the swing arms (approximately 90 to 100 feet) and the related fast disconnect and swing time (less than 1.5 seconds) required to clear the booster canard and wing at liftoff.

The rise-off disconnect concept requires rapid movement of the swing-arm structure to provide liftoff clearance. All this must occur in less than 6 seconds and leads to ranking of this concept as second highest in development risk.

Except for increased length, the swing arms required for the pad service tower are typical of the type being used for present Saturn launches. The service tower itself is not a problem from a development standpoint. Therefore, this concept is rated lowest in development risk.

Compatibility With Shuttle

The LUT swing-arm concept requires permanent modification of one LUT. The swing arms must be designed to "double-hinge" and fold along side of the LUT within the tower 40-foot width or they will obstruct the shuttle VAB operation. This concept is rated second in compatibility with shuttle.

Table 6-1. ESS Launch Pad Configuration Concept Evaluation

	ALTERNATE CONCEPT		
EVALUATION FACTORS	LUT SWING ARMS	RISEOFF PYLONS	PAD SERVICE TOWER
TOTAL COST (STAGE II & FAC)	24.7	50.9	35.5
ADDED ENVIRONMENT EXPOSURE	NONE	NONE	1 DAY LONGER THAN SHUTTLE
DEVELOPMENT RISK	HIGHEST	2ND HIGHEST	LOWEST
SAFETY ASSESSMENT	LOWEST	2ND PREFERRED	PREFERRED
LIFTOFF CLEARANCE	LOWEST	2ND HIGHEST	HIGHEST
COMPATIBILITY WITH SHUTTLE BASELINE	2ND HIGHEST	LOWEST	HIGHEST

Table 6-2. ESS Launch Facility Cost Summary

COST ELEMENT	CONFIGURATION								
	LUT SWING ARMS			RISE-OFF PYLONS			PAD SERVICE TOWER		
	NR	R	TOT.	NR	R	TOT.	NR	R	TOT.
SERVICE CONNECTIONS	4.4	-	4.4	1.9	-	1.9	4.4	-	4.4
VAB MODIFICATIONS	.1	-	.1	.1	-	.1	.1	-	.1
SWING ARMS	17.2	-	17.2		-		11.5	-	11.5
RISEOFF PYLON MODS		-		5.7	.2	5.9		-	
LAUNCH TOWER		-			-		16.5		16.5
SPECIAL FLUID/GAS/ELECT. ROUTING	3.0	-	3.0	3.0	-	3.0	3.0	-	3.0
ESS MODIFICATIONS		-		15.9	24.1	40.0		-	
TOTAL	24.7	-	24.7	26.6	24.3	50.9	35.5	-	35.5

*COSTS REPRESENT DELTA TO BASELINE LAUNCH FACILITY.

Rise-off pylon extension is least desirable. The orbiter pylon swing-arm must be disconnected and removed from the pylon, and the ESS swing arm must be installed prior to each ESS launch. The obvious teardown and reassembly of shuttle equipment is not desirable.

Since only minor modification of the LUT is required (routing of servicing lines around the base), the pad-located service tower provides the least interference with shuttle operations.

Safety Assessment and Liftoff Clearance

LUT swing arms are ranked lowest in desirability from a safety standpoint due to the close proximity of the arms to the booster wing and canard. Extremely rapid swing-arm retraction capability is required to provide clearance at liftoff since swing arms remain connected until first motion to retain backout capability.

The rise-off disconnect pylon concept is considered second highest in desirability since a relatively complex retraction motion is required to provide liftoff clearance.

The pad service tower was rated most desirable because of the least possibility of swing arm interference with the booster.

6.2.6 Summary and Conclusions

The LUT swing-arm concept, while lowest in cost, poses the highest development risk. Also, catastrophic loss of the vehicle and crew could possibly occur in the event of swing-arm malfunction. The rise-off disconnect pylon would provide minimum compatibility with shuttle operations and would be highest in cost. The pad service tower concept provides maximum compatibility with shuttle operations and minimum development risk at intermediate cost. Therefore, the pad service tower was the concept selected for ESS operations.

6.3 GSE AND FACILITY MODIFICATIONS

For two ESS launches per year, only one launch pad will require modification. A service tower will be located on the pad near the southwest corner of the mobile launcher. The tower will be approximately 230 feet high (measured from the top of the pad) and approximately 28 by 28 feet at the base and top. The tower will provide all the services required by the ESS and an elevator for transportation of parts, personnel, and support equipment. Tower swing arms will furnish access to the forward and aft ends of the ESS as well as propellant, fluid, gas, and electrical services.

The service tower becomes a permanent part of the launch pad facility; therefore, a one-time modification of the pad will be required. The tower, when installed, will not interfere with normal shuttle operations and will be located clear of all existing equipment on the pad.

The modifications to the mobile launcher will consist of routing gas and fluid lines from the existing launch pad/mobile launcher interfaces to a new set of mobile launcher/ESS service tower interfaces. Facility lines will be routed from these new interfaces to the new ESS service tower support equipment. The support equipment will be categorized for description as follows:

1. Propellant loading
2. Pneumatic servicing
3. GN_2 thermal conditioning and purge
4. Vacuum servicing

6.3.1 Propellant Loading

The propellant loading system on the new ESS service tower will supply liquid and gaseous hydrogen and liquid and gaseous oxygen to the ESS vehicle. The support equipment will consist of the following items:

1. GO_2 fill umbilical disconnect
2. GH_2 fill umbilical disconnect
3. Main LH_2 fill and drain umbilical disconnect
4. OMS LH_2 fill and drain umbilical disconnect
5. LO_2 fill and drain umbilical disconnect
6. LO_2 valve unit
7. GO_2 valve unit
8. LH_2 valve unit
9. GH_2 valve unit
10. GH_2 vent umbilical disconnect (main tank)

11. GH_2 vent umbilical disconnect (OMS tank)

12. The interconnecting plumbing

The liquid and gaseous oxygen propellant loading system is shown in Figure 6-5 in block diagram form, and the location of the equipment is shown in Figure 6-6.

The liquid and gaseous hydrogen propellant loading system is shown in Figure 6-7 in block diagram form, and the location of the equipment is shown in Figure 6-8.

The countdown propellant loading will be revised as follows: complete booster vehicle rapid liquid oxygen loading before initiating the ESS vehicle rapid loading; complete booster vehicle rapid liquid hydrogen loading before initiating the ESS vehicle rapid loading; and complete the ESS vehicle rapid liquid oxygen loading before initiating ESS vehicle rapid liquid hydrogen loading. This change will accomplish the propellant loading in the same time span provided for the space shuttle launch. See Figure 6-9 for the propellant loading time.

The LO_2 valve unit will contain the valves and associated hardware to provide for the control of the propellant loading. Slow fill to five percent of the main tank volume will be 500 gpm, rapid fill to 95 percent of the main tank volume will be less than 5000 gpm, and final fill will be 500 gpm. The main and OMS LO_2 tanks are filled from one umbilical disconnect.

The GO_2 valve unit will contain the regulators, valves, and associated hardware to regulate the 6000-psi supply to 1500 psi for the auxiliary propulsion system GO_2 accumulator charge.

The LH_2 valve unit will contain the valves and associated hardware to provide for the control of the line chilldown, propellant loading, and venting of gaseous hydrogen. Slow fill to five percent of the main tank volume will be 1000 gpm, rapid fill to 95 percent of main tank volume will be 10,000 gpm, and final fill will be 1000 gpm. There are separate valves and fill lines in the LH_2 valve unit for the main tank and the OMS tank. The two main tank vent lines and the OMS tank vent line from the ESS vehicle to the LH_2 valve unit are routed to the 10-inch vent line in the LH_2 valve unit.

6.3.2 Pneumatic Servicing

The pneumatic servicing on the new ESS servicing tower will supply the gaseous nitrogen and helium requirements of the ESS vehicle for valve actuation, component checkout, line purges, propellant tank prepressurization, and other such requirements.

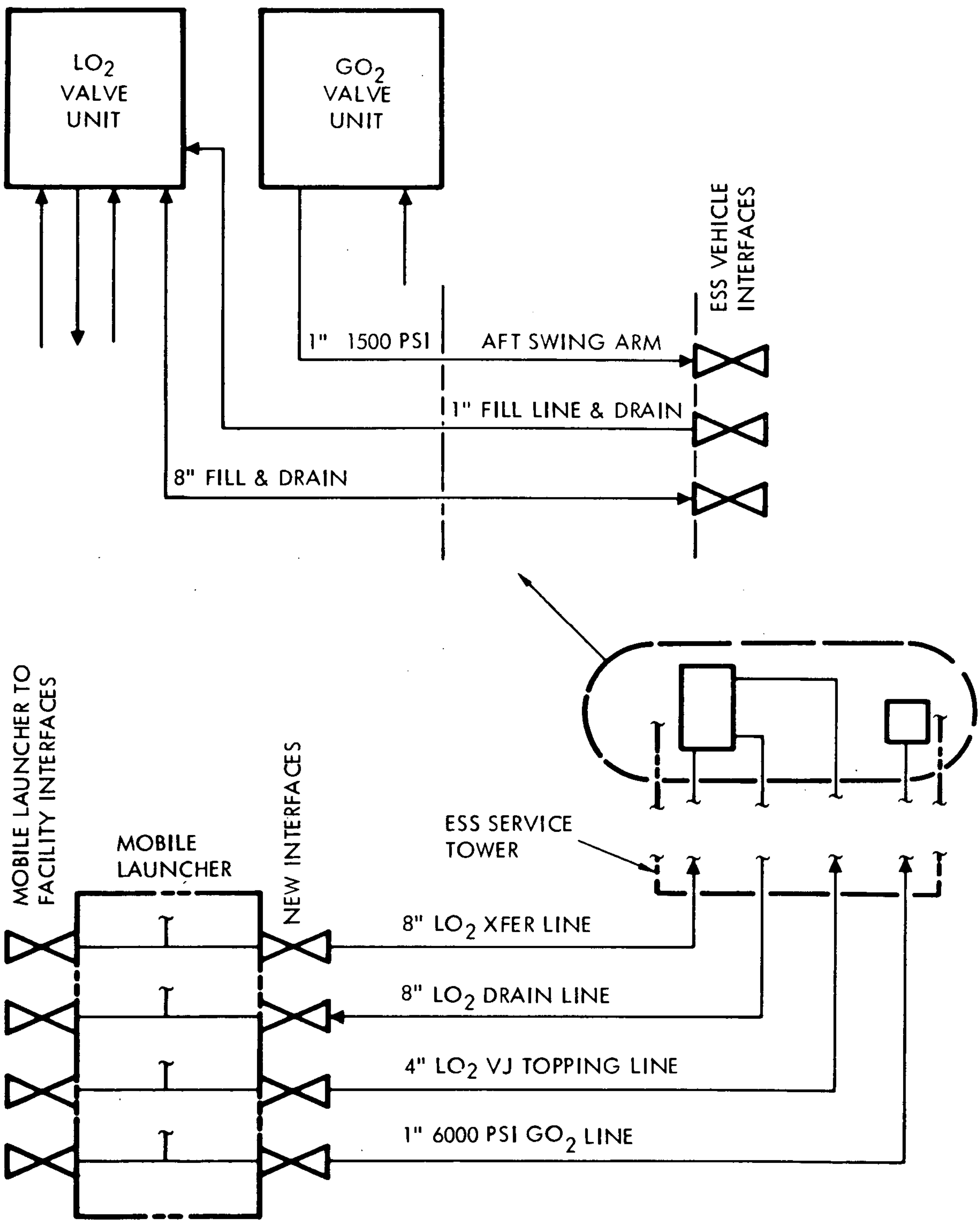


Figure 6-5. LO_2 and GO_2 Propellant Loading System

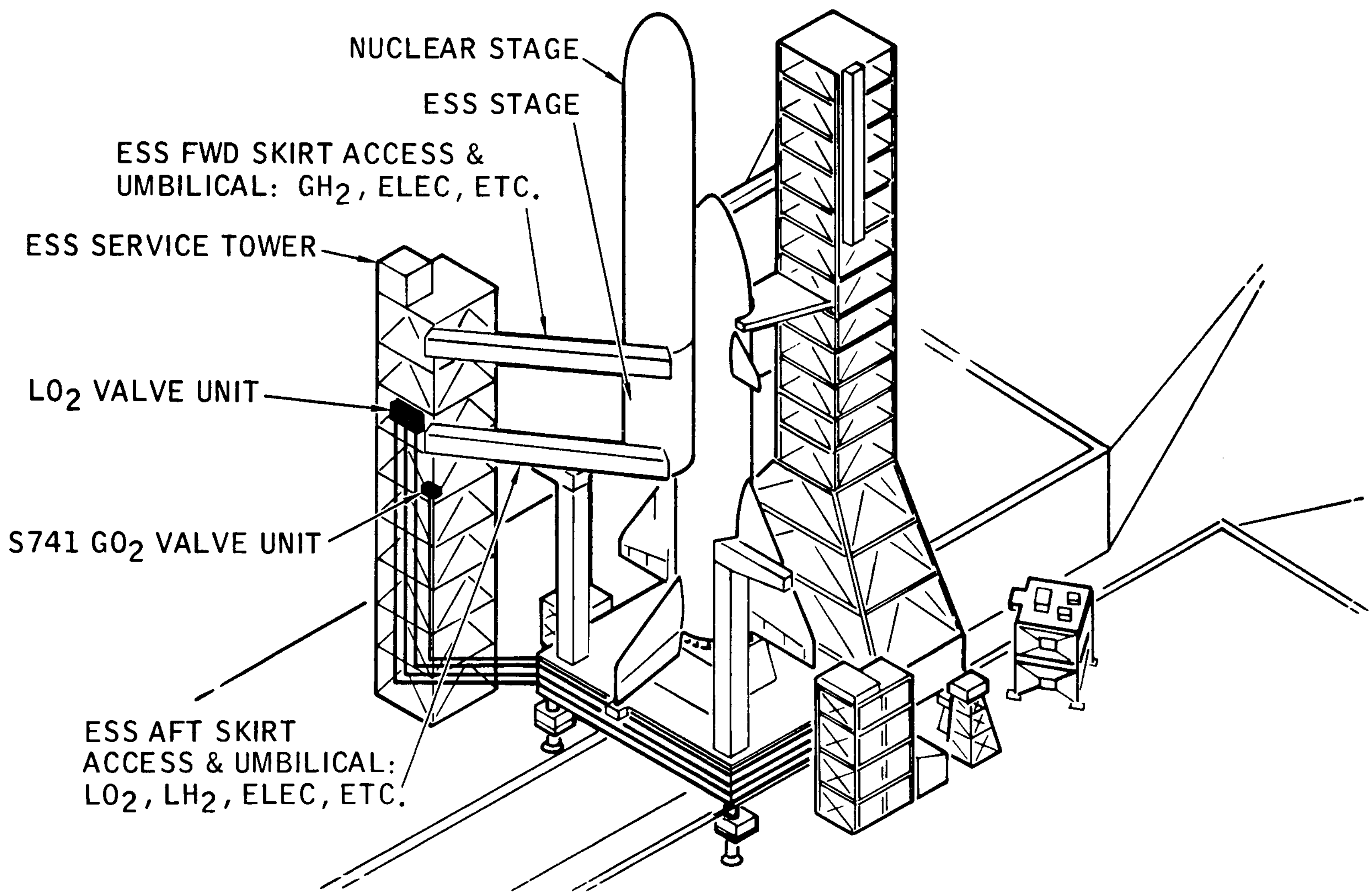


Figure 6-6. Launch Pad Operations

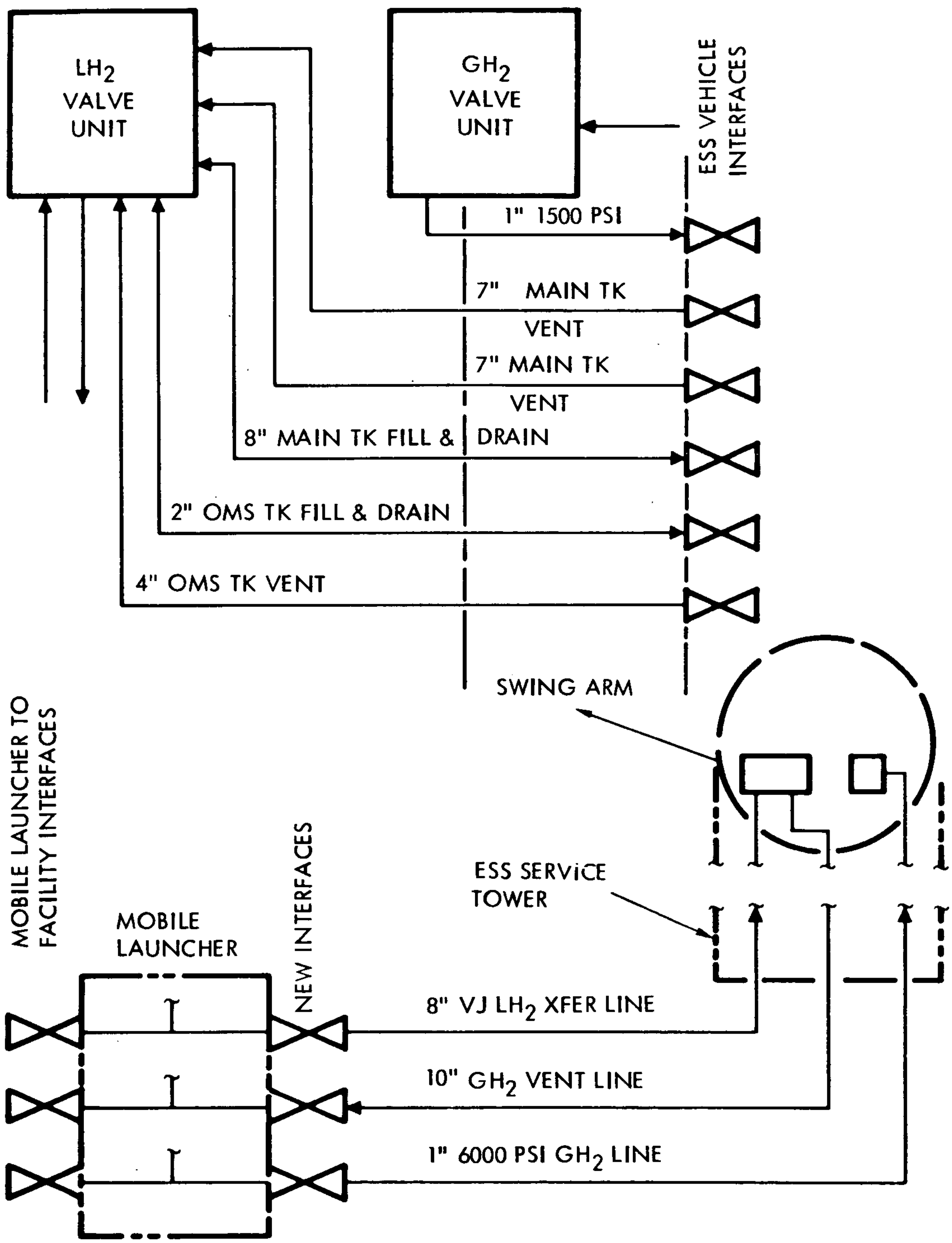


Figure 6-7. LH_2 and GH_2 Propellant Loading System

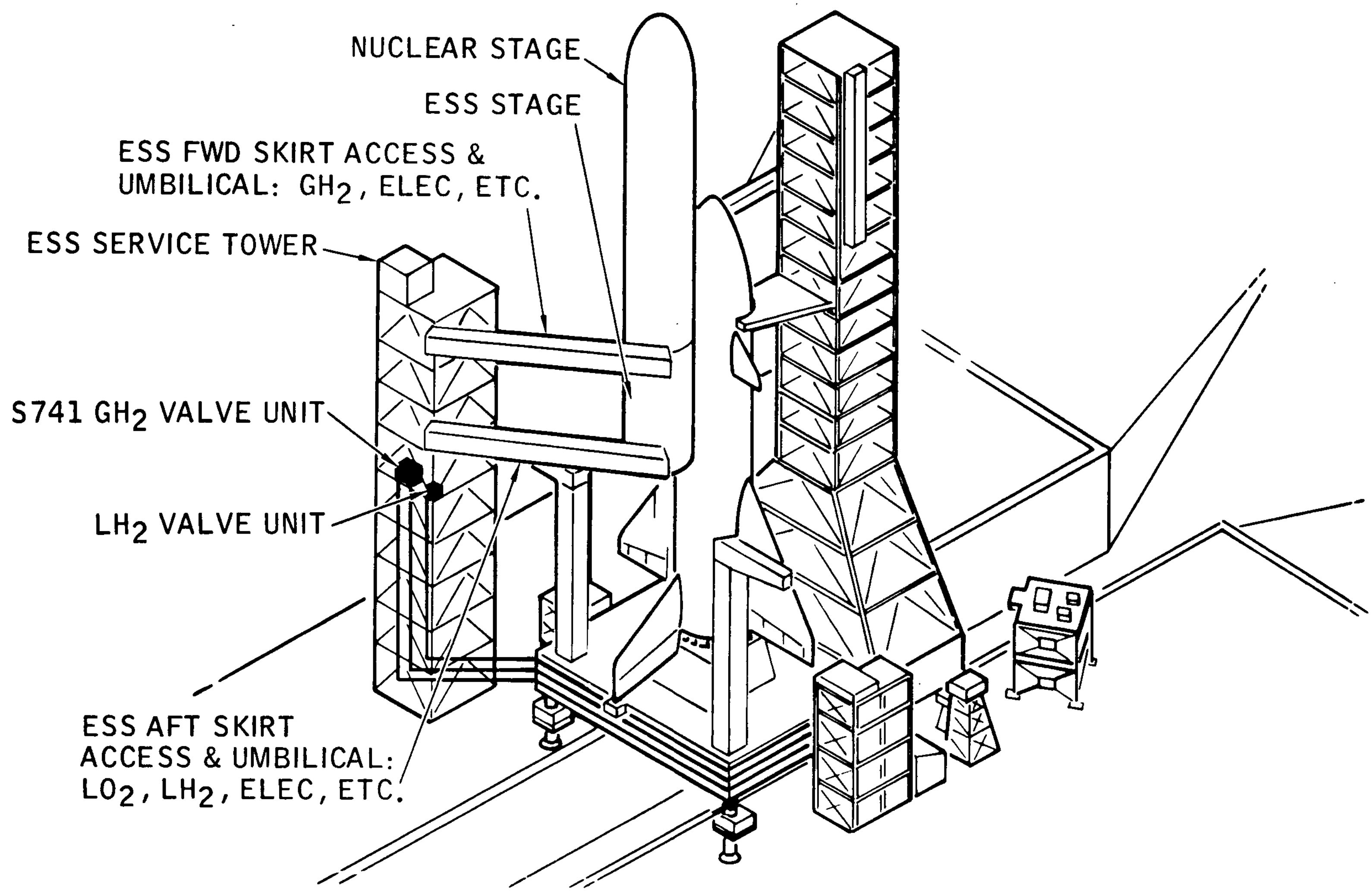


Figure 6-8. Launch Pad Operations

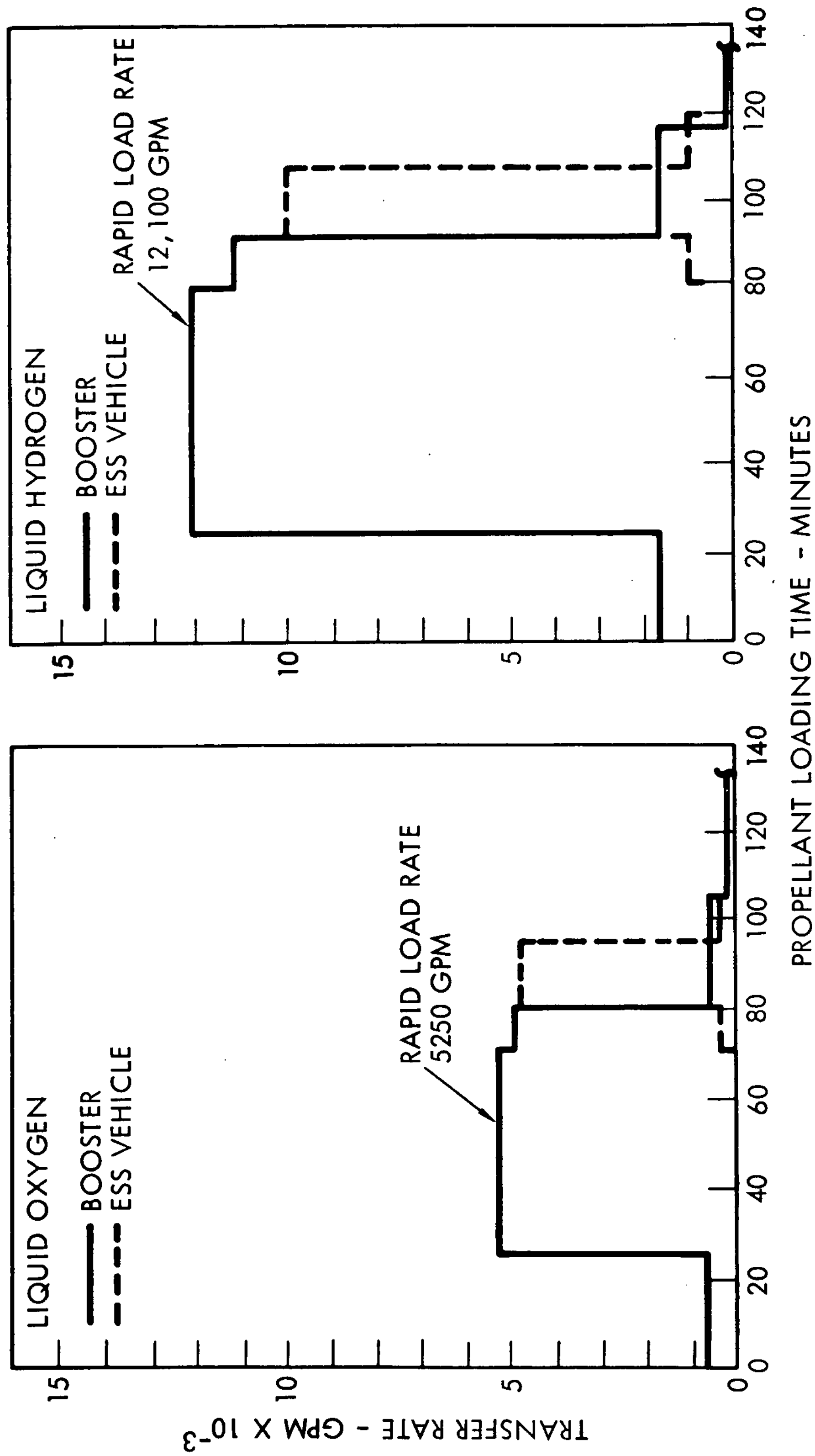


Figure 6-9. Propellant Loading Time

The support equipment will consist of the following items:

1. Umbilical disconnects

2. Pneumatic control unit

3. Interconnecting plumbing

The system is shown in Figure 6-10 in block diagram form, and location of the equipment is shown in Figure 6-11.

The pneumatic control unit will contain the regulators, valves, and associated hardware to regulate the 6000-psi GHe and GN_2 supplies to the various ESS vehicle pressure and flow requirements.

6.3.3 GN_2 Thermal Conditioning and Purge

The thermal conditioning and purge system on the new ESS servicing tower will supply the preflight conditioning and purge low-pressure GN_2 ESS vehicle requirements. The support equipment will consist of the following items.

1. Umbilical disconnects

2. GN_2 valve unit

3. Interconnecting plumbing

The system is shown in Figure 6-12 in block diagram form, and location of the equipment is shown in Figure 6-13.

The GN_2 valve unit will contain the regulators, valves, and associated hardware to regulate the 150-psi supply to a pressure of 42 inches of water. The total system demand is 500 pounds per minute at ambient temperature.

6.3.4 Vacuum Servicing

Vacuum servicing of the vacuum-jacketed (VJ) lines and ESS vehicle peculiar vacuum requirements will be provided by a vacuum pump unit on the new ESS service tower. This unit will contain the vacuum pumps, valves and associated hardware to provide the vacuum servicing.

Figure 6-14 shows the location of the vacuum pump unit.

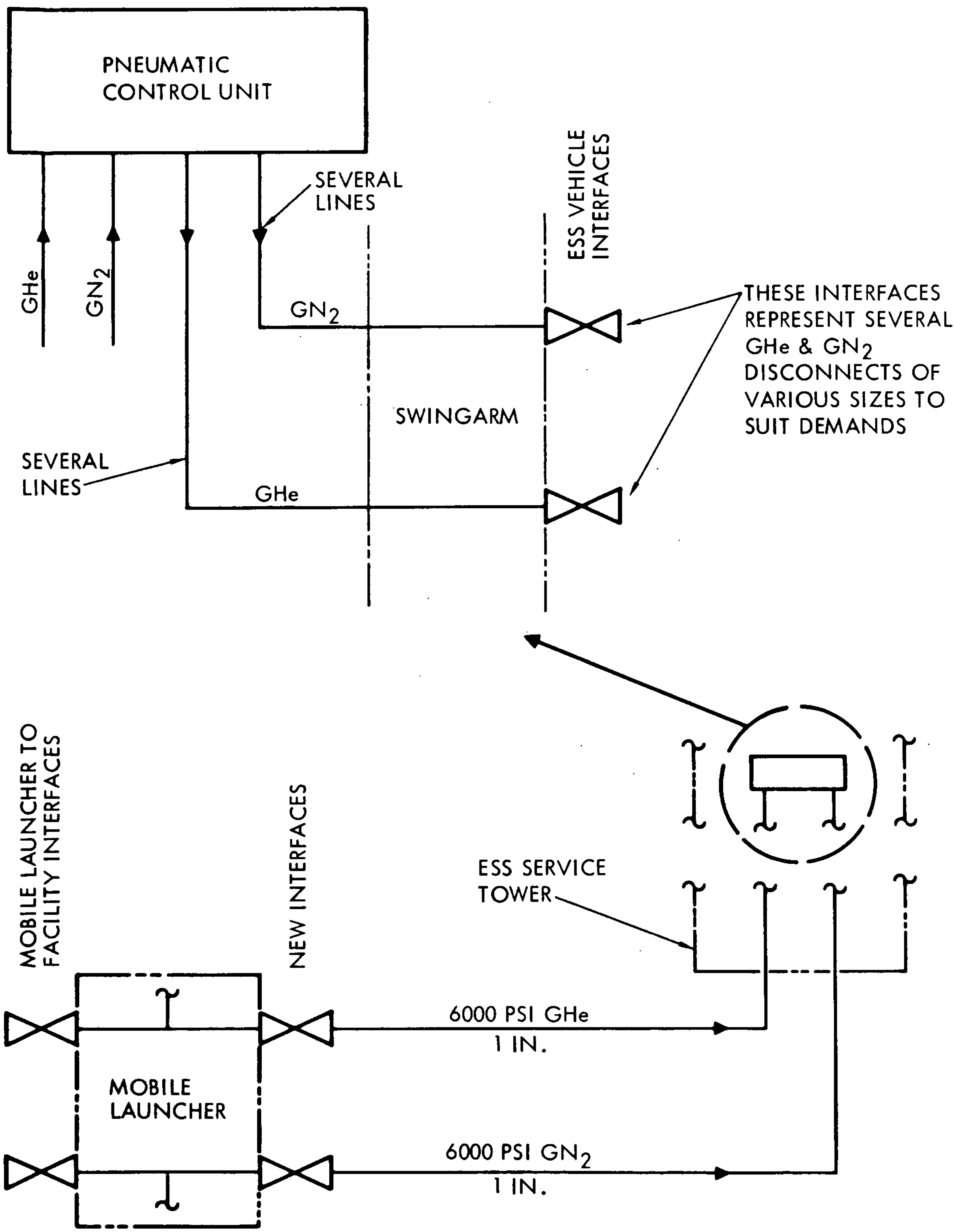


Figure 6-10. Pneumatic Servicing

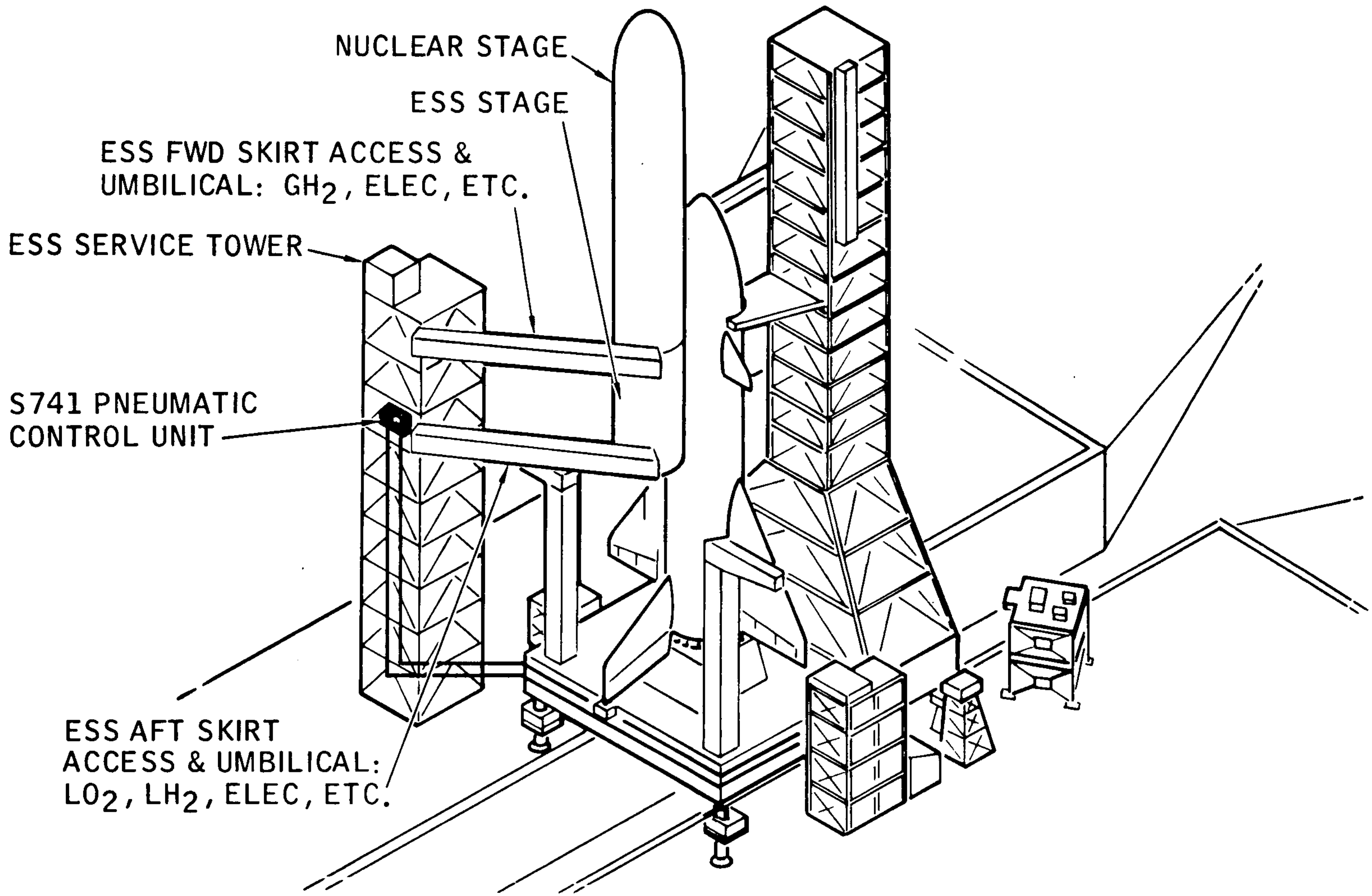


Figure 6-11. Launch Pad Operations (S741 Pneumatic Control Unit)

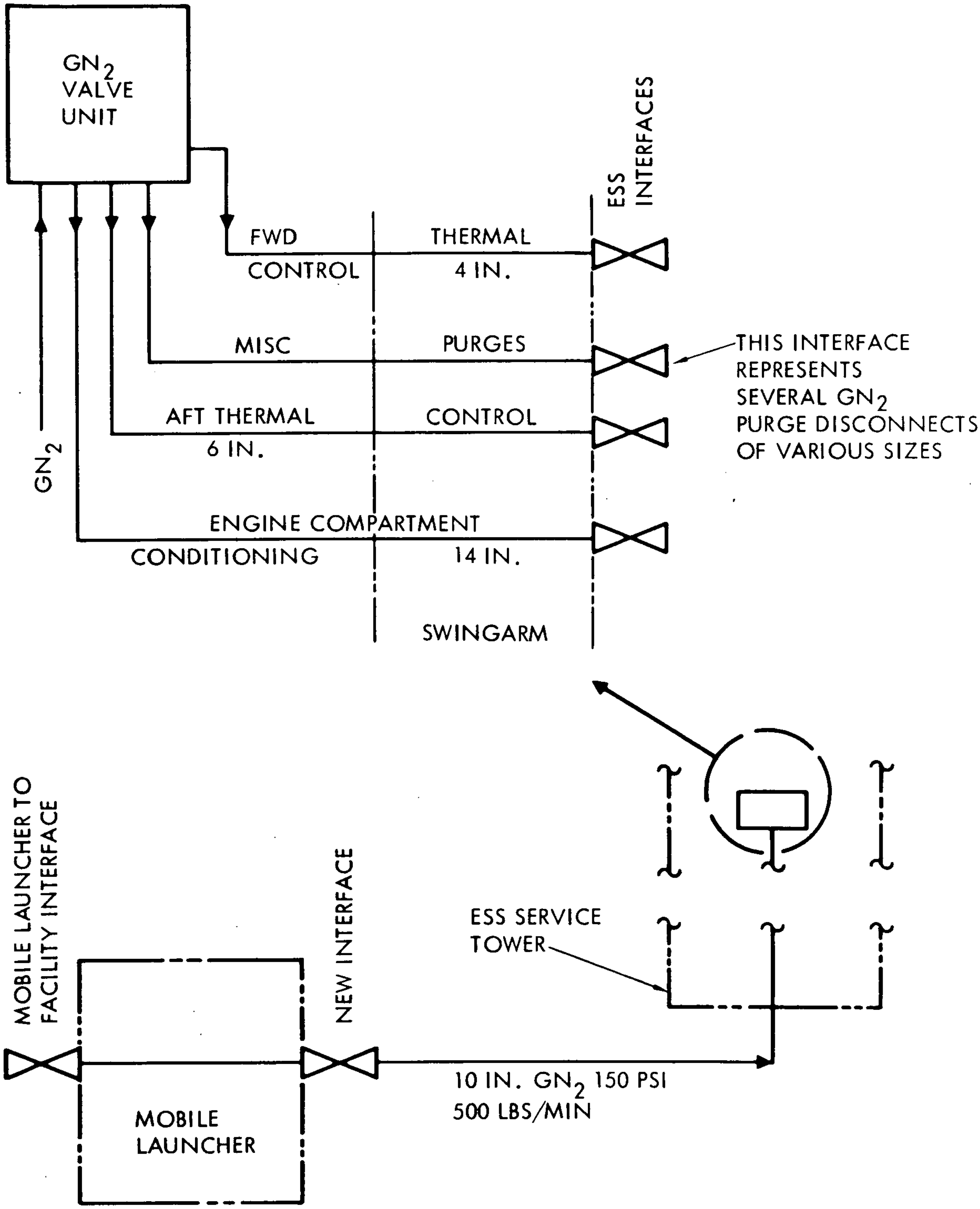


Figure 6-12. GN_2 Thermal Conditioning and Purge

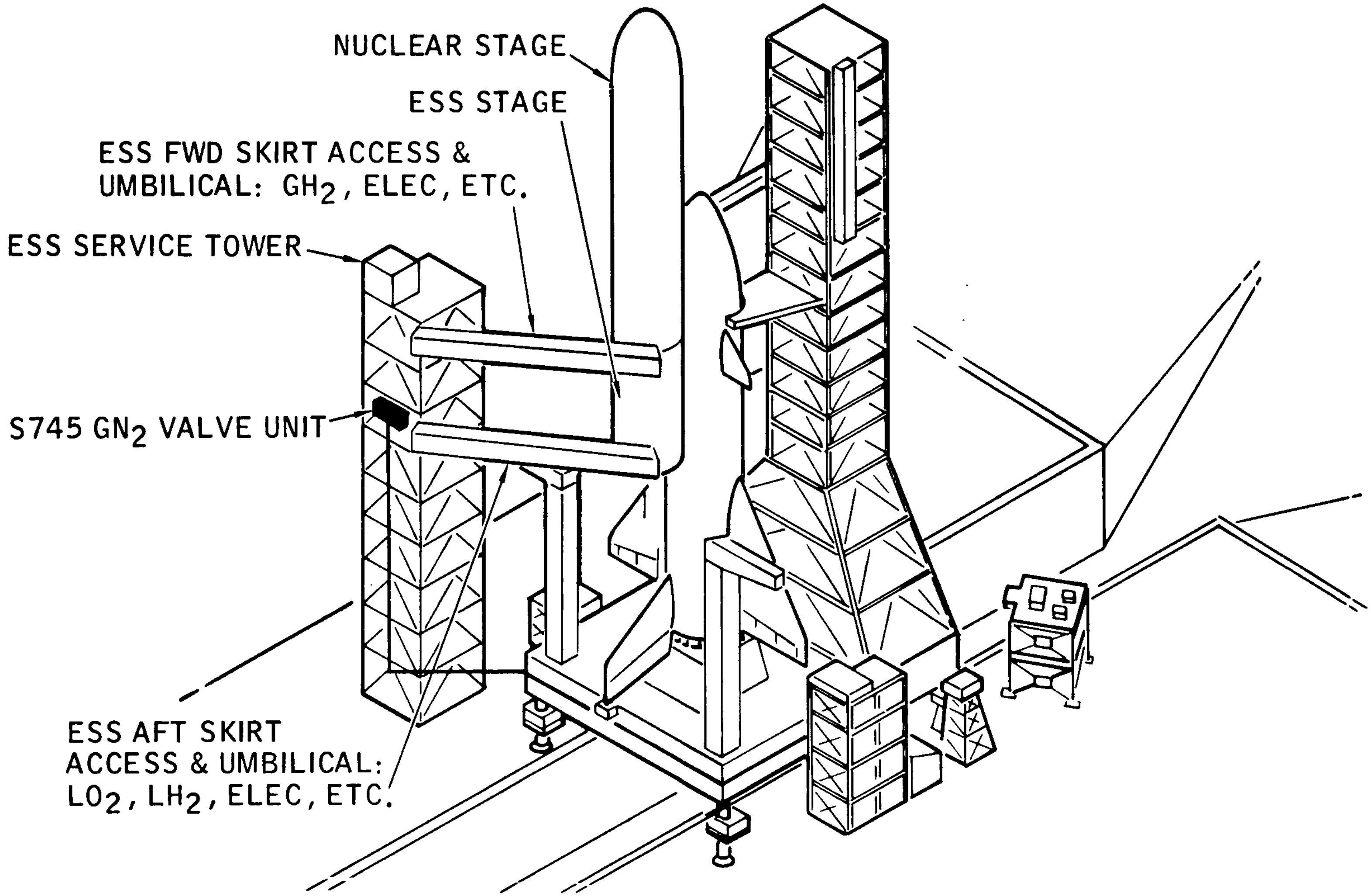


Figure 6-13. Launch Pad Operations (S745 GN_2 Valve Unit)

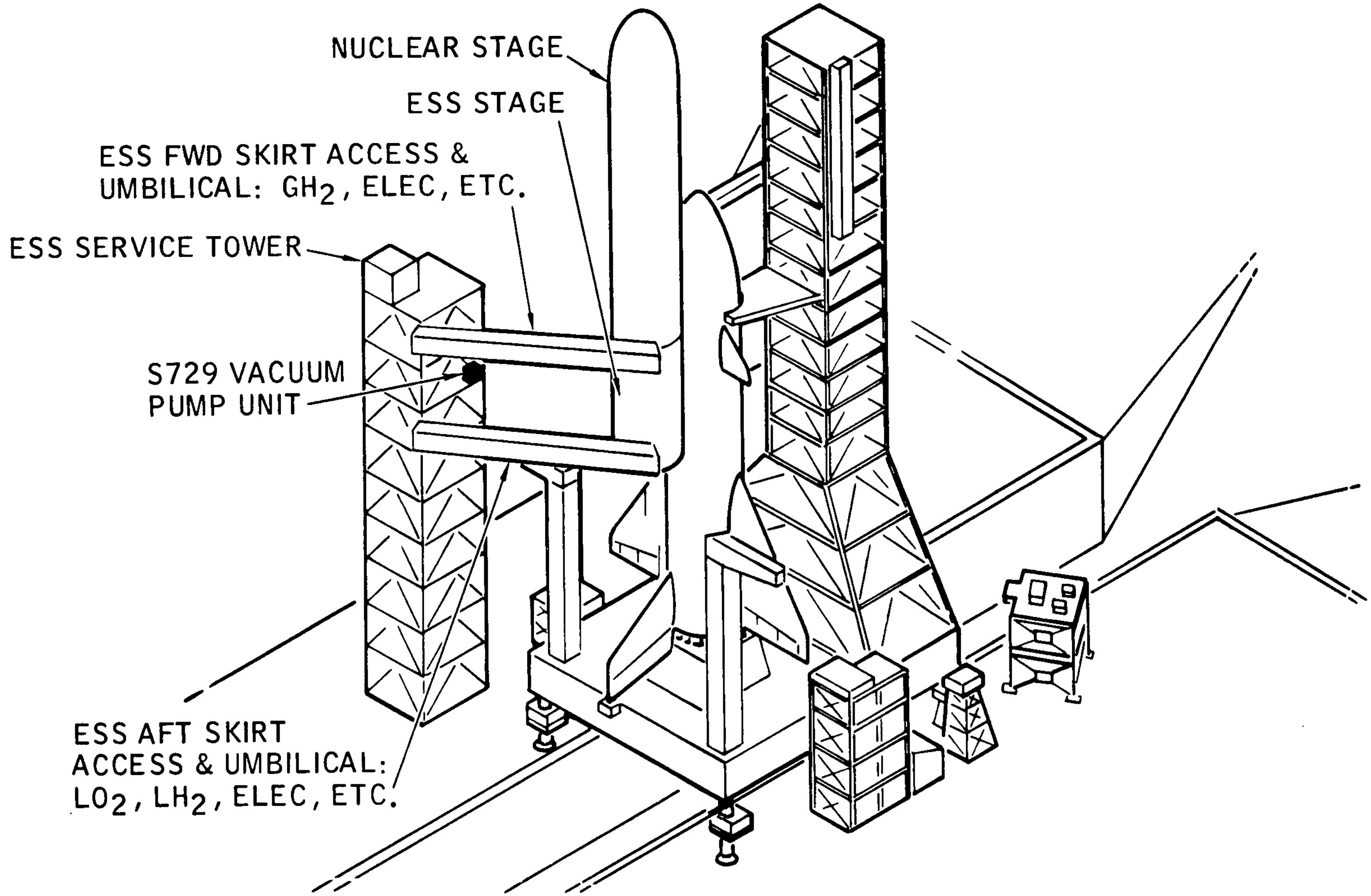


Figure 6-14. Launch Pad Operations (S729 Vacuum Pump Unit)

6.4 OPERATIONAL CONCEPT

6.4.1 Operational Sequence

The operational concept established for the ESS imposes minimum impact on normal shuttle operations. The operational sequence functional flow diagram (FFD), Figure 6-15 illustrates the interrelation of the ESS and shuttle booster during one complete mission cycle. Operational requirements associated with ESS missions are shown in shaded blocks.

There are three booster functions affected as shown on the subject FFD: (1) turnaround maintenance and checkout after a normal shuttle mission; (2) mate, erect, checkout, and launch of an ESS mission, and (3) turnaround maintenance following the ESS missions.

In preparation for an ESS mission, the ESS is transported to KSC where it is processed in the VAB low bay. There receiving and inspection and preliminary checkouts are accomplished. During this period, the shuttle booster turnaround maintenance is initiated. Booster software changes must be incorporated as required by specific ESS mission trajectories. Also, the booster/orbiter separation system links are removed, and the ESS separation system links and platforms are installed and checked out.

The ESS is transferred from the low bay to the high bay and mated to the booster. High-bay checkout after mating is held to a minimum. The mated ESS/booster is transferred to the pad for integrated checkout and launch.

Subsequent to completion of the ESS mission (during turnaround maintenance), the ESS mission software is removed, the ESS separation system linkage is removed, and the booster/orbiter separation system linkage is reinstalled.

6.4.2 Ground Operations Timeline

The ground operations timeline associated with the operational sequence is shown in Figure 6-16. The timeline commences with the conclusion of a normal shuttle flight operation and identifies the associated operations flow up to initiation of ESS flight operations.

Booster software changes and separation system modifications are accomplished during the normal turnaround maintenance cycle. The ESS low-bay operations are started in advance of the shuttle operations cycle and are concluded in time to permit mating of the ESS to the booster during the normal erection and assembly schedule. ESS integration and checkout time requirements at the launch pad of 3 days extends the launch operations schedule one day, however, the normal turnaround-to-launch of 2 weeks can be accomplished.

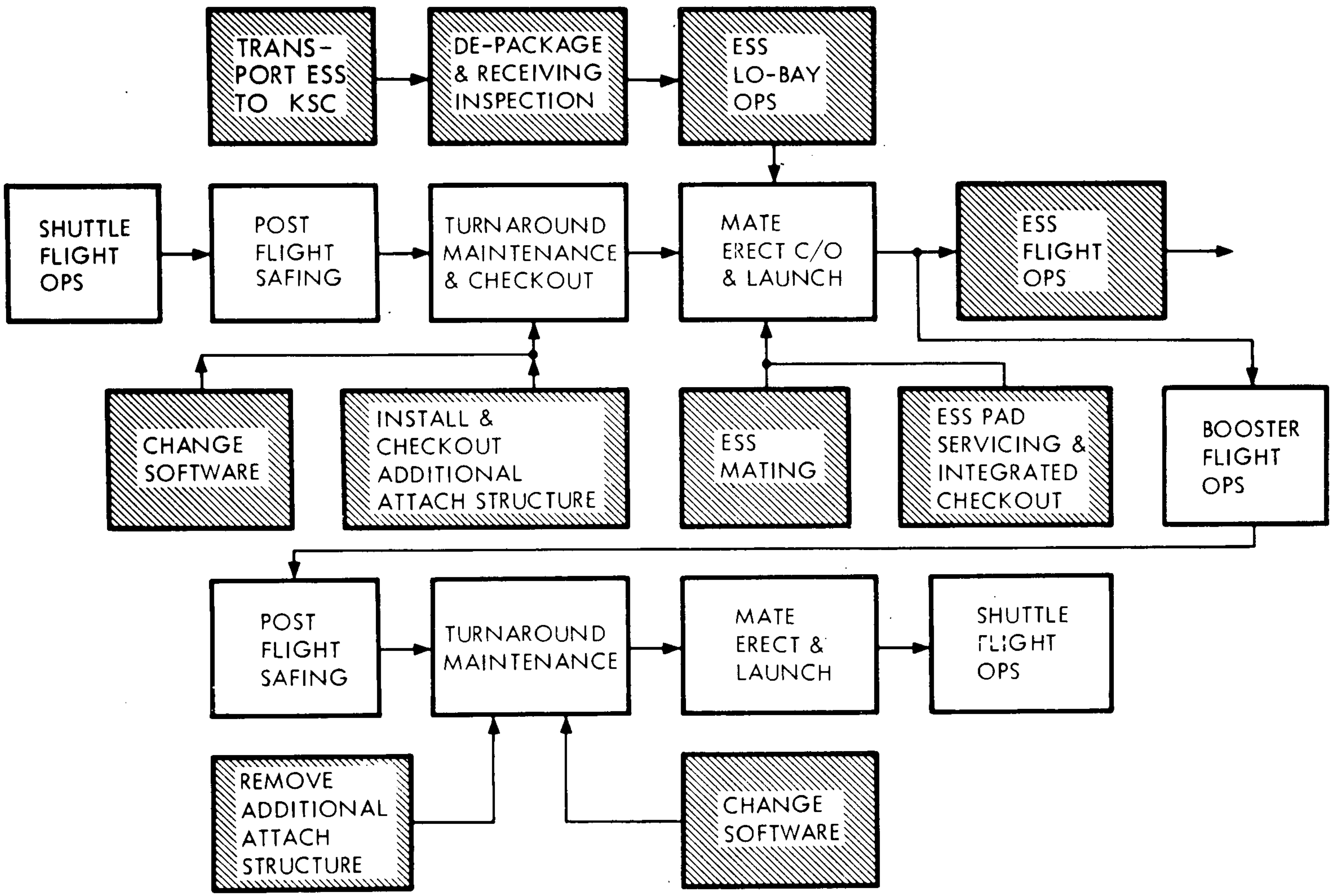


Figure 6-15. Operational Sequence

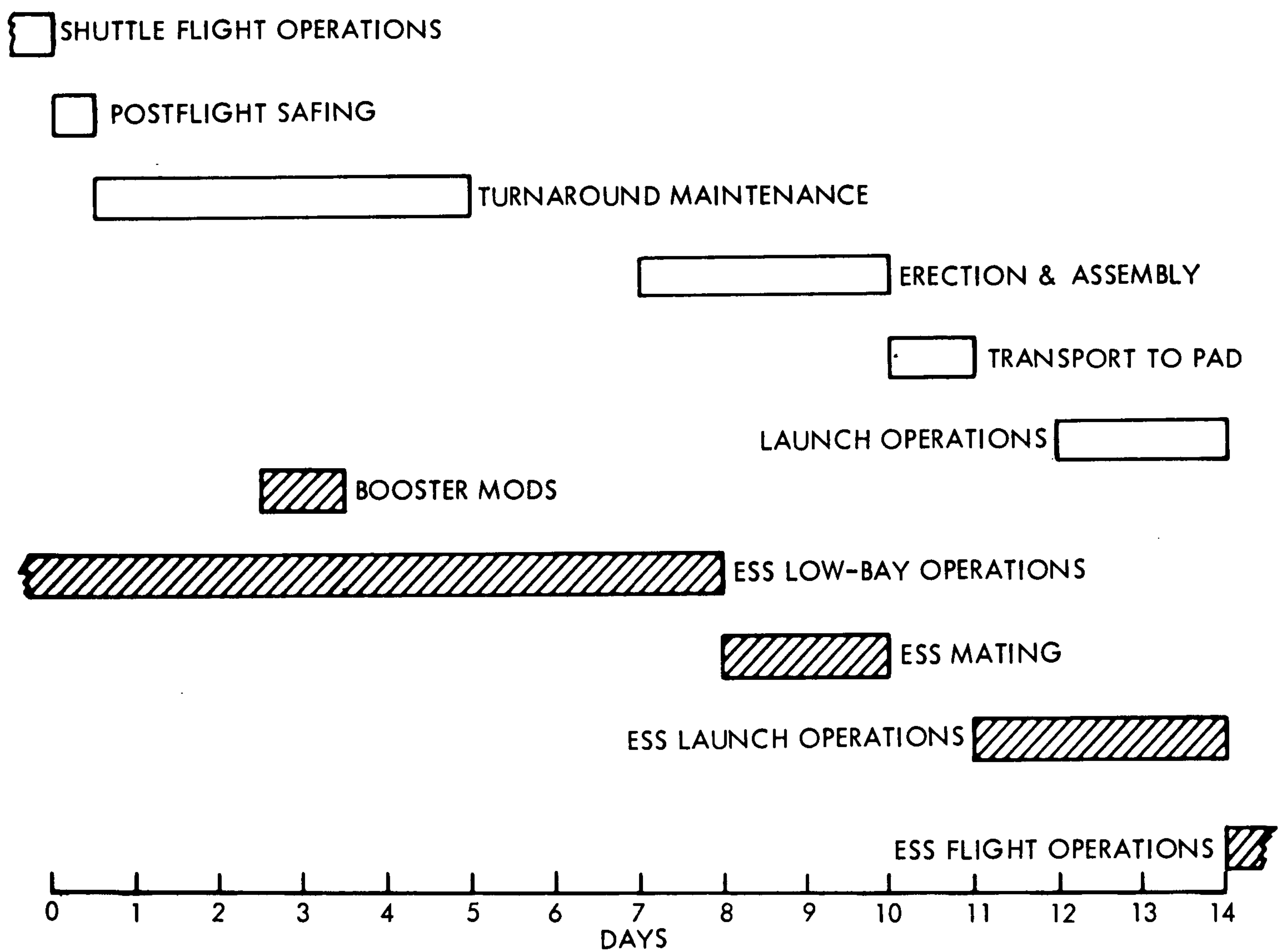


Figure 6-16. Ground Operations Timeline

The timeline excludes swing-arm and propellant loading tests which will be accomplished at the pad for the first ESS mission only.

6.4.3 Operations in the VAB

Upon arrival at KSC, the ESS will be processed through Receiving Inspection and stored or checked out in the same VAB low-bay cells now utilized for similar S-II stage operations. When ready for mating with the booster in preparation for a mission, the affected stage will be erected, moved on its transporter into the transfer aisle, and transported to a location in the transfer aisle directly opposite the booster. As shown in Figure 6-17, orbiter storage and checkout bays are unaffected by ESS VAB operations.

The booster will have been previously erected and mated to the mobile launcher in the VAB in the same manner as in the equivalent shuttle operation (Figure 6-18). The payload and ESS will be positioned in the transfer aisle. The ESS will be lifted from the transporter by overhead crane, moved over the diaphragm wall in the mating bay, and attached to the booster. The payload (space station, tug, or nuclear stage) will then be hoisted, moved into the mating bay, and mated to the ESS stage.

6.4.4 Launch Operations

The launch complex configuration for ESS operations is summarized in Figure 6-19. The ESS service tower, forward and aft swing arms, and other significant items of ESS support equipment are highlighted in the figure.

Subsequent to arrival at the pad, the booster/ESS and pad interfaces are connected and verified. Booster/ESS integrated tests and launch readiness checkouts are performed. Launch countdown operations are similar to normal shuttle operations (Figure 6-20). See the Operations Plan in Volume 5, for a detailed description of launch operations.

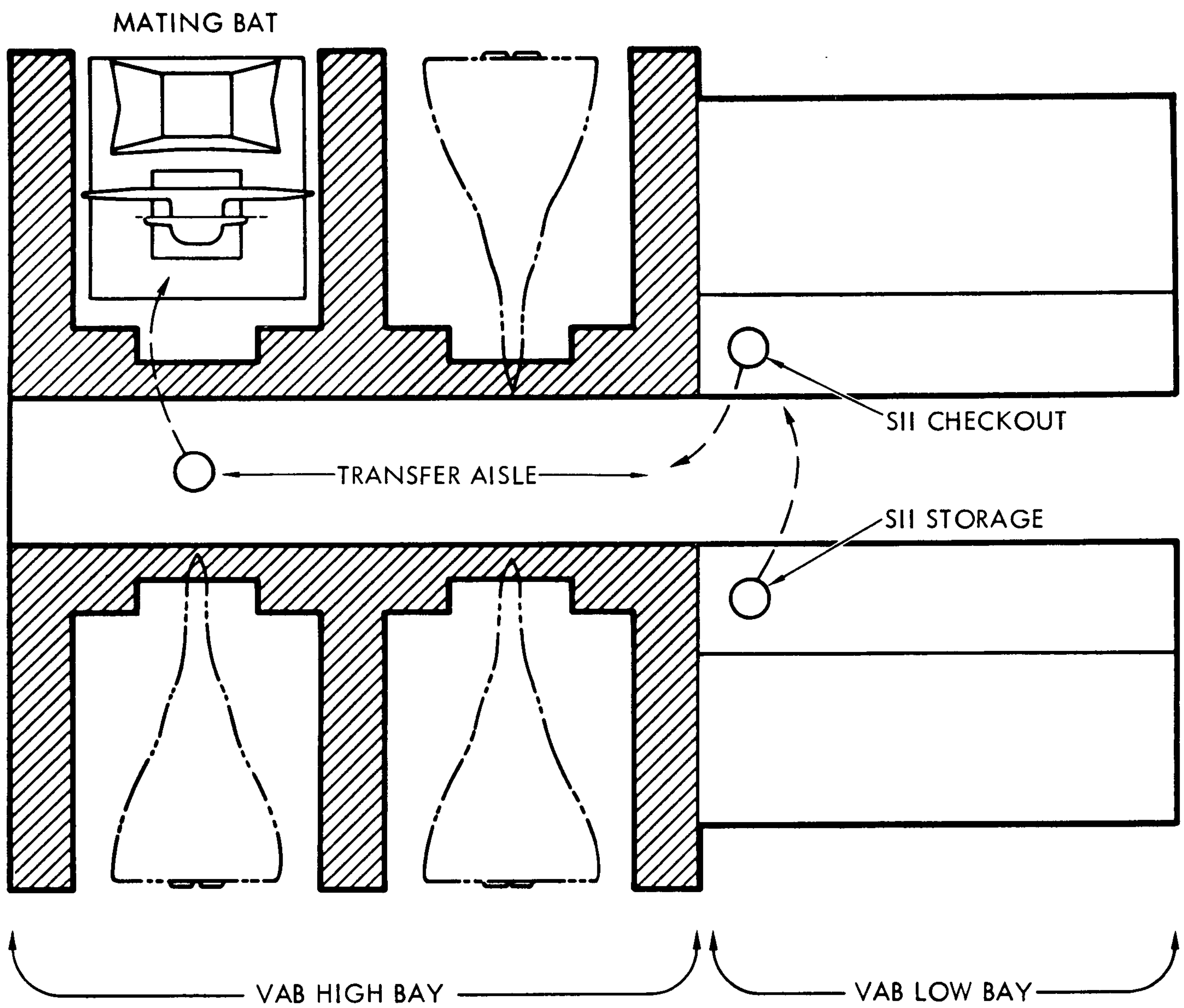


Figure 6-17. ESS Operations in the VAB

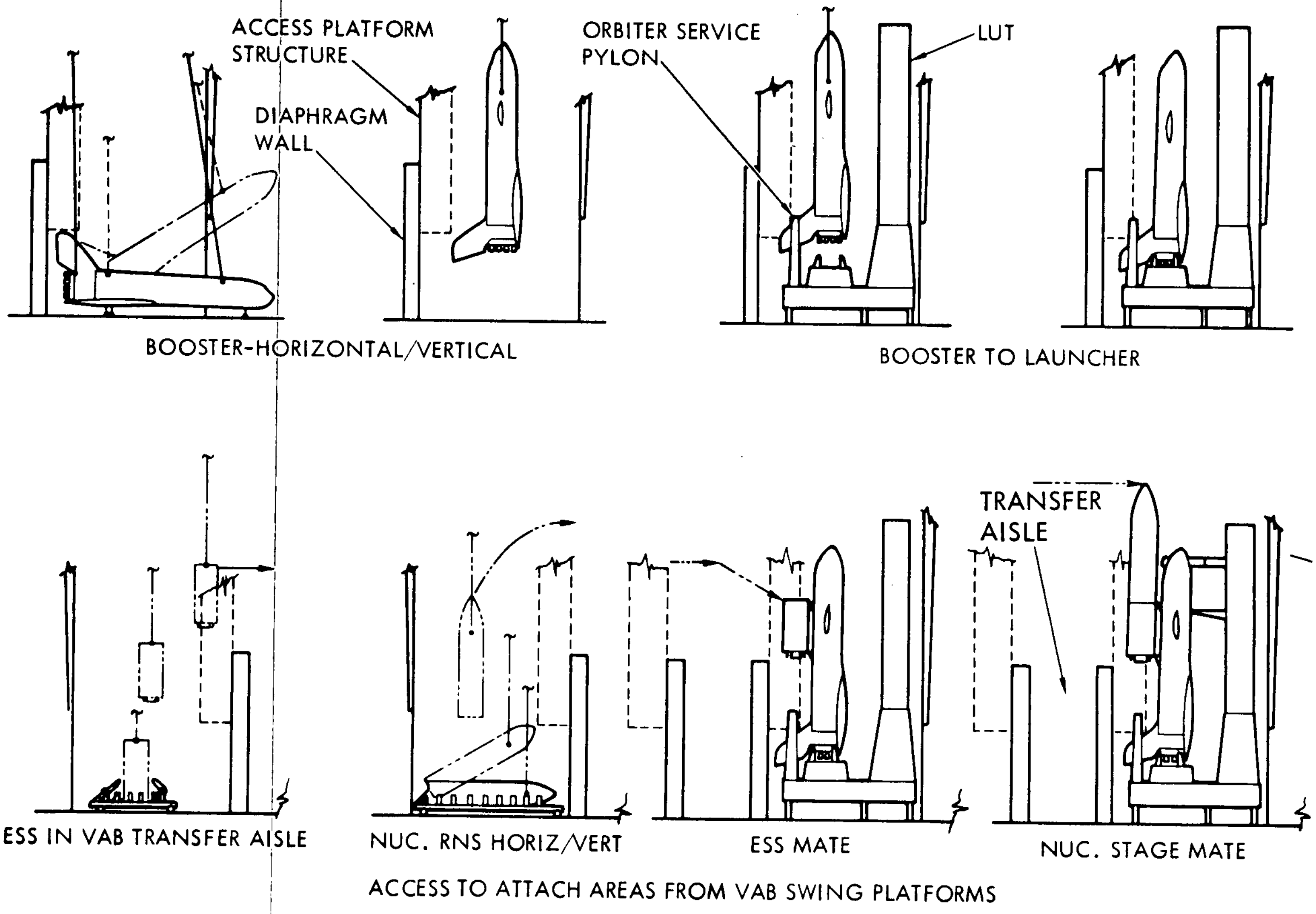


Figure 6-18. ESS Mating in the VAB

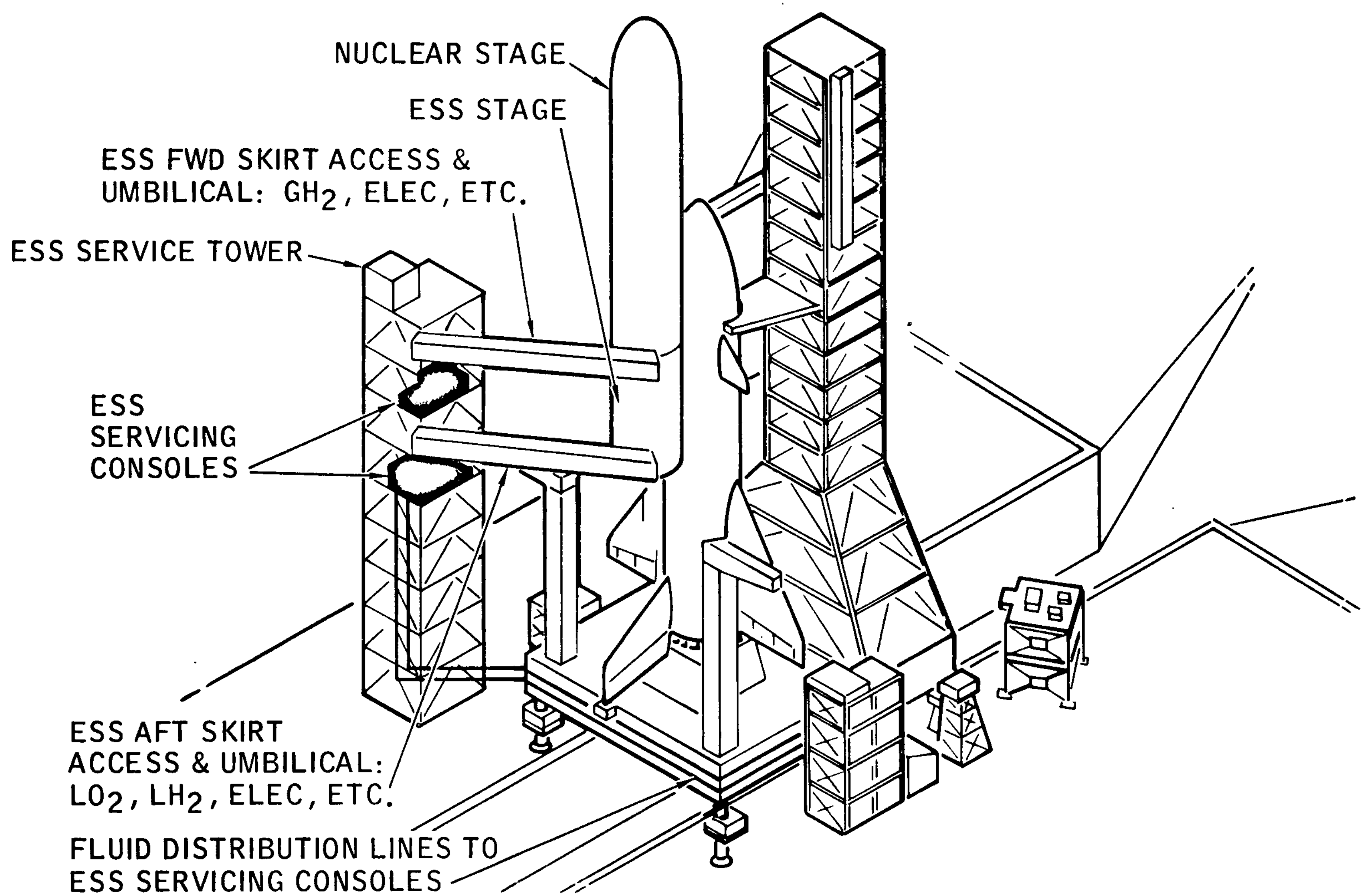


Figure 6-19. Launch Pad Operations

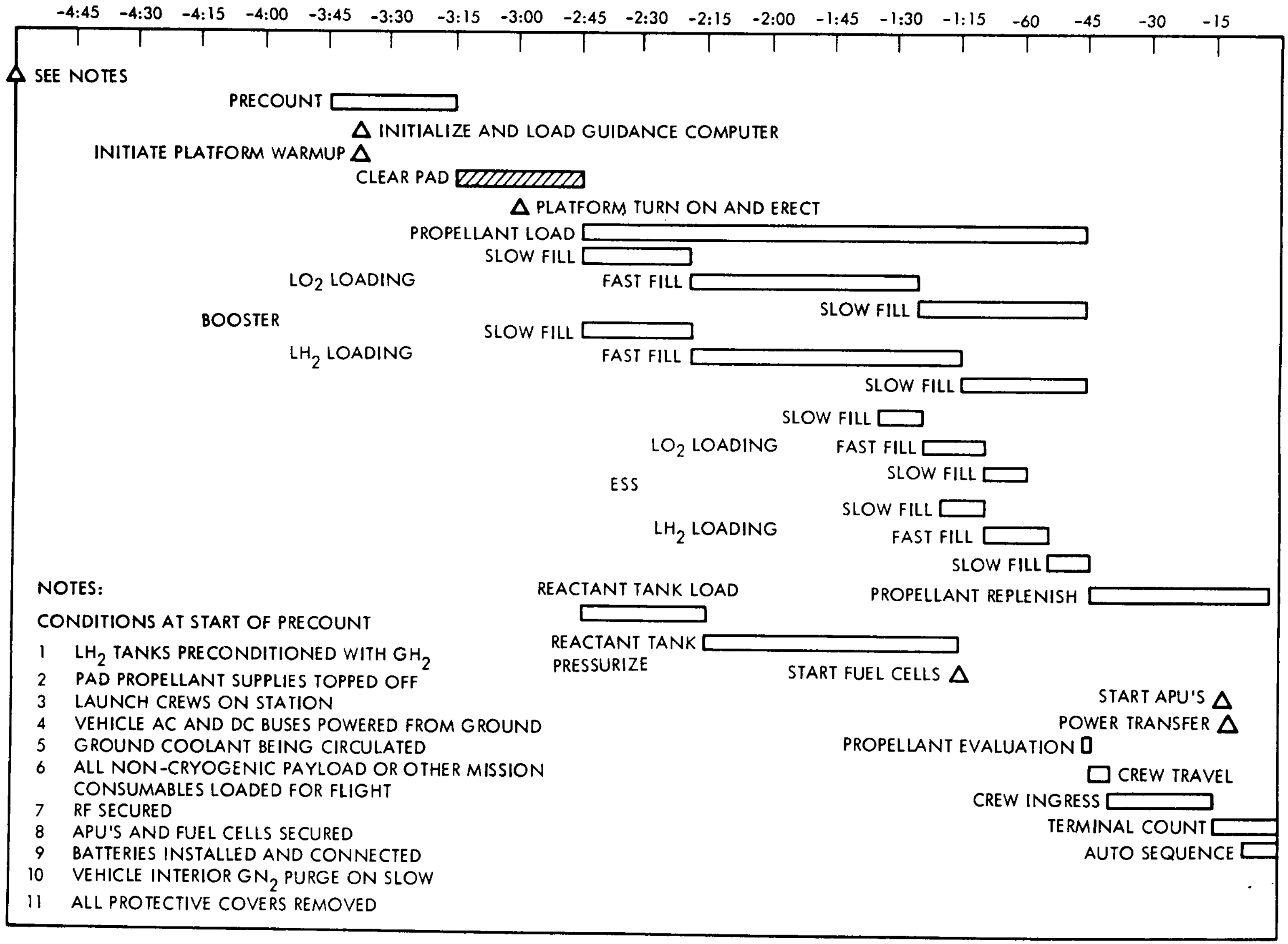


Figure 6-20. ESS Countdown Timeline

APPENDIXES

APPENDIX A

ALTERNATE ESS/BOOSTER CONFIGURATION

1.0 COMPARISON B-17E AND B-9U BOOSTER

The analyses conducted in this study and described in the other sections of this report were based on the shuttle B-9U booster as defined for the 270-day data dump, and described in Volume II, Section IV, paragraph 1.0. A second shuttle booster, designated B-17E and shown in Figure A-1 is currently in the process of definition. The B-17E booster is designed for use with an orbiter incorporating external hydrogen fuel tanks for the main propulsion system. The more significant physical and performance differences between the B-17E and the B-9U booster are summarized in Table A-1 and the difference in the mating/attachment loads are shown in Figure A-2.

The following sections describe the results of a study conducted to determine the shuttle/ESS program implications if a decision were made to use the B-17E instead of the B-9U as the shuttle booster. Since the basic study results using the B-9U booster have shown that the RNS and space tug payloads are not the critical payloads for booster design, the results discussed below consider only the space station payload. The space station weight was kept constant at 183,000 pounds for both boosters. However, the ESS velocity at separation is lower when used with the B-17E booster, resulting in an ESS/payload weight at separation of 1.223M pounds compared to 0.992M pounds when used with the B-9U booster.

1.1 MASS PROPERTIES

Table A-2 contains the weight statement for the B-17E booster for the ESS-space station mission and Table A-3 is the sequence mass property statement for the same mission.

1.2 AIRLOADS

Airload distributions of the B17E/MDAC configuration are presented in Figures A-3 and A-4 for the maximum "βq" pitch and yaw plane conditions, respectively. A comparison of these loads with those obtained for the B-9U/MDAC configuration shows the MDAC loads ($C_{N_{o(B)}}$ and $C_{A_{o(B)}}$) to act further forward on the nose of the B-17E booster than on the B-9U. The magnitude of these loads, in pounds, is the same.

Table A-1. Comparison - B-9U and B-17E Boosters

	BOOSTER	
	B-9U	B-17E
WEIGHTS		
BOOSTER AT LIFTOFF (LBS)	4,188,223	2,860,274
TOTAL VEHICLE AT LIFTOFF (LBS)	5,047,430	3,983,723
STAGING		
ALTITUDE (FT)	242,074	206,616
VELOCITY (FPS)	10,832	7,719
FLIGHT PATH ANGLE (DEG)	6	14
BOOSTER ENGINES		
THRUST-SEA LEVEL (LBS)	550,000	415,000
CANT ANGLE (DEG)	3	0
NUMBER OF ENGINES	12	13
FLYBACK DISTANCE (N. MI.)	399	263
MAXIMUM BODY DIMENSIONS		
LENGTH (FT)	255.6	211
WIDTH (FT)	36	30.55
DEPTH (FT)	41	30.55
BODY STRUCTURE - TYPE	AL. ALLOY PROTECTED BY HEAT SHIELDS	AL. ALLOY HEAT SINK

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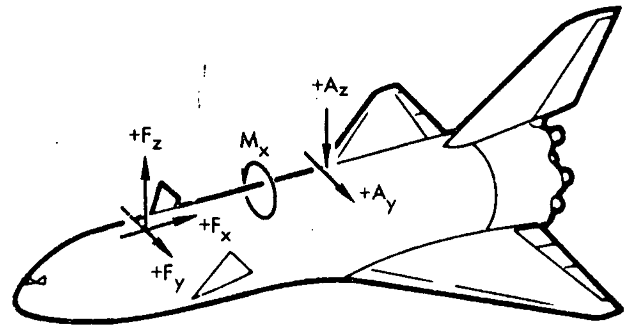


CONDITION	B-9U					B-17E				
	F_x	F_y	F_z	A_y	A_z	F_x	F_y	F_z	A_y	A_z
ONE HOUR GROUND WINDS FUELED UNPRESSURIZED	859	+33.2	84.5	±10.3	137	1122	±27.7	99.6	±11.5	178
DYNAMIC LIFTOFF + ONE HOUR GROUND WINDS	1296	±21.1	118	±2.24	177	1746	±1.64	118	±13.1	254
MAX α-q	1676	0	127	0	-254 +842	2342	0	-190 +283	0	-590 +873
MAX β-q	1796	±50.5	139	±225	119	2356	±126	36.5	±279	20.3
3G MAX THRUST	2825	±54.9	195	±31.0	358	3697	0	32.1	0	430
BOOSTER BURNOUT	2817	±54.9	118	±31.0	408	3685	0	32.1 -50.8	0	430 -423

LOADS IN KIPS

Figure A-2. Booster (Limit) Loads Comparison (Orbiter Induced)

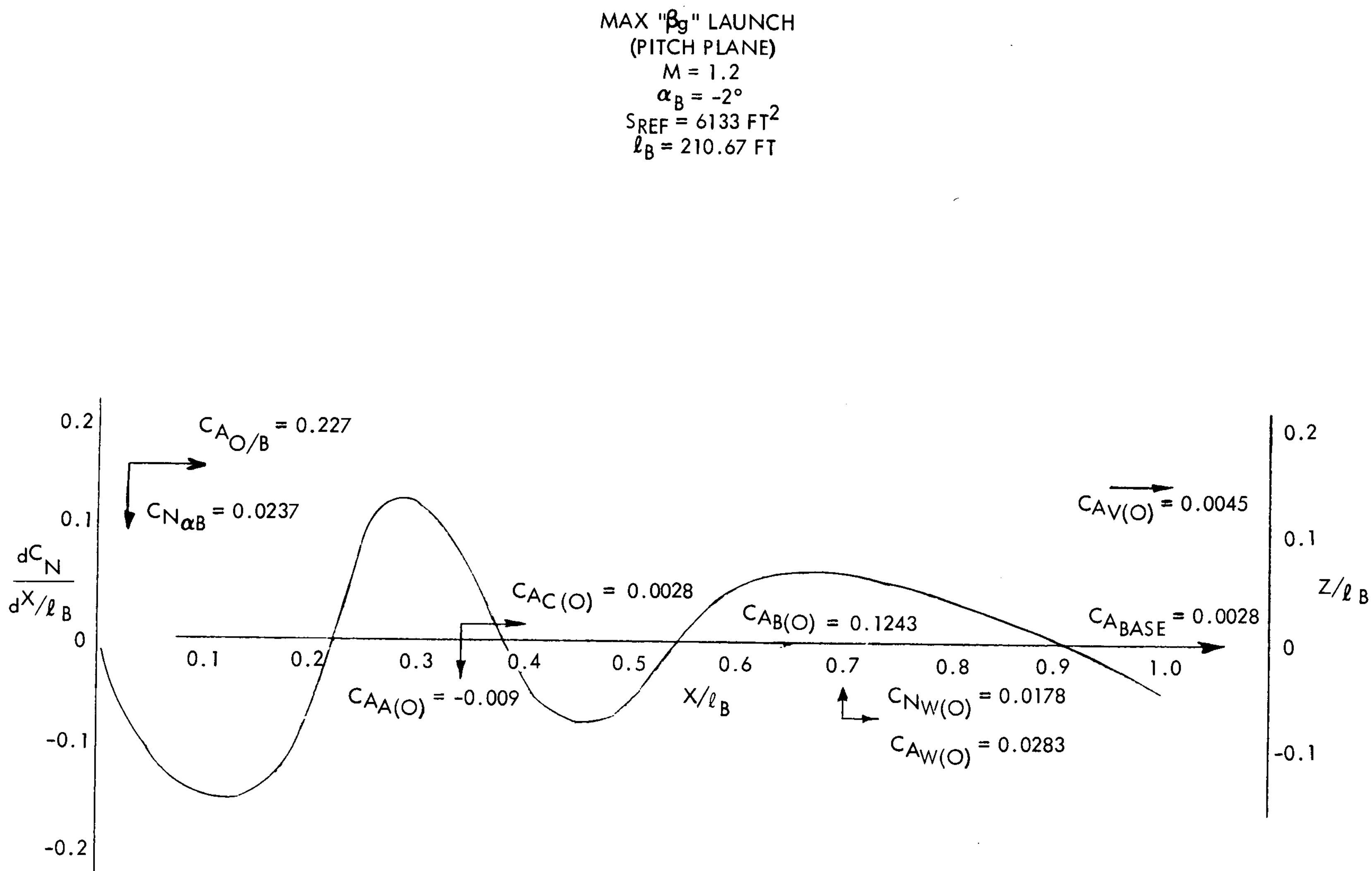


Figure A-3. Air-Load Distribution, Maximum "βq" Launch-Pitch Plane

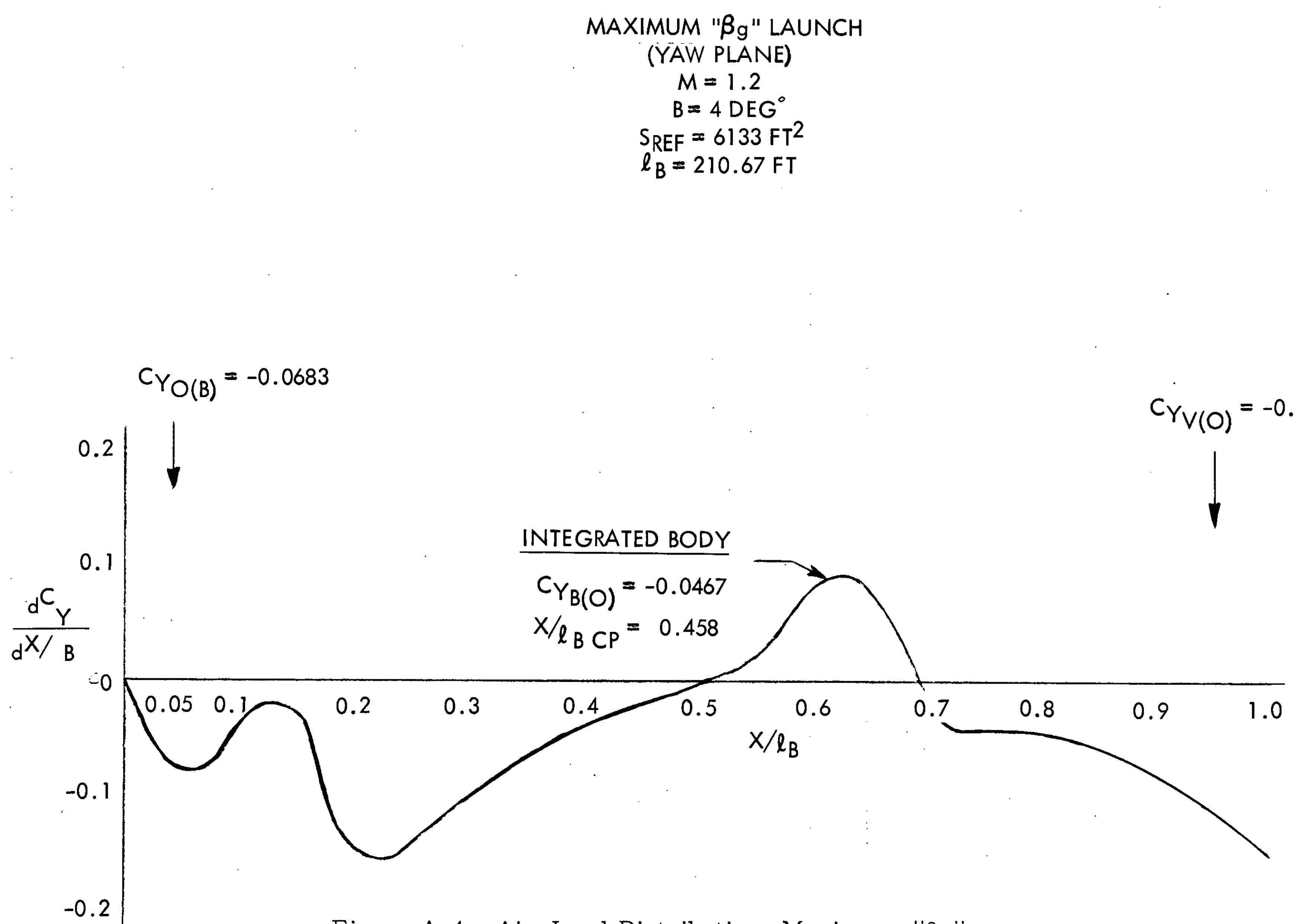


Figure A-4. Air-Load Distribution, Maximum "βq" Launch-Yaw Plane

Table A-2. Summary Weight Statement (Launch Condition)

B-17E DELTA WING BOOSTER

SYSTEM	Reusable Orbiter	Space Station
Wing Group	49453	49453
Tail Group	15487	15487
Body Group+	141247	144362
Induced Environ Protect	38371	38371
Landing, Docking	19856	19856
Propulsion, Ascent	99012	99012
Propulsion, Cruise	30498	30498
Propulsion, Auxiliary	6596	6596
Prime Power/Electrical	3011	3011
Hydraulic Conv. & Dist	2395	2395
Surface Controls	5702	5702
Avionics	4214	4214
Personnel Provision/ECS	2935	2935
Contingency/Growth	32617	32617
Subtotal (Dry Wt)	451395	454309
Personnel	476	476
Residual Fluids	11534	11534
Subtotal (Inert Wt)	463404	466519
Inflight Losses/ACS	16050	16050
Propellant - Ascent	2322205	2322205
Propellant - Cruise	58615	58615
Total Booster Weight	2860274	2863389
Second Stage	1123449	1222625
Total Vehicle Weight	3983723	4086014

+ The Space Station requires a special separation mechanism (+200 lbs) and some beef-up to the separation system bulkheads and skins (+2915 lbs).

Table A-3. Spacecraft Sequence Mass Properties Statement

SPACECRAFT SEQUENCE MASS PROPERTIES STATEMENT

Configuration: B-17E + MDAC SPACE STATION | By: | Page: Of: | Date: 6/17/71

No.	Mission Event	Weight (lb)	Center of Gravity (inches)			Moment of Inertia (slug-ft^2 × 10^6)			Product of Inertia (slug-ft^2 × 10^6)		
			x	y	z	I_{x-x}	I_{y-y}	I_{z-z}	I_{xy}	I_{xz}	I_{yz}
	Booster										
	Liftoff	2863389	1947	0	383	7.898	266.10	265.70	0	- 9.09	0
	Max Q	1789680	2184	0	373	7.029	186.30	186.00	0	- 6.64	0
	Max Q (2 g)	1450614	2320	0	367	6.723	158.00	157.70	0	- 5.22	0
	Burnout (Entry)	541184	2727	0	348	5.045	64.04	63.91	0	- 1.62	0
	Start Cruise	525134	2724	0	348	4.946	62.65	62.59	0	- 1.44	0
	Landing	466519	2758	0	361	4.670	55.78	55.91	0	- 1.20	0
	MDAC Space Station										
	Liftoff	1222625	1815	0	817	1.571	46.95	46.97	0	0	0
	Combined Vehicle										
	Liftoff	4086014	1908	0	513	44.270	351.10	315.90	0	-19.70	0
	Max Q	3012305	2034	0	533	39.500	285.50	254.20	0	-32.30	0
	Max Q (2 g)	2673239	2089	0	573	37.320	270.50	241.20	0	-37.80	0
	Burnout	1763809	2095	0	673	24.440	196.10	178.10	0	-36.20	0

NOTES:

All c.g.s in Booster coordinate system.

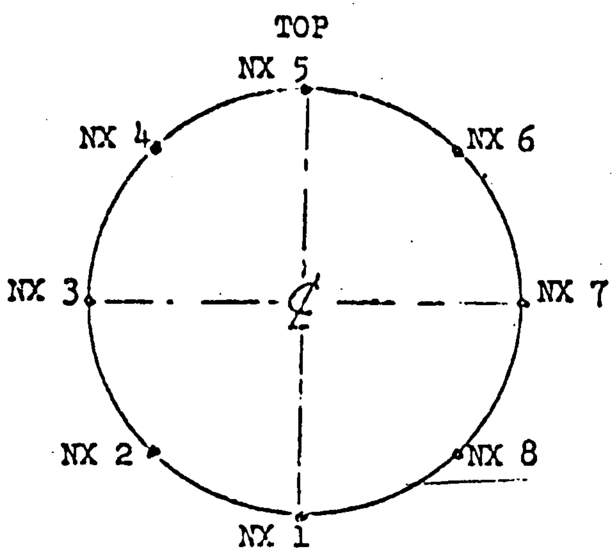
Booster nose = 1000, + aft

Propellant tank $\mathbb{C}_L$ = 400

Ref. MIL-M-38310A or SP-6004

Table A-4. Booster B-17E Ultimate Internal Loads

COND 1	BOOSTER B-17E/NR ORBITER VB70-0500	1HR GROUND HEADWINDS TANKED UNPRES
COND 2	1BOOSTER B-17E/NR ORBITER VB70-0500	1HR GROUND TAILWINDS TANKED UNPRES
COND 3	BOOSTER B-17E/NR ORBITER VB70-0500	1HR GROUND SIDEWINDS TANKED UNPRES
COND 4	BOOSTER B-17E/NR ORBITER VB70-0500	LIFT OFF +1HR GROUND HEADWINDS
COND 5	BOOSTER B-17E/NR ORBITER VB70-0500	LIFT OFF +1HR GROUND TAILWINDS
COND 6	BOOSTER B-17E/NR ORBITER VB70-0500	LIFT OFF +1HR GROUND SIDEWINDS
COND 7	BOOSTER B-17E/NR ORBITER VB70-0500	MAX ALPHA Q HEADWINDS
COND 8	BOOSTER B-17E/NR ORBITER VB70-0500	MAX ALPHA Q TAILWINDS
COND 9	BOOSTER B-17E/NR ORBITER VB70-0500	MAX BETA Q
COND 10	BOOSTER B-17E/NR ORBITER VB70-0500	3.0 G MAX THRUST
COND 11	BOOSTER B-17E/NR ORBITER VB70-0500	3 G BOOSTER BURNOUT
COND 12	BOOSTER B-17E/NR ORBITER VB70-0500	4G RECOVERY



VIEW LOOKING AFT

Table A-5. Booster B-17E Peak Ultimate Axial Tension Load Intensities

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
1000	0(12)	0(12)	0(12)	0(12)	0(10)	0(12)	0(12)	0(12)
1143	21(12)	16(12)	5(12)	-1(8)	14(8)	-1(8)	5(12)	16(12)
1284	54(12)	39(12)	3(12)	29(8)	70(8)	29(8)	3(12)	39(12)
1286	55(12)	40(12)	3(12)	30(8)	72(8)	30(8)	3(12)	40(12)
1288	56(12)	40(12)	3(12)	31(8)	73(8)	31(8)	3(12)	40(12)
1414	107(12)	75(12)	-2(12)	87(8)	159(8)	78(8)	-2(12)	75(12)
1416	2354(12)	2322(12)	2243(12)	2194(10)	2228(10)	2194(10)	2243(12)	2322(12)
1418	2355(12)	2323(12)	2243(12)	2193(10)	2227(10)	2193(10)	2243(12)	2323(12)
1461	2382(12)	2341(12)	2242(12)	2184(10)	2226(10)	2184(10)	2242(12)	2341(12)
1463	2383(12)	2342(12)	2242(12)	2184(10)	2226(10)	2184(10)	2242(12)	2342(12)
1465	2384(12)	2343(12)	2242(12)	2172(10)	2210(10)	2172(10)	2242(12)	2343(12)
1573	2732(10)	2525(10)	2235(12)	2088(12)	2027(12)	2088(12)	2235(12)	2525(10)
1591	3554(10)	3098(10)	2219(12)	2014(12)	1929(12)	2014(12)	2219(12)	3098(10)
1592	3311(11)	2926(11)	2219(12)	2014(12)	1929(12)	2014(12)	2219(12)	2926(11)
1593	1069(11)	684(11)	-26(12)	-232(12)	-317(12)	-232(12)	-26(12)	684(11)
1595	1093(11)	691(11)	-27(12)	-234(12)	-320(12)	-234(12)	-27(12)	691(11)
1838	2700(11)	1165(11)	-41(12)	-339(12)	-463(12)	-339(12)	-41(12)	1165(11)
1840	2720(11)	1170(11)	-52(12)	-353(12)	-478(12)	-353(12)	-52(12)	1170(11)
1842	2740(11)	1174(11)	-52(12)	-355(12)	-480(12)	-355(12)	-52(12)	1174(11)
1986	4341(11)	1542(11)	-69(12)	-342(12)	-455(12)	-342(12)	-69(12)	1642(11)
1988	7225(11)	4510(11)	2330(12)	2060(12)	1948(12)	2060(12)	2330(12)	4510(11)
1990	7227(11)	4510(11)	2330(12)	2062(12)	1951(12)	2062(12)	2330(12)	4510(11)
2002	7206(11)	4494(11)	2328(12)	2075(12)	1970(12)	2075(12)	2328(12)	4494(11)
2261	6718(11)	4123(11)	2310(12)	2280(12)	2268(12)	2280(12)	2310(12)	4123(11)
2263	6714(11)	4120(11)	2310(12)	2281(12)	2270(12)	2281(12)	2310(12)	4120(11)
2265	6099(11)	4108(11)	2310(12)	2283(12)	2271(12)	2283(12)	2310(12)	4108(11)

Table A-5. Booster B-17E Peak Ultimate Axial Tension Load Intensities (Cont)

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
2396	5681(11)	3372(11)	2315(12)	2353(12)	2369(12)	2353(12)	2315(12)	3372(11)
2398	5066(11)	3361(11)	2315(12)	2354(12)	2370(12)	2354(12)	2315(12)	3361(11)
2400	5650(11)	3349(11)	2315(12)	2355(12)	2371(12)	2355(12)	2315(12)	3349(11)
2558	4423(11)	2464(11)	2319(12)	2407(12)	2444(12)	2407(12)	2319(12)	2464(11)
2748	2929(11)	2223(12)	2323(12)	2423(12)	2464(12)	2423(12)	2323(12)	2223(12)
2898	2121(12)	2186(12)	2345(12)	2503(12)	2569(12)	2503(12)	2345(12)	2186(12)
2900	1936(12)	2074(12)	2286(12)	2499(12)	2587(12)	2499(12)	2286(12)	2074(12)
2902	1983(12)	2072(12)	2287(12)	2501(12)	2590(12)	2501(12)	2287(12)	2072(12)
3078	1517(12)	1731(12)	2247(12)	2763(12)	2976(12)	2763(12)	2247(12)	1731(12)
3166	1320(12)	1595(12)	2258(12)	2921(12)	3196(12)	2921(12)	2258(12)	1595(12)
3168	1357(12)	1633(12)	2300(12)	2967(12)	3244(12)	2967(12)	2300(12)	1633(12)
3170	-1047(12)	-769(12)	-99(12)	572(12)	859(12)	572(12)	-99(12)	-769(12)
3255	-1337(12)	-967(12)	-74(12)	819(12)	1189(12)	819(12)	-74(12)	-967(12)
3392	-389(12)	-285(12)	-34(12)	216(12)	320(12)	216(12)	-34(12)	-285(12)
3395	132(1)	124(1)	110(3)	207(12)	307(12)	207(12)	103(2)	124(1)
3397	129(1)	121(1)	108(3)	201(12)	298(12)	201(12)	101(2)	121(1)
3400	514(10)	458(10)	323(10)	232(7)	285(12)	270(9)	323(10)	458(10)
3402	503(10)	448(10)	316(10)	229(7)	276(12)	263(9)	316(10)	448(10)
3423	409(10)	364(10)	256(10)	164(11)	138(12)	164(11)	256(10)	364(10)
3528	0(4)	0(4)	0(6)	0(5)	0(5)	0(5)	0(5)	0(4)
3670	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)
3770	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)

Table A-6. Booster B-17E Peak Ultimate Axial Compression Load Intensities

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
1000	-0(10)	-0(10)	-0(10)	-0(6)	-0(5)	-0(5)	-0(11)	-0(10)
1143	-116(10)	-98(10)	-56(9)	-48(7)	-53(7)	-48(7)	-55(10)	-96(10)
1284	-211(8)	-170(8)	-131(9)	-94(9)	-93(7)	-38(7)	-90(10)	-170(8)
1286	-214(8)	-173(8)	-132(9)	-95(9)	-94(7)	-38(7)	-91(10)	-173(8)
1288	-218(8)	-175(8)	-134(9)	-97(9)	-95(7)	-39(7)	-93(10)	-175(8)
1414	-339(8)	-309(8)	-217(9)	-157(9)	-138(7)	-133(7)	-132(10)	-309(8)
1416	-140(6)	170(5)	339(4)	409(1)	441(1)	409(1)	299(6)	157(6)
1418	-145(6)	167(5)	308(4)	410(1)	443(1)	410(1)	299(6)	154(6)
1461	-245(6)	-152(6)	296(4)	437(1)	485(1)	437(1)	288(6)	-163(6)
1463	-250(6)	-156(6)	295(4)	439(1)	487(1)	439(1)	288(6)	-167(6)
1465	-244(6)	-152(6)	295(4)	435(1)	482(1)	435(1)	287(6)	-163(6)
1578	259(2)	264(4)	267(6)	236(1)	208(1)	229(3)	221(3)	262(3)
1591	363(2)	344(2)	236(6)	-262(1)	-359(1)	-277(3)	-177(3)	336(3)
1592	-3274(4)	-3338(4)	-3508(6)	-3713(5)	-3806(5)	-3713(5)	-3491(4)	-3338(4)
1593	-3402(4)	-3465(4)	-3637(6)	-3842(5)	-3935(5)	-3842(5)	-3619(4)	-3465(4)
1595	-3393(4)	-3464(4)	-3652(6)	-3874(5)	-3975(5)	-3874(5)	-3634(4)	-3464(4)
1838	-2930(7)	-3356(4)	-4760(6)	-6785(10)	-8332(10)	-6785(10)	-4706(4)	-3356(4)
1840	-2963(7)	-3354(4)	-4776(6)	-6857(10)	-8419(10)	-6857(10)	-4722(4)	-3354(4)
1842	-2958(7)	-3352(4)	-4792(6)	-6928(10)	-8507(10)	-6928(10)	-4737(4)	-3352(4)
1986	-3308(7)	-3869(7)	-5901(6)	-11974(10)	-14701(10)	-11974(10)	-5964(9)	-3869(7)
1988	-1782(7)	-2744(4)	-5495(6)	-10275(10)	-13018(10)	-10275(10)	-5404(4)	-2744(4)
1990	-1810(7)	-2745(4)	-5499(6)	-10288(10)	-13034(10)	-10288(10)	-5408(4)	-2745(4)
2002	-1933(7)	-2757(4)	-5503(6)	-10292(10)	-13023(10)	-10292(10)	-5409(4)	-2757(4)
2261	-4748(7)	-4484(7)	-5597(6)	-10131(10)	-12773(10)	-10131(10)	-5451(4)	-4483(7)
2263	-4770(7)	-4499(7)	-5597(6)	-10130(10)	-12771(10)	-10130(10)	-5452(4)	-4499(7)
2265	-4776(7)	-4504(7)	-5598(6)	-10120(10)	-12757(10)	-10120(10)	-5452(4)	-4504(7)

Table A-6. Booster B-17E Peak Ultimate Axial Compression Load Intensities (Cont)

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
2396	-5186(7)	-4806(7)	-5622(6)	-9505(10)	-11864(10)	-9506(10)	-5480(4)	-4806(7)
2398	-5192(7)	-4810(7)	-5623(6)	-9495(10)	-11850(10)	-9496(10)	-5480(4)	-4810(7)
2400	-5193(7)	-4815(7)	-5623(6)	-9487(10)	-11837(10)	-9487(10)	-5480(4)	-4815(7)
2558	-5652(7)	-5148(7)	-5643(6)	-8725(10)	-10734(10)	-8725(10)	-5509(4)	-5148(7)
2748	-6200(7)	-5551(7)	-5658(6)	-7790(10)	-9381(10)	-7790(10)	-5544(4)	-5551(7)
2898	-6398(7)	-5102(7)	-5825(6)	-7194(10)	-8375(10)	-7194(10)	-5731(4)	-6102(7)
2900	-7039(7)	-5220(7)	-5826(6)	-7184(10)	-8360(10)	-7184(10)	-5732(4)	-6220(7)
2932	-7046(7)	-5225(7)	-5827(6)	-7174(10)	-8345(10)	-7174(10)	-5733(4)	-6225(7)
3070	-7743(7)	-5760(7)	-5871(6)	-6300(10)	-7047(10)	-6300(10)	-5803(4)	-6760(7)
3166	-7310(7)	-5468(7)	-5895(6)	-6009(5)	-6212(10)	-6009(5)	-5844(4)	-6468(7)
3168	-7909(7)	-7069(7)	-6781(6)	-6389(5)	-6955(5)	-6839(5)	-6731(4)	-7069(7)
3170	-9432(7)	-8595(7)	-7204(6)	-8205(10)	-8670(10)	-8205(10)	-7155(4)	-8595(7)
3255	-9130(7)	-8405(7)	-7262(6)	-7752(10)	-7962(10)	-7752(10)	-7243(10)	-8405(7)
3392	-8206(5)	-7993(10)	-7519(10)	-7045(10)	-6848(10)	-7045(10)	-7519(10)	-7993(10)
3395	-8234(10)	-8028(10)	-7530(10)	-7032(10)	-6825(10)	-7032(10)	-7530(10)	-8028(10)
3397	-8263(10)	-8050(10)	-7537(10)	-7023(10)	-6810(10)	-7023(10)	-7537(10)	-8050(10)
3400	-344(12)	-252(12)	-30(12)	79(1)	71(1)	79(1)	-30(12)	-252(12)
3402	-333(12)	-244(12)	-29(12)	77(1)	69(1)	77(1)	-29(12)	-244(12)
3420	-221(12)	-168(12)	-41(12)	63(1)	56(1)	63(1)	-41(12)	-168(12)
3528	-0(5)	-0(5)	-0(5)	-0(4)	-0(4)	-0(4)	-0(6)	-0(5)
3670	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)
3770	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)	0(12)

Table A-7. ESS/MDAC/B-17E Booster Ultimate Internal Loads

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CCND  1    BOOSTER B-17E/ESS-MDAC MAX BETA Q
CCND  2    BOOSTER B-17E/ESS-MDAC 2.0G MAX THRUST
CCND  3    BOOSTER B-17E/ESS-MDAC 1HR GROUND SIDEWINGS TANKED UNPRESS
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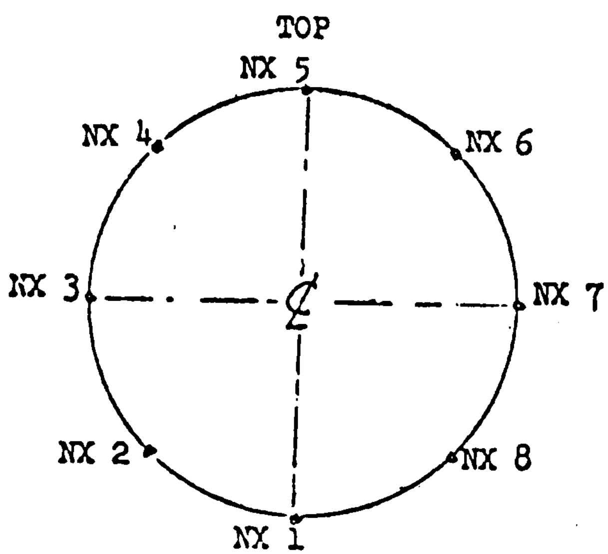

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Table A-8. ESS/MDAC/B-17E Booster Peak Ultimate Axial Tension Load Intensities

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
1000	-0(3)	-0(3)	-0(3)	-0(3)	-0(3)	-0(3)	-0(3)	-0(3)
1143	-23(3)	-19(3)	-14(3)	-11(3)	-4(1)	-4(1)	-19(3)	-23(3)
1284	-36(3)	-28(3)	-19(3)	-15(3)	8(1)	12(1)	-28(1)	-40(3)
1286	-37(3)	-28(3)	-19(3)	-15(3)	8(1)	12(1)	-29(1)	-40(3)
1288	-37(3)	-28(3)	-19(3)	-15(3)	9(1)	12(1)	-29(1)	-41(3)
1414	-147(2)	-125(3)	-22(3)	71(3)	99(3)	45(3)	-46(1)	-127(2)
1416	2101(2)	2117(2)	2157(2)	2197(2)	2213(2)	2197(2)	2157(2)	2117(2)
1418	2100(2)	2116(2)	2156(2)	2196(2)	2213(2)	2196(2)	2156(2)	2116(2)
1461	2069(2)	2090(2)	2139(2)	2188(2)	2208(2)	2188(2)	2139(2)	2090(2)
1463	2068(2)	2088(2)	2138(2)	2187(2)	2208(2)	2187(2)	2138(2)	2088(2)
1465	2075(2)	2093(2)	2137(2)	2181(2)	2199(2)	2181(2)	2137(2)	2093(2)
1578	2487(2)	2373(2)	2099(2)	1826(2)	1712(2)	1956(1)	2111(1)	2373(2)
1691	2789(2)	2582(2)	2081(2)	1581(2)	1672(1)	2141(1)	2333(1)	2582(2)
1692	1086(2)	879(2)	-400(2)	-899(2)	-678(1)	472(1)	664(1)	879(2)
1693	-1160(2)	-1367(2)	-1866(2)	-2031(3)	-1897(1)	-1426(1)	-1234(1)	-1367(2)
1695	-1134(2)	-1355(2)	-1888(2)	-2056(3)	-1959(1)	-1473(1)	-1251(1)	-1355(2)
1838	587(2)	-616(2)	-2560(3)	-3816(3)	-4639(3)	-4549(3)	-2502(1)	-589(1)
1840	615(2)	-603(2)	-2568(3)	-3841(3)	-4674(3)	-4578(3)	-2529(1)	-578(1)
1842	642(2)	-590(2)	-2576(3)	-3867(3)	-4708(3)	-4608(3)	-2547(1)	-566(1)
1986	2706(2)	390(2)	-3121(3)	-5667(3)	-7147(3)	-6695(3)	-3813(1)	390(2)
1988	5596(2)	3266(2)	-3092(3)	-5646(3)	-7135(3)	-6678(3)	-2300(1)	3266(2)
1990	5604(2)	3270(2)	-3081(3)	-5650(3)	-7143(3)	-6686(3)	-2302(1)	3269(2)
2002	5614(2)	3276(2)	-3065(3)	-5642(3)	-7149(3)	-6703(3)	-2288(1)	3276(2)
2261	5797(2)	3388(2)	-2705(3)	-5465(3)	-7274(3)	-6955(1)	-1977(1)	3388(2)
2263	5798(2)	3389(2)	-2703(3)	-5464(3)	-7275(3)	-6953(1)	-1975(1)	3389(2)
2265	5799(2)	3389(2)	-2700(3)	-5463(3)	-7276(3)	-6956(1)	-1977(1)	3389(2)

Table A-8. ESS/MDAC/B-17E Booster Peak Ultimate Axial Tension Load Intensities (Cont)

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
2396	5829(2)	3400(2)	-2551(3)	-5421(3)	-7377(3)	-7116(1)	-2116(1)	3400(2)
2398	5830(2)	3400(2)	-2549(3)	-5420(3)	-7378(3)	-7118(1)	-2118(1)	3400(2)
2400	5830(2)	3400(2)	-2546(3)	-5420(3)	-7380(3)	-7121(1)	-2120(1)	3400(2)
2558	5000(2)	2801(2)	-2354(3)	-5076(3)	-7097(3)	-6782(1)	-2332(1)	2801(2)
2748	3294(2)	1581(2)	-2112(3)	-4424(3)	-6430(3)	-5974(1)	-2585(1)	1581(2)
2898	1598(2)	-788(2)	-2013(3)	-3977(3)	-5968(3)	-5469(1)	-3004(1)	-788(2)
2900	1577(2)	-803(2)	-2010(3)	-3971(3)	-5961(3)	-5465(1)	-3051(1)	-803(2)
2902	1556(2)	-818(2)	-2008(3)	-3964(3)	-5954(3)	-5458(1)	-3056(1)	-818(2)
3070	-1288(2)	-1560(3)	-1798(3)	-3365(3)	-5344(3)	-4797(1)	-3462(1)	-2086(2)
3166	-2723(2)	-1750(3)	-1673(3)	-3014(3)	-4988(3)	-4474(1)	-3676(1)	-2834(2)
3168	-3053(2)	-2323(3)	-2240(3)	-3576(3)	-5549(3)	-5027(1)	-4241(1)	-3558(2)
3170	-3833(3)	-2373(3)	-2283(3)	-3615(3)	-5588(3)	-6551(1)	-5777(1)	-5218(1)
3255	-4228(3)	-2571(3)	-2196(3)	-3322(3)	-5290(3)	-6297(1)	-6006(1)	-5841(1)
3392	-4876(3)	-2892(3)	-2051(3)	-2845(3)	-4809(3)	-5840(1)	-6383(1)	-6840(3)
3395	119(3)	119(3)	110(3)	97(3)	88(3)	87(3)	96(3)	109(3)
3397	116(3)	117(3)	108(3)	95(3)	86(3)	86(3)	95(3)	107(3)
3400	273(2)	256(2)	214(2)	172(2)	202(1)	220(1)	214(2)	256(2)
3402	268(2)	250(2)	209(2)	168(2)	200(1)	215(1)	209(2)	250(2)
3420	219(2)	204(2)	169(2)	134(2)	120(2)	134(2)	169(2)	204(2)
3528	0(3)	0(3)	0(3)	0(3)	0(3)	0(2)	0(2)	0(2)
3670	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)
3770	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)

Table A-9. ESS/MDAC/B-17E Booster Peak Ultimate Axial Compression Load Intensities

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
1000	-0(2)	-0(2)	-0(2)	-0(2)	-0(2)	-0(2)	-0(2)	-0(2)
1143	-62(2)	-61(1)	-44(1)	-21(1)	-11(2)	-19(2)	-36(2)	-54(2)
1284	-134(1)	-138(1)	-98(1)	-37(1)	-23(2)	-34(2)	-60(2)	-89(1)
1286	-136(1)	-140(1)	-99(1)	-38(1)	-24(2)	-34(2)	-61(2)	-90(1)
1288	-138(1)	-142(1)	-100(1)	-38(1)	-24(2)	-35(2)	-61(2)	-91(1)
1414	-239(1)	-239(1)	-159(1)	-48(2)	-32(2)	-48(2)	-88(2)	-159(1)
1416	190(3)	245(3)	350(3)	445(3)	473(3)	419(3)	313(3)	219(3)
1418	187(3)	242(3)	350(3)	446(3)	476(3)	420(3)	313(3)	216(3)
1461	-211(3)	193(3)	347(3)	487(3)	531(3)	453(3)	300(3)	-167(3)
1463	-214(3)	191(3)	347(3)	489(3)	534(3)	455(3)	299(3)	-170(3)
1465	-213(3)	193(3)	349(3)	489(3)	532(3)	452(3)	296(3)	-170(3)
1578	180(3)	337(3)	475(3)	514(3)	431(3)	274(3)	-191(3)	-230(3)
1691	207(3)	458(3)	615(3)	586(3)	387(3)	-191(3)	-348(3)	-318(3)
1692	-2366(3)	-2113(3)	-1956(3)	-1986(3)	-2186(3)	-2439(3)	-2596(3)	-2566(3)
1693	-2412(3)	-2380(1)	-2572(1)	-2372(1)	-2572(2)	-2485(3)	-2643(3)	-2612(3)
1695	-2799(3)	-2374(1)	-2596(1)	-2424(1)	-2642(2)	-2513(3)	-2656(3)	-2608(3)
1838	-1517(3)	-1860(1)	-4299(1)	-6422(2)	-7624(2)	-6422(2)	-3596(3)	-2341(3)
1840	-1504(3)	-1853(1)	-4372(1)	-6482(2)	-7700(2)	-6482(2)	-3610(3)	-2337(3)
1842	-1491(3)	-1845(1)	-4356(1)	-6542(2)	-7775(2)	-6542(2)	-3624(3)	-2333(3)
1986	-547(3)	-1250(1)	-6059(1)	-10790(2)	-13105(2)	-10790(2)	-5200(2)	-2028(3)
1988	1711(3)	1254(3)	-4552(1)	-9080(2)	-11410(2)	-9080(2)	-4542(3)	-1978(3)
1990	1714(3)	1258(3)	-4560(1)	-9093(2)	-11427(2)	-9093(2)	-4547(3)	-1978(3)
2002	1719(3)	1267(1)	-4585(1)	-9104(2)	-11442(2)	-9104(2)	-4566(3)	-1988(3)
2261	1789(3)	884(1)	-5090(1)	-9335(2)	-11743(2)	-9335(2)	-4979(3)	-2219(3)
2263	1790(3)	881(1)	-5094(1)	-9336(2)	-11746(2)	-9336(2)	-4982(3)	-2221(3)
2265	1791(3)	882(1)	-5093(1)	-9338(2)	-11747(2)	-9338(2)	-4985(3)	-2222(3)

Table A-9. ESS/MDAC/B-17E Booster Peak Ultimate Axial Compression Load Intensities (Cont)

STATION (IN)	NX1 (LB/IN)	NX2 (LB/IN)	NX3 (LB/IN)	NX4 (LB/IN)	NX5 (LB/IN)	NX6 (LB/IN)	NX7 (LB/IN)	NX8 (LB/IN)
2396	1856(3)	971(1)	-5026(1)	-9425(2)	-11854(2)	-9425(2)	-5170(3)	-2299(3)
2398	1857(3)	977(1)	-5025(1)	-9426(2)	-11856(2)	-9426(2)	-5172(3)	-2301(3)
2400	1858(3)	974(1)	-5024(1)	-9427(2)	-11858(2)	-9427(2)	-5175(3)	-2302(3)
2558	1538(3)	559(1)	-4918(1)	-8909(2)	-11108(2)	-8909(2)	-5404(3)	-2682(3)
2748	-1373(3)	-1340(1)	-4728(1)	-7786(2)	-9500(2)	-7786(2)	-5691(3)	-3379(3)
2898	-2075(3)	-2218(1)	-4682(1)	-7034(2)	-8327(2)	-7034(2)	-6030(3)	-4065(3)
2900	-2083(3)	-2308(1)	-4722(1)	-7021(2)	-8309(2)	-7021(2)	-6034(3)	-4073(3)
2902	-2091(3)	-2318(1)	-4720(1)	-7009(2)	-8291(2)	-7009(2)	-6037(3)	-4082(3)
3070	-2791(3)	-3217(1)	-4552(1)	-5938(2)	-6736(2)	-6575(3)	-6337(3)	-4770(3)
3166	-3200(3)	-3630(1)	-4428(1)	-5305(2)	-5817(2)	-6438(3)	-6515(3)	-5174(3)
3168	-3778(3)	-4199(1)	-4985(1)	-6300(2)	-6505(2)	-7003(3)	-7087(3)	-5751(3)
3170	-5203(1)	-5739(1)	-6550(2)	-7756(2)	-8255(2)	-7756(2)	-7137(3)	-5806(3)
3255	-5990(1)	-6147(1)	-6656(2)	-7224(2)	-7460(2)	-7224(2)	-7322(3)	-6195(3)
3392	-7544(2)	-7337(2)	-6839(2)	-6341(2)	-6134(2)	-6792(3)	-7634(3)	-7337(2)
3395	-7585(2)	-7368(2)	-6846(2)	-6324(2)	-6107(2)	-6324(2)	-6846(2)	-7368(2)
3397	-7612(2)	-7389(2)	-6851(2)	-6313(2)	-6090(2)	-6313(2)	-6851(2)	-7389(2)
3400	113(3)	113(3)	104(3)	92(3)	83(3)	83(3)	92(3)	104(3)
3402	110(3)	110(3)	102(3)	90(3)	81(3)	81(3)	90(3)	102(3)
3420	90(3)	89(3)	82(3)	72(3)	65(3)	65(3)	77(3)	83(3)
3528	0(3)	0(2)	0(2)	0(2)	0(2)	-0(3)	-0(3)	-0(3)
3670	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)
3770	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)

1.3 LOADS AND STRUCTURES

The loads imposed by the ESS/MDAC stage on the B-17E booster structure were compared to those imposed by the NR orbiter VB70-0500, which represents the present structural capability. The three loading conditions that proved to be critical in the previous ESS/MDAC/B-9U analyses were used in this study since these conditions would probably produce the most critical effects on the B-17E/ESS/MDAC configuration. The three critical loading conditions were maximum beta q, 2-g maximum thrust, and one-hour ground sidewinds.

Table A-4 lists the loading conditions used to develop the current design load envelope for the B-17E booster. Tables A-5 and A-6 give the peak tension and compression ultimate loads versus booster station for the B-17E/NR orbiter VB70-0500 as of 9 June 1971.

Table A-7 lists the loading conditions investigated for the ESS/MDAC stage. Tables A-8 and A-9 give the peak tension and compression ultimate loads versus booster station for the ESS/MDAC stage. Figures A-5, A-6, and A-7 are plots of the loads shown in Tables A-5 through A-8. The areas on the booster where the ESS/MDAC load intensities exceed the baseline are shown on these plots along with the loading condition which caused the overload.

Figure A-8 gives the design limit attachment loads that are applied to the B-17E/ESS/MDAC fixed-platform separation system from the ESS/MDAC stage.

The effects of the ESS/MDAC stage on the structural weight of the B-17E booster have been evaluated and the results are presented in Figure A-9. The critical flight condition is at maximum thrust—the point in the trajectory where the axial accelleration initially reaches 2.0g and throttling is initiated. The critical component is the B-17E hydrogen tank bulkhead at Station 2398. This station is comparable to B-9U Station 2866 shown in Figure A-10, except that the distance between this bulkhead and the adjacent bulkhead has been decreased by 65 inches, increasing the angle of the diagonal link. A drag support is required, as shown in Figure A-10, to transfer the longitudinal loads from the aft ESS structure to the forward booster structure. This arrangement, as explained in Volume II, Section IV, provides the maximum structural compatibility between the ESS and the booster, but it induces a vertical load component in the aft booster bulkhead as shown. This vertical load component establishes the requirement for the additional 2530 pounds of bulkhead weight and 150 pounds of additional weight to the adjacent skins as shown in Table A-8.

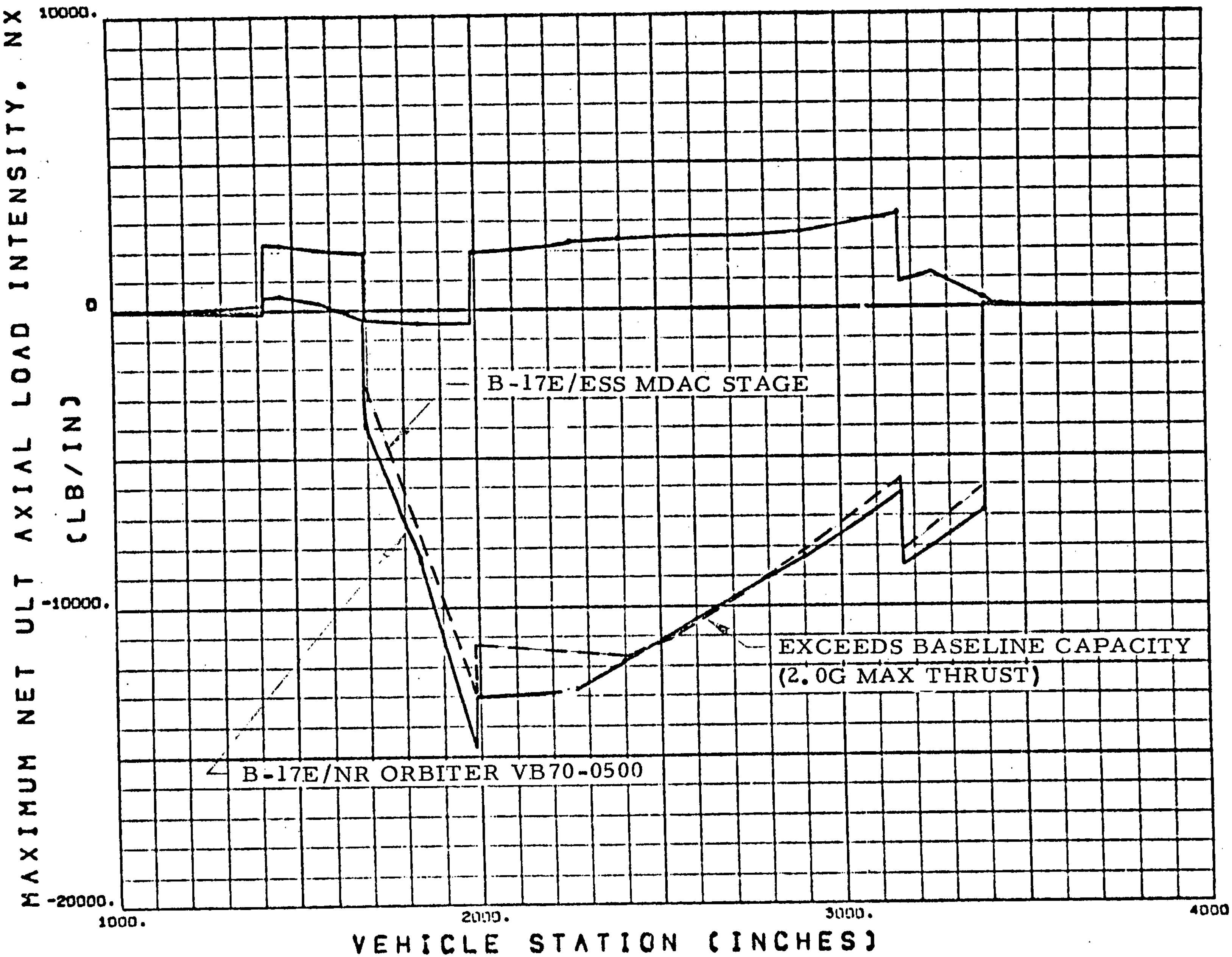


Figure A-5. GDC/B-17E Internal Loads at Top Centerline

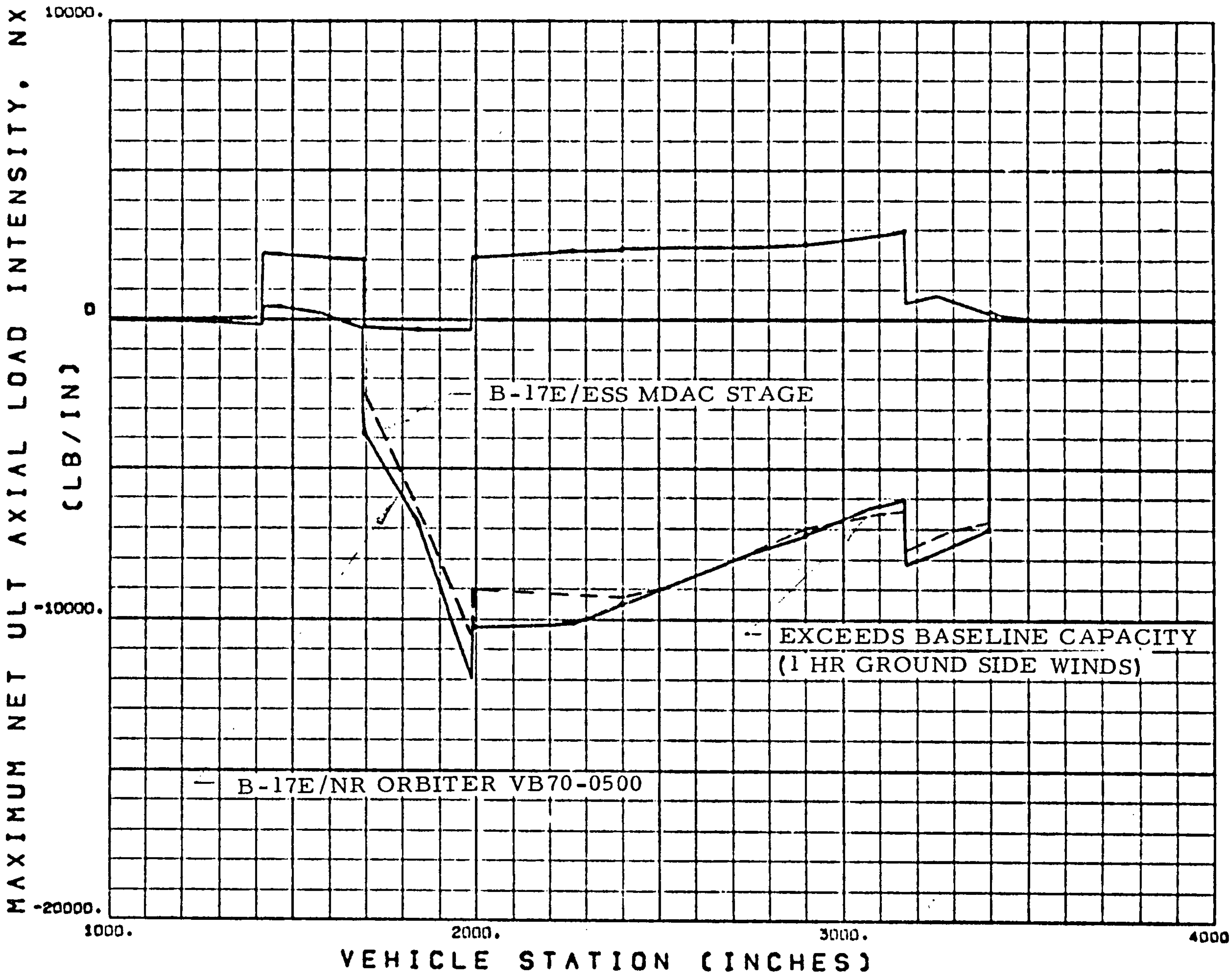


Figure A-6. GDC/B-17E Internal Loads 45 Degrees From Top

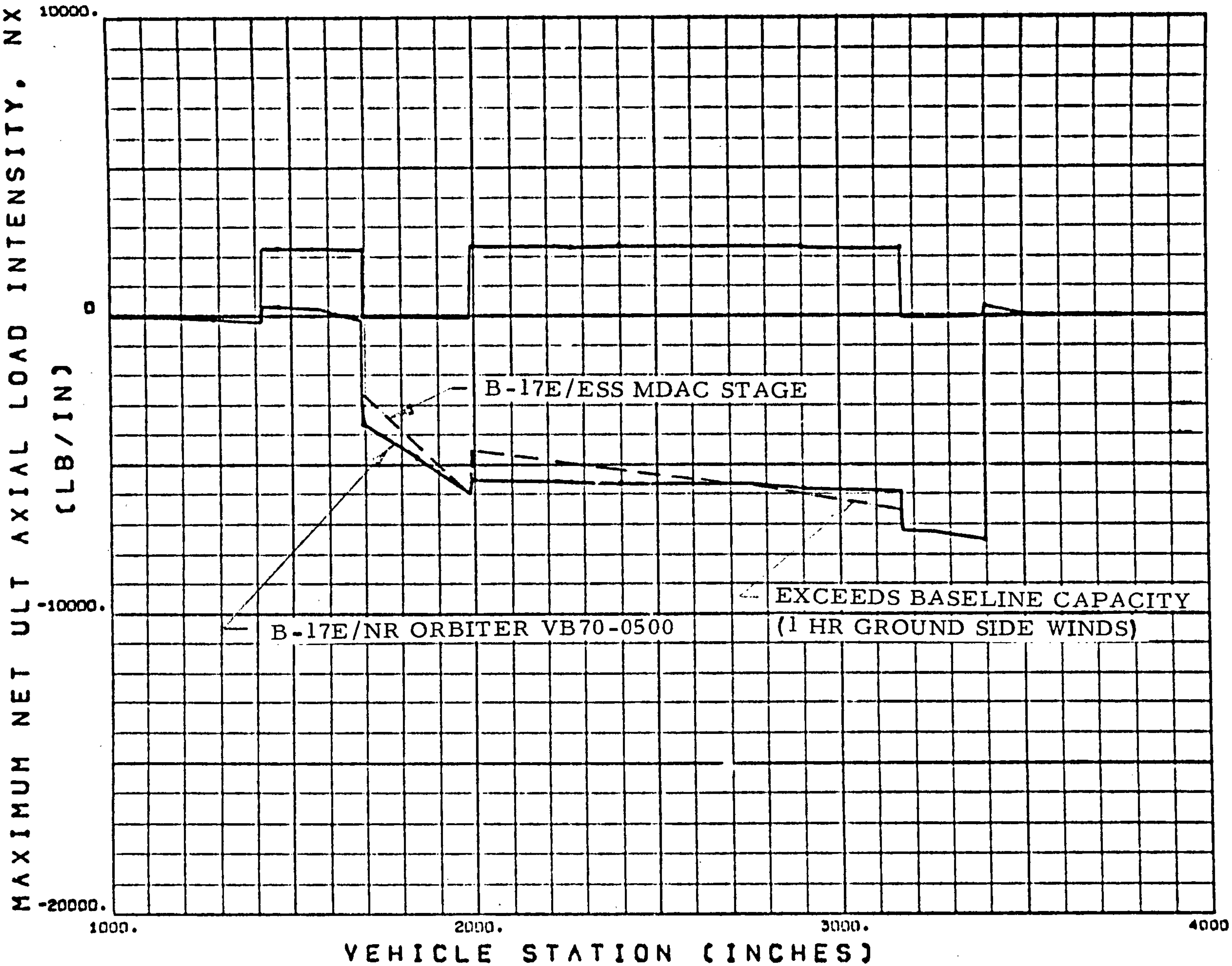
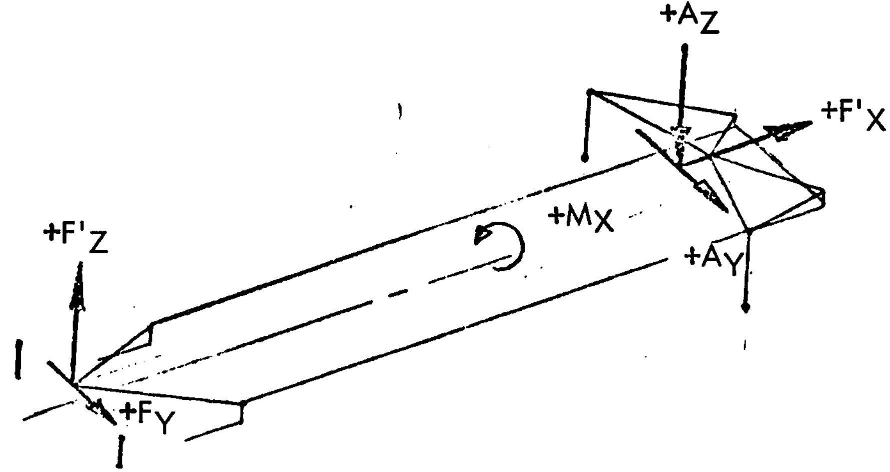


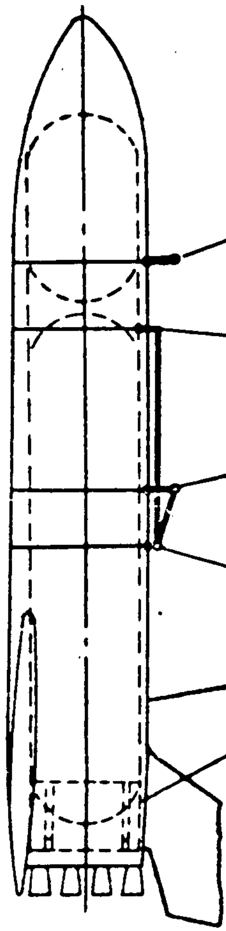
Figure A-7. GDC/B-17E Internal Loads at Side



B-17E/ESS MDAC STAGE LIMIT LOADS)

CONDITION	WIND	F'X (X 10^3 LB)	FY (X 10^3 LB)	F'Z (X 10^3 LB)	AY (X 10^3 LB)	A'Z (X 10^3 LB)	MX (10^6 IN./LB)
TWO WEEK GROUND WINDS UNFUELED	HEAD TAIL SIDE						
1 HOUR GROUND WINDS FUELED UNPRESSURIZED	HEAD TAIL SIDE	1219	± 84.9	192	± 21.5	285	±14.4
DYNAMIC LIFT OFF + 1 HOUR GROUND WINDS	HEAD TAIL SIDE						
MAX -Q	HEAD TAIL						
MAX -Q	SIDE	2354	±186.0	258	±175.0	541	±11.06
2 g MAX THRUST	-	2664		324		697	
BOOSTER BURNOUT	-						

Figure A-8. B-17E/ESS Fixed-Platform Separation System Attachment Loads



AFFECTED COMPONENT	CRITICAL CONDITION	ADDED WEIGHT (LBS)	
		GROUND CONDITIONS	FLIGHT CONDITIONS
STA 1463 BULK'D	MAX. βq	0	94
STA 1693 BULK'D	—	0	0
STA 2263 BULK'D	—	0	0
STA 2398 BULK'D ADJACENT SKIN	2.0 MAX g	0 0	2821
LH_2 TANK THRUST STRUCT.	—	0	0
	TOTALS	0	2915
		2915	

Figure A-9. ESS/Space Station Effect on Structure Weight of B-17E Booster

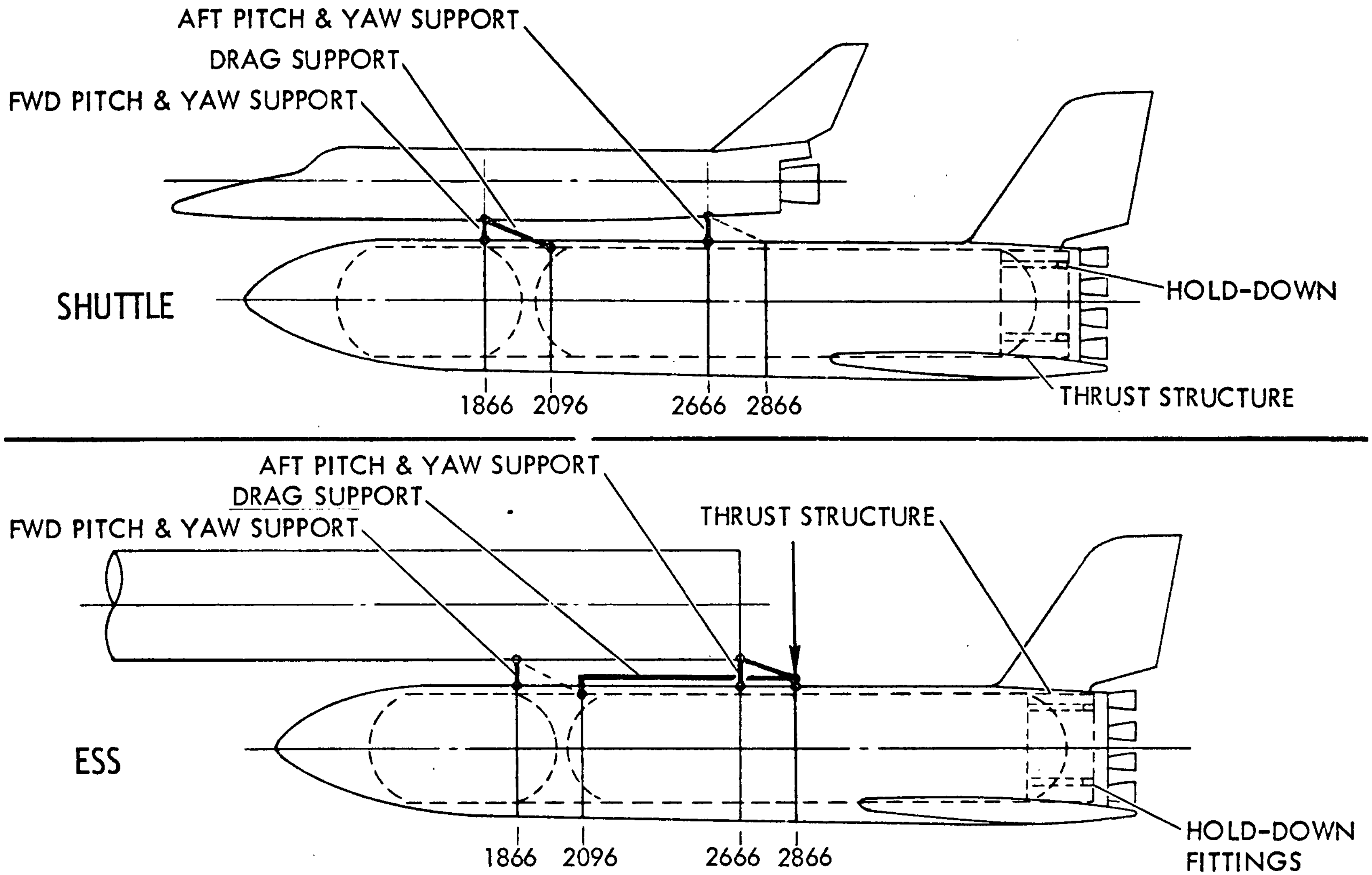


Figure A-10. Mating/Separation System Structure Schematic

1.4 AERODYNAMIC HEATING

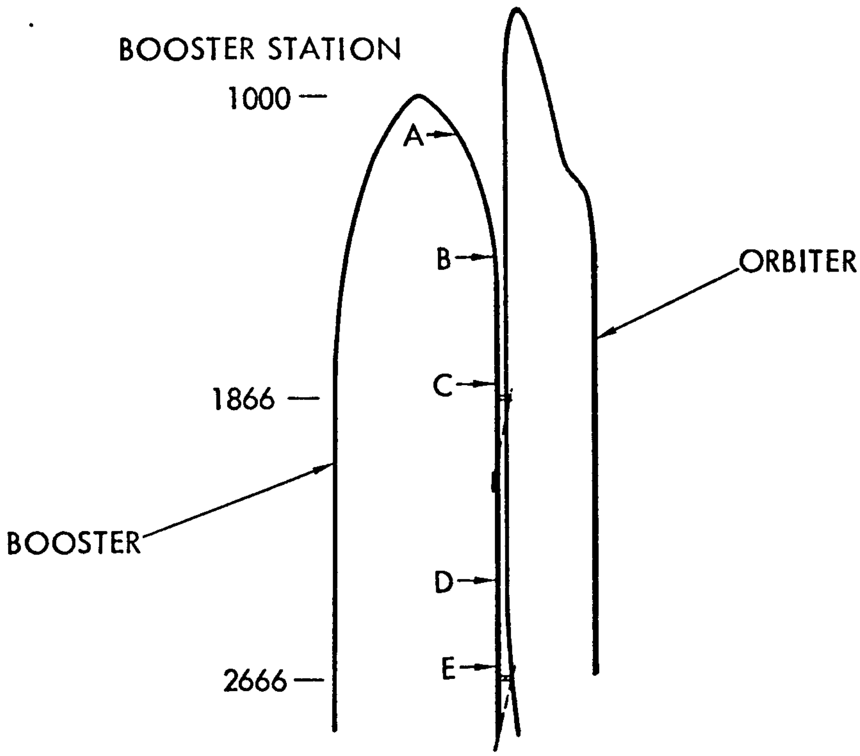
The B-9U booster entered from a staging velocity of 10,800 fps, and the aluminum alloy liquid hydrogen and liquid oxygen propellant tank structure were protected by a heat shield. The B-17E booster enters from a staging velocity of 7,720 fps with the aluminum alloy liquid hydrogen and liquid oxygen tank structure exposed to the entry environment and sized to provide an adequate heat sink. Material thicknesses for the B-17E body have been selected to prevent temperatures from exceeding 300 F.

The effects of the ESS missions on B-9U booster temperatures during ascent, including shock impingement effects, and during entry are shown in Figures A-11 and A-12 and compared to peak booster temperatures encountered during a shuttle mission. The results clearly show that eh "low q" trajectories selected for the ESS missions significantly reduce the temperatures when compared to the shuttle booster temperatures encountered along its maximum performance or "high q" trajectory. There is a corresponding reducting in heat transfer rates.

A time history of dynamic pressure for the B-9U and B-17E boosters during ascent on an ESS/space station mission is shown in Figure A-13 and compared to a shuttle mission. Since there is a similar reduction in ascent dynamic pressure for the B-17E booster when used for the ESS mission, there would be comparable reduction in booster temperatures and heating rates encountered during ascent.

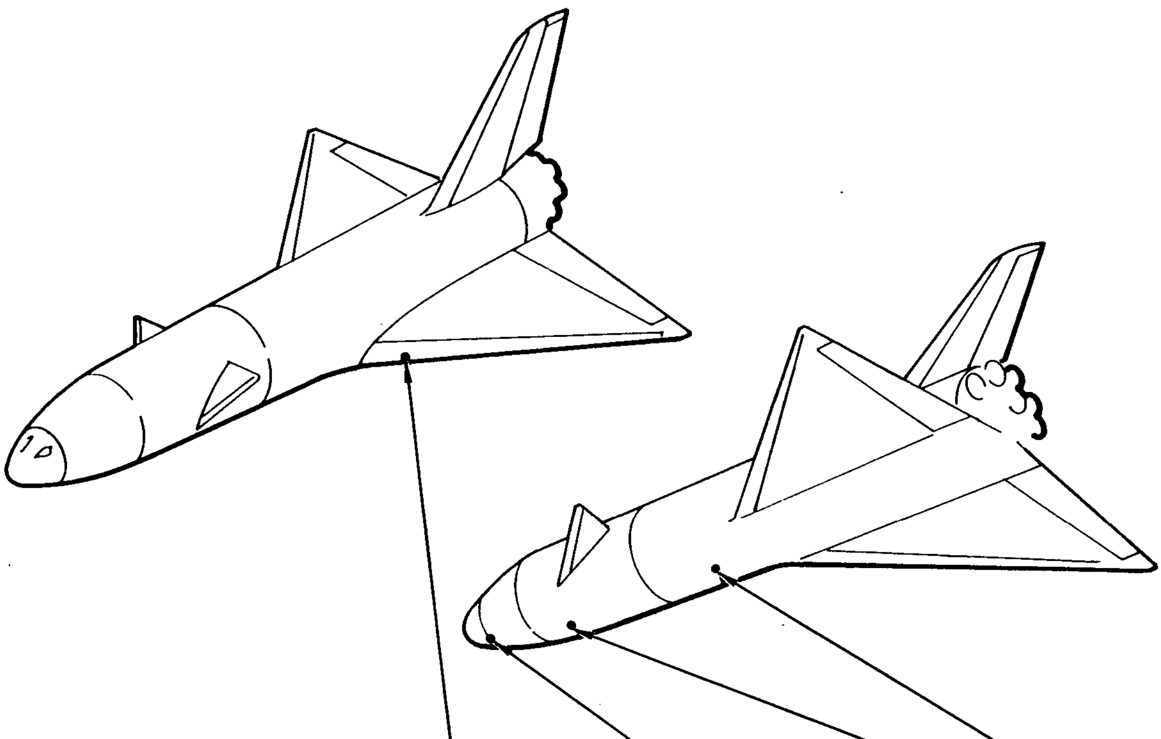
Figure A-14 shows the B-9U thermostructural limits as a function of booster apogee velocity and altitude. The B-9U apogee velocity and altitude are shown in this figure for the shuttle mission and ESS-space station mission. Since the slope of the limit line is generally consistent for variations in temperature limits the line was translated, as shown in Figure A-14, through the B-17E apogee conditions. Two ESS-space station mission apogee points are also identified, representing two trajectory runs that resulted in payloads of 183,000 pounds and 187,000 pounds (alternate trajectory). These data indicate that the space station mission can be accomplished without exceeding the B-17E heating limitations. If the B-17E displays the same characteristic heating trends as the B-9U booster for the other ESS missions, the RNS payload would result in less severe and the space tug would result in slightly more severe heating environments.

It is reasonable to conclude, in the absence of detailed aerodynamic heating analyses that the use of the B-17E heat sink booster for the ESS missions should present no severe structural heating problems. In addition, since the ESS missions do not force the use of maximum performance trajectories, it would be possible to use trajectory shaping if required to alleviate any marginal conditions.



SECOND STAGE	TRAJECTORY	PEAK TEMPERATURE DURING ASCENT (DEG F)				
		POINT A	POINT B	POINT C	POINT D	POINT E
ORBITER	B-9U-1	1770	1780	2250	130	410
NUCLEAR STAGE	ESS/RNS	650	720	1280	100	190
SPACE STATION	ESS/SPACE STATION	930	740	1180	100	190
SPACE TUG	ESS/SPACE TUG	1270	1430	1510	110	270

Figure A-11. Peak Temperatures on Booster Top Surface During Ascent



SPACE TUG	2150	1630	1555	1540
NUCLEAR STAGE	1855	1340	1285	1245
SPACE STATION	2070	1530	1480	1440
ORBITER	2380	1790	1730	1700
SECOND STAGE	PEAK TEMPERATURE DURING ENTRY (DEG F)			

Figure A-12. Maximum Booster Entry Temperatures

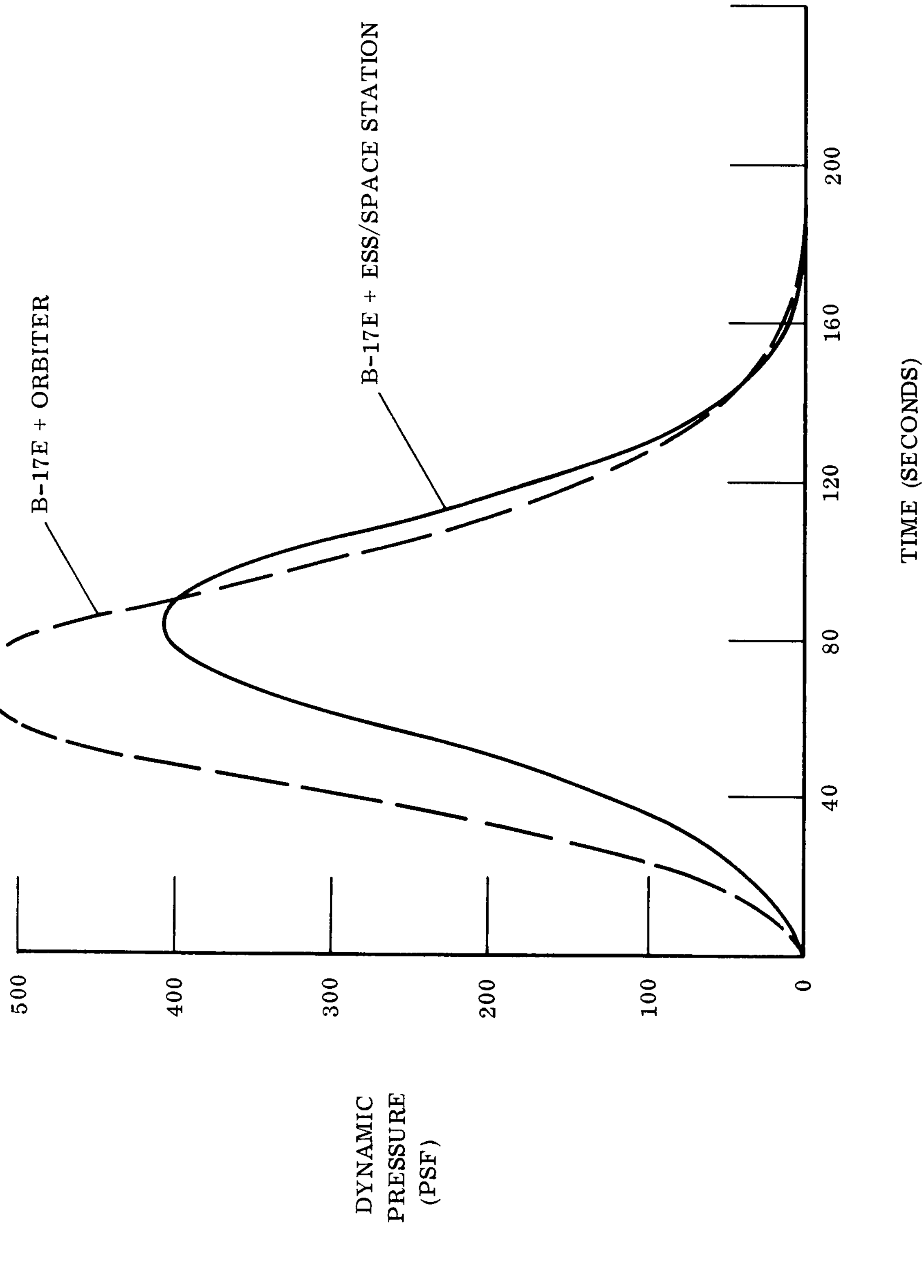


Figure A-13. Comparison of Ascent Dynamic Pressures

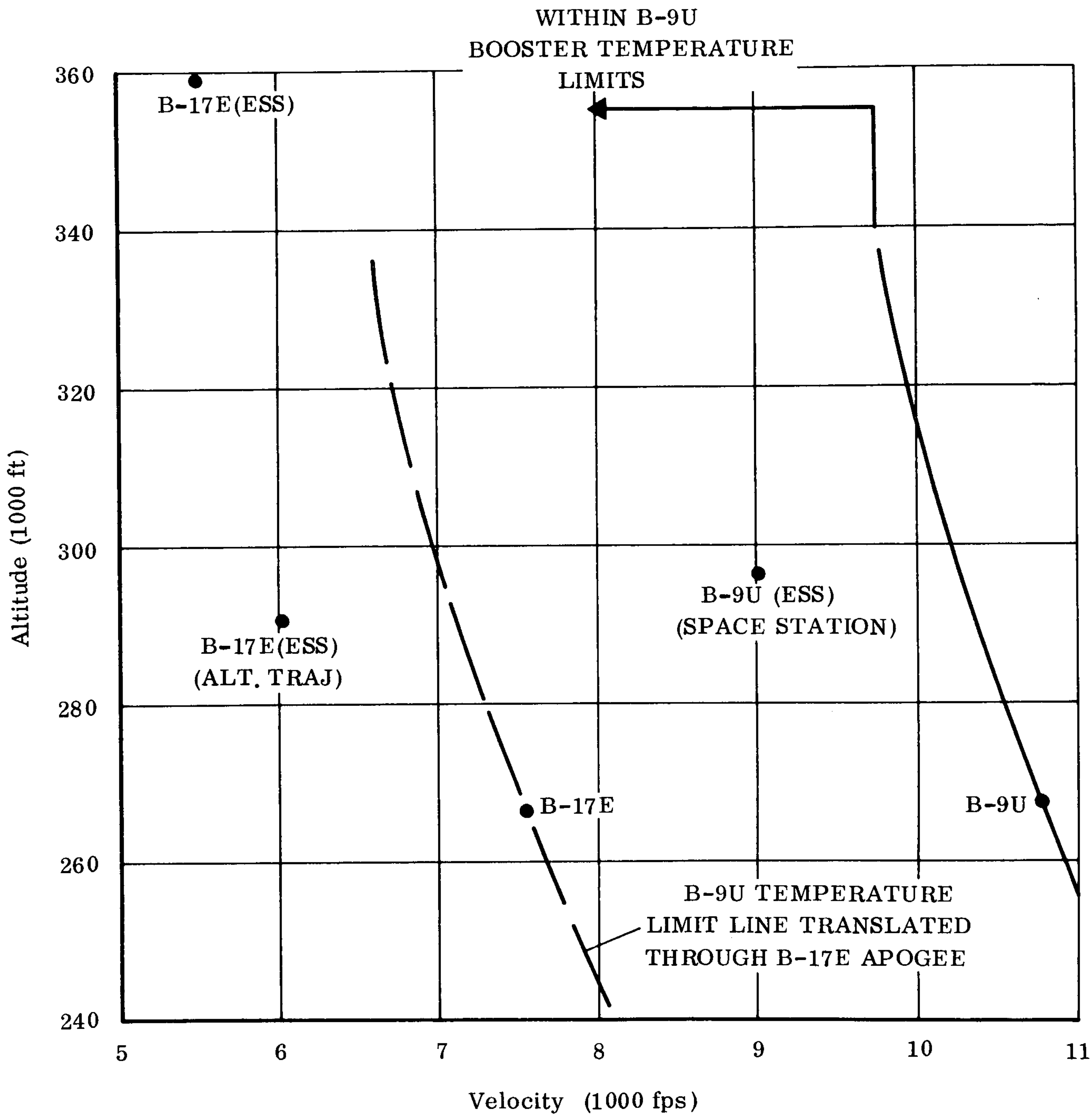


Figure A-14. Shuttle Booster Thermostructural Apogee Limits

1.5 ASCENT CONTROLS

The main rocket engines on the B-9U booster were canted at an angle of three degrees relative to a booster water-line plane. This cant angle was also shown to be satisfactory when the booster was used for ESS missions. On the B-17E booster the engine centerlines are parallel to a water line plane, that is, at zero cant angle. Figure A-15 shows the gimbal angles required on the B-17E to track the vehicle center of gravity. If the zero cant angle were retained, a gimbal angle of 11.80 degrees in a negative direction would be required to track the center of gravity for the composite vehicle at booster burnout. This exceeds the engine capability of ±10 degrees. To remain within the engine capability the engines should be installed in a canted position of approximately 4 degrees as shown in Figure A-1. This would require the installation of tapered plates at the engine attachment surface to prepare the booster for an ESS mission. This also affects the propellant feed lines. Detailed studies would have to be conducted to determine whether or not the propellant feed lines could be designed to permit attachment to the engine when installed at either with zero or four degrees of cant.

The application of load relief as described in Volume II, Section II, is for the B-17U booster is also applicable to the B-17E. The gimbal angle limits defined for the B-9U in the region of maximum dynamic regions would differ for the B-17E. Determination of the actual required gimbal limits would require detailed analyses using the six-degree-of-freedom digital simulation program.

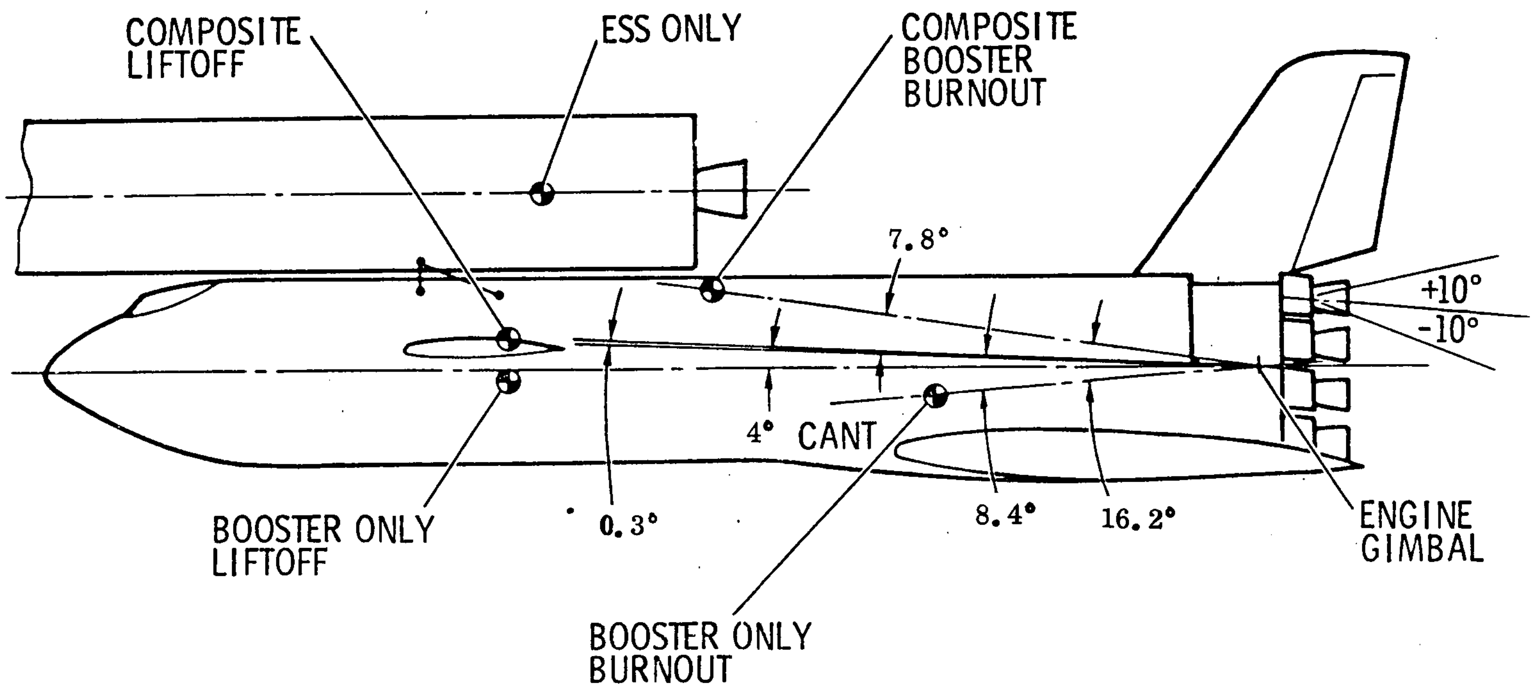


Figure A-15. B-17E Booster/ESS Space Station Gimbal Requirements Due to CG Travel, Nominal

APPENDIX B

ESS/BOOSTER SEPARATION TRADE STUDY

1.0 OBJECTIVE

Adaptation of the expendable second stage (ESS) to the space shuttle booster represented a possible major design problem. Consequently, considerable effort has been expended in the synthesis and selection of a suitable adaptation scheme. During the study, a paramount requirement emerged. The adaptation concept utilized must, in addition to satisfying other basic requirements, facilitate wedding of the two vehicles while minimizing adverse impacts on each due to induced intervehicular loads. Because the booster thrusted linkage concept has been recommended for the baseline shuttle/orbiter separation system, that concept was incorporated in the ESS/booster adaptation scheme.

The objective of this study was, therefore, to devise and select a basic adaptation scheme that utilized the baseline separation mechanism concept and that minimized the structural impacts on each vehicle.

For study purposes, the designated baseline booster was the B-9U as described in a final report, dated 26 March 1971. Also, the booster payload considered was an ESS mated to a nuclear stage (RNS).

2.0 ALTERNATIVES

The combined vehicle system is depicted on Figure B-1. Corresponding mass properties may be found elsewhere in this report.

Three adaptation concepts, each utilizing the booster, thrusted linkage separation mechanism were study candidates. Each concept devised used an adapter to transfer longitudinal loads from the forward structural hard points (baseline separation system linkage attach points) to the aft skirt structure of the ESS. Figure B-2 illustrates the need for a load transfer element and Figure B-3 depicts the three concepts schematically. The concepts, tension link, movable platform, and fixed platform, are further defined in Figures B-4, B-5, and B-6 (Drawings 76Z1226, 76Z1225, and 76Z0253). The longitudinal load transfer elements are the tension links and platforms. Operational sequences for each concept are shown on Table B-1 to facilitate comparison of the concepts. Functionally, the vertical links, lateral

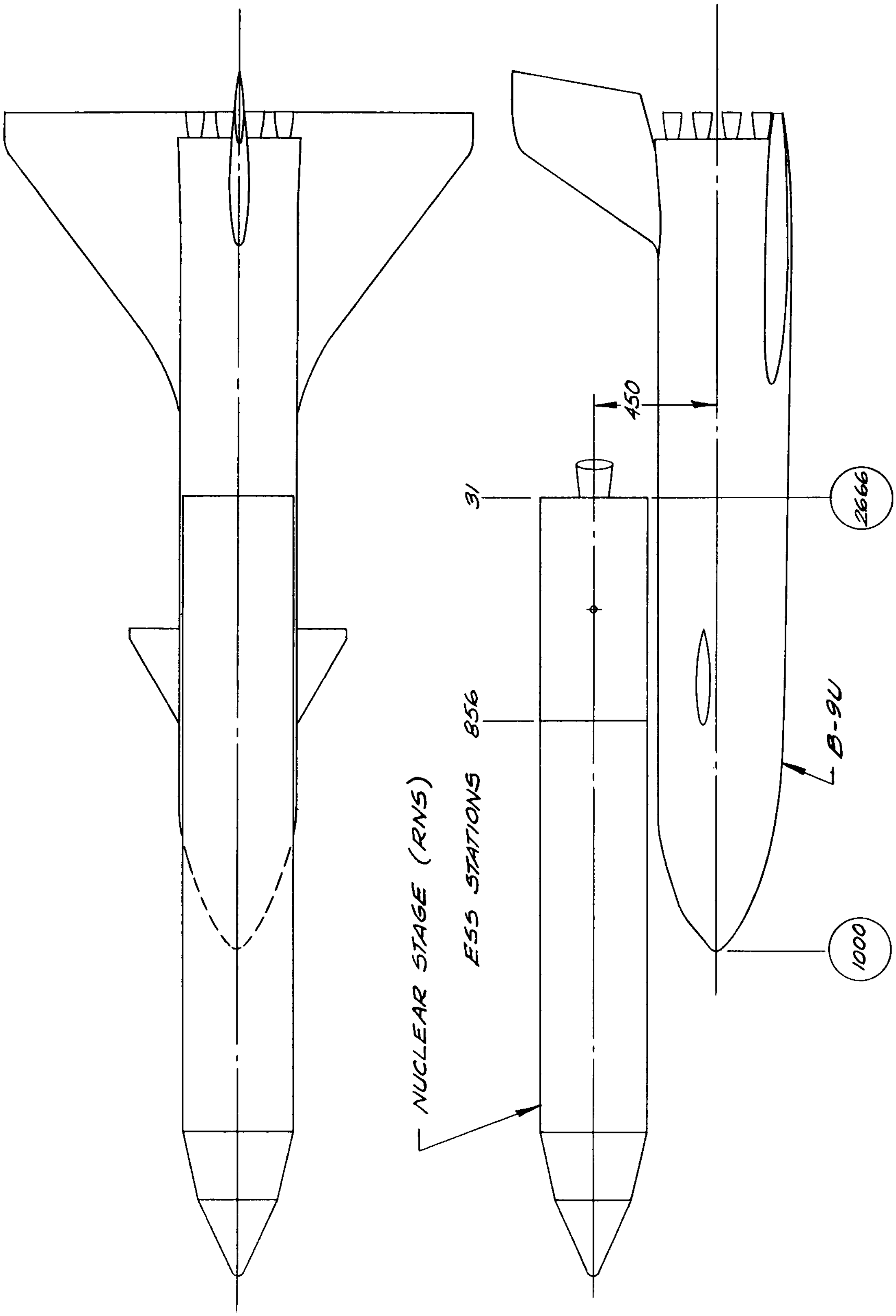


Figure B-1. ESS/RNS and Booster Combined Vehicle System

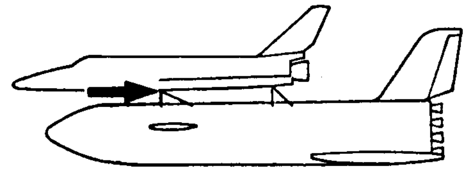
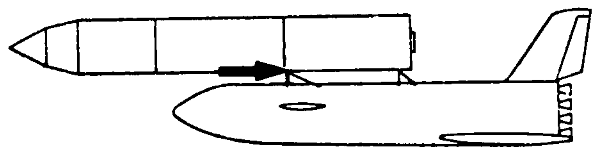
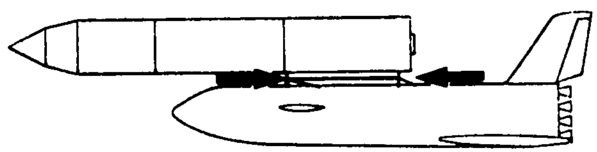
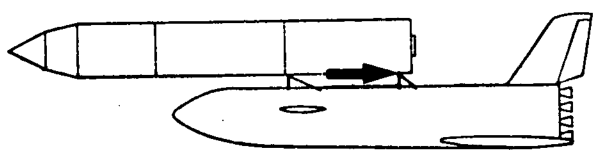
	CONFIGURATION	COMMENTS
SHUTTLE		AXIAL LOAD APPLIED AND REACTED AT FORWARD BOOST AND ORBITER ATTACHMENT FITTINGS
ESS OPTIONS		SHUTTLE APPROACH – REQUIRES REDESIGN OF ESS FORWARD SKIRT AND LH_2 TANK STRUCTURE
		ADAPTER TO TRANSFER AXIAL LOAD FROM FORWARD BOOSTER FITTINGS TO AFT SECTION OF ESS
		REACT AXIAL LOAD AT AFT BOOSTER/ESS ATTACHMENT. REQUIRES EXTENSIVE MODIFICATIONS TO BOOSTER HYDROGEN TANK STRUCTURE

Figure B-2. Separation System, Shuttle Versus ESS, Axial Load Application/Reaction

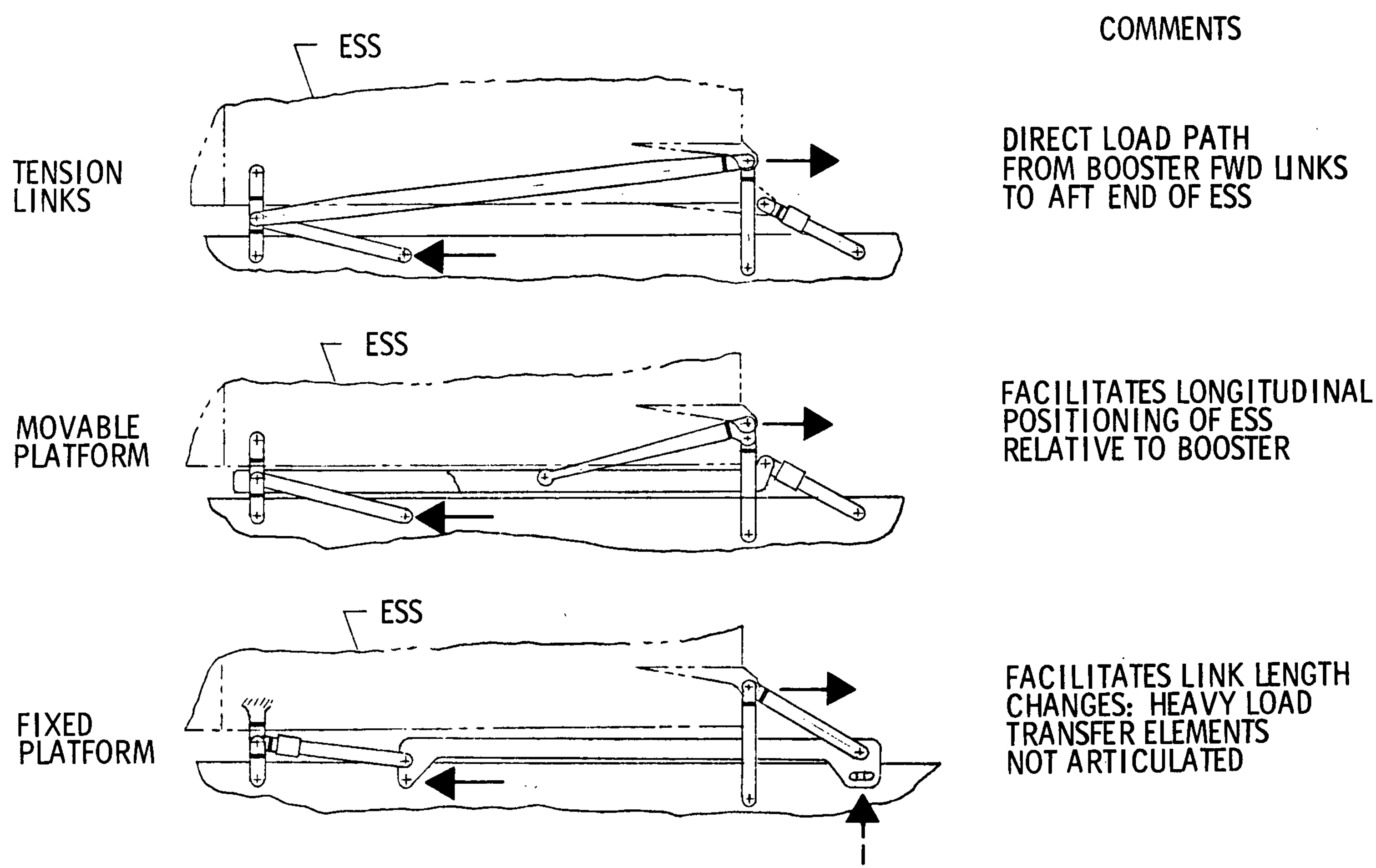


Figure B-3. Booster/ESS Separation System Trade Study, Load Transfer Concepts

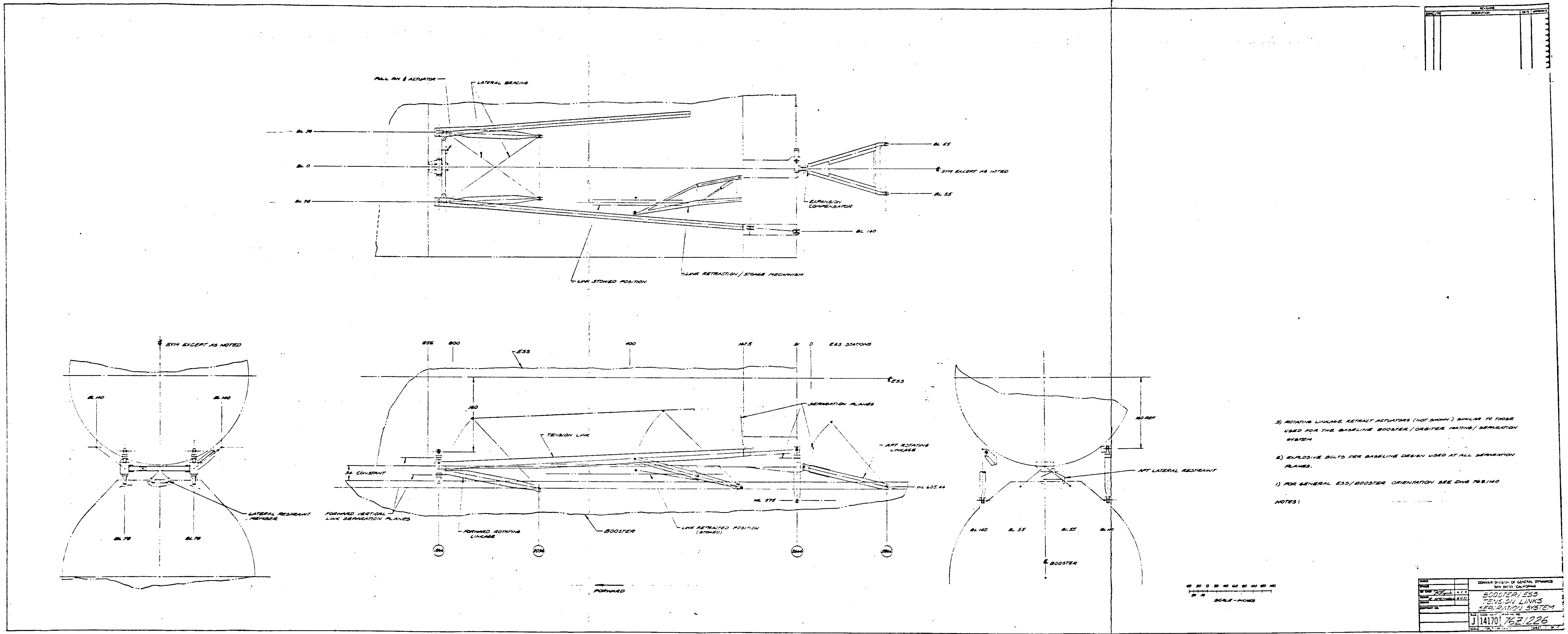


Figure B-4. Booster/ESS Tension Links Separation System

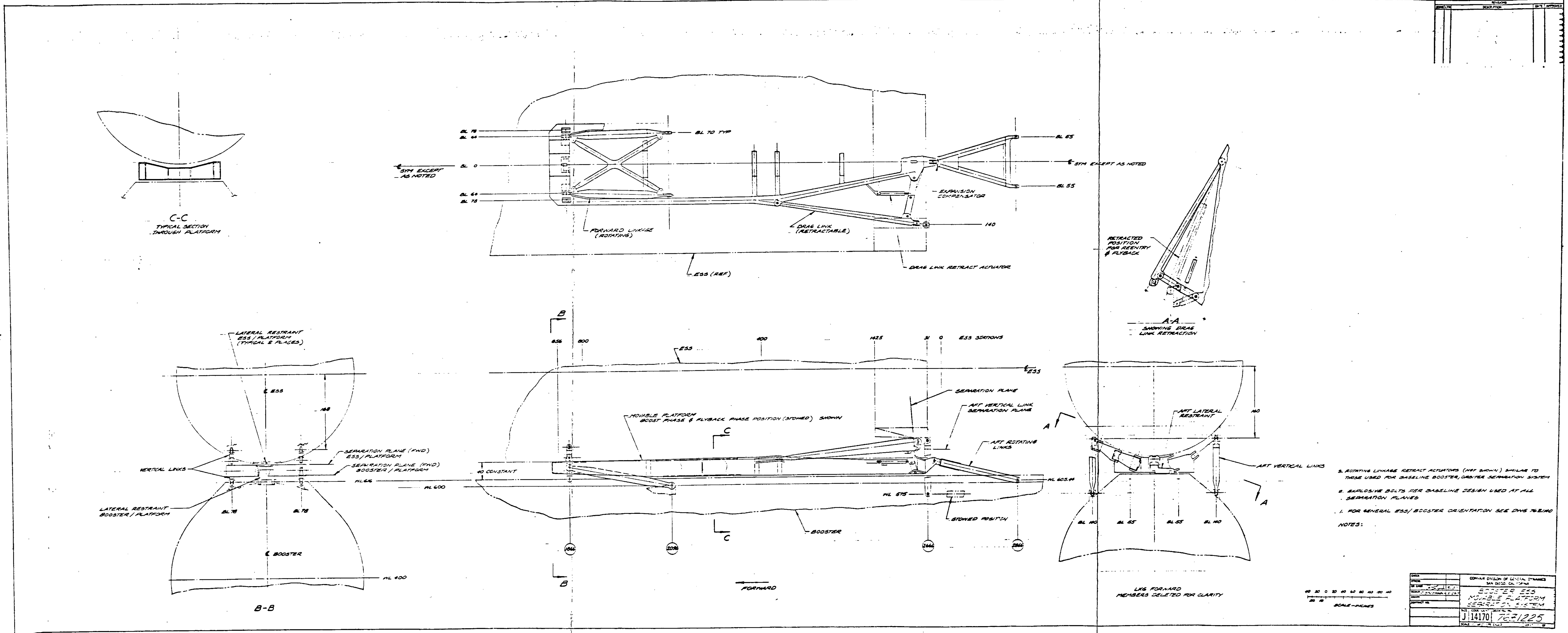


Figure B-5. Booster/ESS Movable Platform Separation System

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

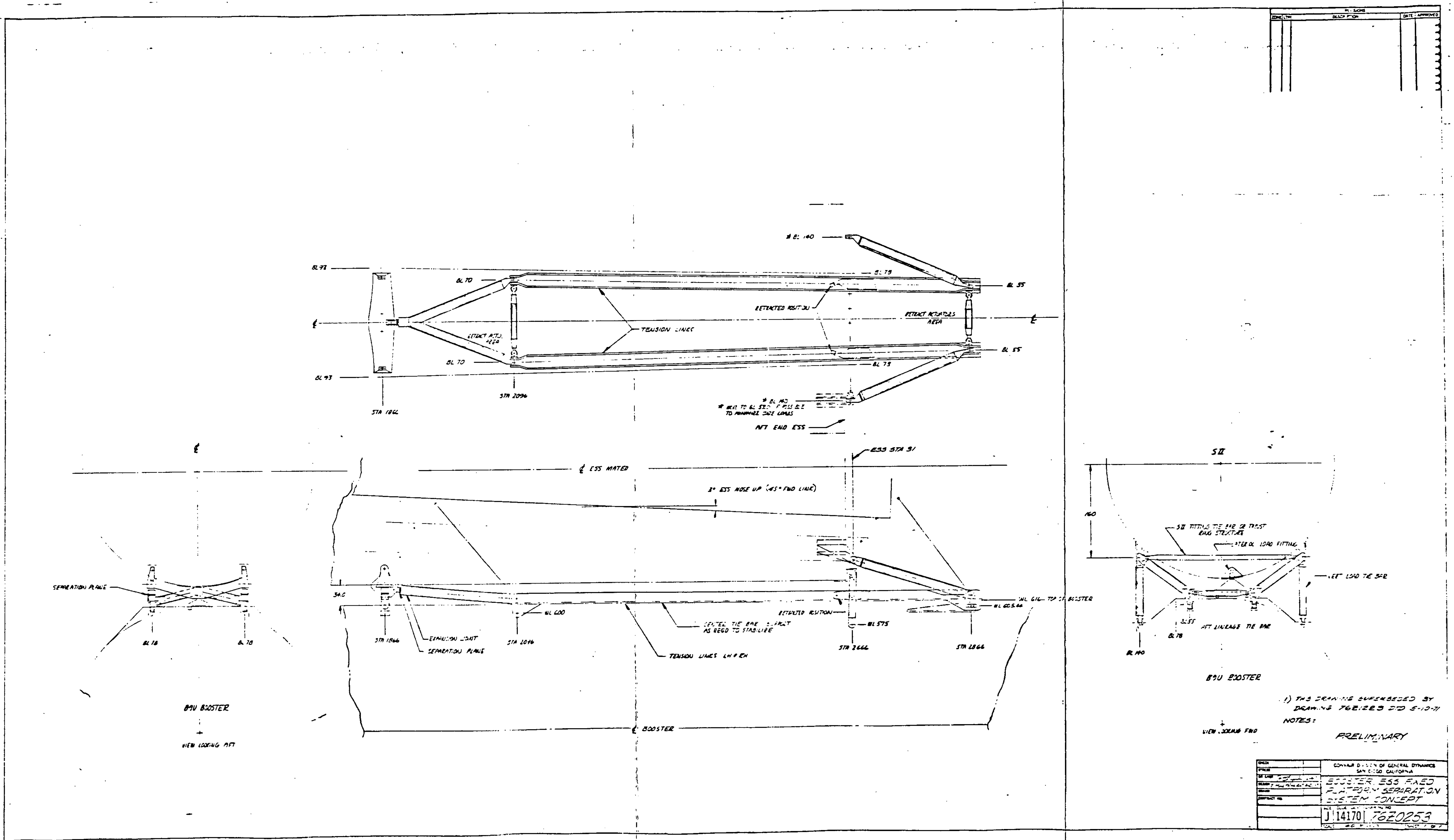


Figure B-6. Booster/ESS Fixed-Platform Separation System Concept

FOLDOUT FRAME 1

B-9, B-10

FOLDOUT FRAME 2

Table B-1. Separation System Concepts Operational Sequence

STEP	TENSION LINK	MOVABLE PLATFORM	FIXED PLATFORM
1	Separation initiated when vertical links restraining ESS/rotating links to booster break at separation planes.	Separation initiated when vertical links restraining ESS/platform/rotating links to booster break at separation planes.	Separation initiated when vertical links restraining ESS/rotating lines to booster break at separation planes.
2	Tension links/ESS/rotating links articulate.	Platform/ESS/rotating links articulate.	ESS/rotating links articulate.
3	ESS separates when upper vertical links, tension links and aft swing link break at separation planes.	ESS separates from platform when upper vertical links restraining ESS to platform break at separation planes.	ESS separates from rotating links when fore and aft swing links break at separation planes.
4	Rotating links and tension links retracted to faired positions by actuators/mechanisms provided.	Platform/rotating links retracted to faired position by actuators provided.	Rotating links retracted to faired position.

restraint members, rotating links, and expansion compensators perform as they do in the baseline booster/orbiter mating/separation system. For each of the concepts, retraction of the separation system elements was deemed necessary in order to afford protection of those components during reentry and minimize drag during booster flyback.

3.0 EVALUATION

Concept evaluations and comparisons were made relative to significant impacts on the booster and ESS. These are summarized on Tables B-2 through B-5.

4.0 CONCLUSION

Figure B-6 indicates that the Fixed Platform concept was selected as the best system from most points of view. Further definition of this system, including a study of the separation system dynamics may be found in other volumes of this report.

Table B-2. Booster/ESS Separation System Concepts Comparison - Advantages/Disadvantages

CONCEPT	TENSION LINKS	MOVABLE PLATFORM	FIXED PLATFORM
Advantages	• Direct load path for transfer of longitudinal load.	• Facilitates longitudinal positioning of ESS relative to booster. • Permits rotating link length changes for proper separation of different payloads.	• Fixed longitudinal load transfer members. • Permits rotating link length changes for proper separation of different payloads. • Ease of installation.
Disadvantages	• Stabilization and retraction of movable tension. links. • Lateral stiffness of load transfer elements.	• Vertical stiffness. • Large moving mass difficult to control.	• Vertical restraint of platform required.

Table B-3. Concept Evaluation (Quantitative)

EFFECT ON: / CONCEPT	TENSION LINKS	MOVABLE PLATFORM	FIXED PLATFORM
WEIGHTS			
ESS (FIXED)	+ 1400 LB	+ 1500 LB	+ 1500 LB
BOOSTER STRUCTURE (FIXED)	+ 125 LB	+ 125 LB	+ 685 LB
MECHANICAL ELEMENTS (REMOVABLE)	+ 12350 LB	+ 20650 LB	+ 11000 LB
FLYBACK RANGE	- 54 NM	- 59 NM	- 22 NM

Table B-4. Concept Evaluation (Effects on Reliability)

FACTORS AFFECTING RELIABILITY	BASELINE	TENSION LINKS	MOVABLE PLATFORM	FIXED PLATFORM	
NO. OF SEPARATION PLANES A) PRIMARY B) SECONDARY	 4 3	 4 5	 4 4	 4 3	NUMBERS OF PARTS
NO. OF BACKUP SEPARATION DEVICES (I.E. SHAPED CHARGE, ETC.)	7	9	8	7	
LOAD BEARING MEMBERS A) VERTICAL B) ARTICULATING	 4 2	 4 4	 4 3	 4 2	
RETRACTION MECHANISMS A) ACTUATORS B) FOLDING MEMBERS	 2 0	 4 2	 2 2	 2 1	
EXPANSION JOINTS (CREEP CYLINDERS)	1	1	1	1	
SEPARATION COMMAND & POWER SOURCES [TWO (REDUNDANT) = 0 PTS ONE = 5 PTS]	0	5	5	5	RATING NUMBERS
LONGITUDINAL LOAD TRANSFER [FIXED = 0 PTS MOVING = 3 PTS]	0	3	3	0	
TOTALS	23	41	36	29	

CONCLUSION: FIXED PLATFORM IS PREFERRED FOR ESS

Table B-5. System Test Costs (Relative)

ITEM / CONCEPT	TENSION LINK	MOVABLE PLATFORM	FIXED PLATFORM
RETRACT/SNUBBER ACTUATORS & MECHANISM	3	2	1
SEPARATION SYST. PYROTECHNIC DEVICES AND CONTROLS	3	2	1
LONGITUDINAL LOAD TRANSFER ELEMENT	1	3	2
TOTAL	7	7	4

CONCLUSION: LEAST COST

Table B-6. Comparison and Selection (Summary)

FACTOR \ CONCEPT	TENSION LINK	MOVABLE PLATFORM	FIXED PLATFORM
WEIGHT			✓
RELIABILITY/SAFETY			✓
SYSTEM TEST COST			✓
EFFECT ON GRD SUPT	✓	✓	✓
MIN. CRUISE DRAG			✓

✓ INDICATES BEST SYSTEM

APPENDIX C

GROUND AND FLIGHT SYSTEMS OPTIMIZATION (GAFSO) STUDY

1.0 STUDY RATIONALE

The expendable second stage (ESS) study control document identifies the following guidelines which are similar to the space shuttle system guidelines.

1. Design for maximum onboard control using onboard and ground capabilities to maximize flexibility and minimize mission operations consistent with low cost.

2. Guidance and navigation functions shall be performed onboard using ground and other navigation aids when appropriate.

3. Minimal checkout requirements at launch pad.

These guidelines, coupled with the planned ESS launches into similar orbits in the space shuttle operational time frame from the shuttle operational site (KSC), make feasible and cost-effective the maximum similarity between ESS and Shuttle in the following areas:

1. Vehicle subsystem hardware and software.

2. Support equipment and software for launch preparation, prelaunch, and launch operations.

3. Mission support satellite and ground equipment, including ground software.

Therefore, the approach decided upon for the ESS GAFSO study was to review the differences between the ESS and the space shuttle orbiter and establish the ESS differences in the optimum total system identified for the orbiter in the space shuttle GAFSO study. The following three sections are presented as a brief summary of the space shuttle GAFSO study.

1.1 ORBITER GAFSO STUDY CONCLUSIONS

The results of the GAFSO study show that a high degree of onboard autonomy permits significant savings to be realized both in the mission support activity and in the ground equipment and operations required for turnaround. This results from significant reductions in ground hardware, software, and personnel.

In the support equipment analysis, the results show that a new checkout system design using off-the-shelf black boxes is preferable to utilizing existing hardware. The existing system contains more dollars of hardware, which results in very high refurbishment costs. Also, the manpower required to operate the existing system is higher because of a dedicated computer room and a large amount of dedicated controls and displays in the control room consoles. In contrast, the new system design will have small current state-of-the-art computers in the ground control and display consoles eliminating the need for separate computer room manpower; also the displays will be multifunctional.

In the servicing equipment area, the equipment required is oriented to vehicle subsystems and/or functions performed. This allows replacement of portions of the servicing equipment and retaining other portions as dictated by minimum costs, time available for turnaround, propellant loading time, and launch windows. Cost tradeoffs indicate that in most cases, the modification and refurbishment costs for existing equipment are very comparable to the new system design and fabrication costs. In the areas where the existing servicing equipment does meet all the vehicle system requirements, and the refurbishment is not extensive, this equipment will be used for the shuttle.

1.2 ORBITER GAFSO STUDY RESULTS

The results of the shuttle GAFSO tradeoff evaluation identified the preferred system for the space shuttle orbiter. This system includes an onboard navigation system which uses vehicle-borne interrogators and ground/space station transponders for approach and landing and rendezvous-bearing and the Tracking and Data Relay Satellite (TDRS) for on-orbit position determination. Maximum data processing and onboard checkout (OBCO) will be accomplished by an onboard data and controls management system with minimum communications required with the ground. The existing 13-station MSFN and MCC will be used during the shuttle preoperational phase, and orbital flight test missions will be performed by flying missions at inclinations which give maximum coverage. TDRS will be used for the operational phase and will provide adequate coverage for all missions with the MILA MSFN station used for tracking and communication during launch through staging. The ground system would make maximum use of existing servicing

GSE; however, a new checkout GSE system using off-the-shelf and existing black boxes would be used at the launch pad, safing area, maintenance and repair area, ferry/horizontal flight test areas, and the final assembly manufacturing areas.

1.3 ORBITER SELECTED SYSTEM DEFINITION

The general specification for the preferred system determined by the tradeoff evaluation is as follows:

1. Mission Support System. Use 13-station MSFN and existing MCC during the Shuttle development phase. Use TDRS and reduced MCC for shuttle operational phase.

2. Communications. Use two-way voice duplex between the shuttle vehicles and the ground and the space station. Provide an up-data rate capability of 200 bps (information bits, not transmission rate) and a down-data rate of 51.2 kbs via MSFN during the development flights which will be reduced to 2 kbs via TDRS when fully operational.

3. Guidance, Navigation and Control. Provide full onboard navigation capability using TDRS and an automatic star tracker. All shuttle vehicle guidance and navigation calculations and all control functions will be performed onboard. The precision ranging system (PRS) will be used for space station rendezvous, as well as approach and landing.

4. Data and Control Management. A full data and control management (DCM) capability will be provided onboard. This system would include computer, multiplexers, stimuli generators, data buses, and the necessary software required for controls, data acquisition, and checkout. The DCM computer will also handle the GN&C computations.

5. Real-Time Mission Planning and Operations. As much as possible of the real-time mission planning and operations would be accomplished onboard. These tasks would include the following:

    a. Rendezvous plan changes

    b. Reentry plan changes

    c. Center-of-gravity and weight determination

    d. Operating system inventory versus minimum standards

e. Consumables monitoring

f. Command and control

g. Early mission termination

h. Rescue plans

i. Alternate mission capability

The Mission Control Center will perform the portion of the real-time mission planning that cannot be performed onboard. Detail analysis shows that the possible variations between onboard/ ground for these functions are not system definition "drivers."

6. Vehicle/Ground Interface. A minimum number of connections will be made between the shuttle vehicle and the ground support equipment. The primary electronic connection will be between the airborne data bus and the ground system used for monitor and control of the vehicle servicing.

7. Checkout GSE. New checkout GSE will be provided to augment the onboard checkout capability when the vehicle is unmanned, and to control and monitor the ground servicing systems. This equipment will provide for the remote control of gases/fluids systems during safing and propellant loading and purging operations, as well as control and monitor of all servicing equipment. A high degree of hardware/software commonality is required in the following areas for cost effective operation:

   a. Launch pad

   b. Safing area

   c. Maintenance and repair area

   d. Horizontal flight test ferry site

   e. Manufacturing areas

8. Servicing GSE. Maximum use sill be made of the existing servicing GSE. Gases/fluids control systems will be modified where feasible for automatic control via the new checkout-type GSE. Where existing servicing equipment will not meet the operational timelines, or modifications and/or refurbishment is not cost-effective, replacement by new designs will be required.

2.0 ESS/ORBITER REQUIREMENT COMPARISONS

Some of the more significant differences between the ESS and the orbiter which affect the GAFSO definition are as follows:

System	ESS	Orbiter
Crew systems	no	yes
Controls and displays	no	yes
Prime electrical power	batteries	fuel cells and APU
DCM systems	Less equipment and more computers and ACT's	
Engines, main system	2	2
OMS	2	3
ACPS	14	29
Air-breathing engines	no	yes
Environmental control system	simpler	more complicated
Communications:		
Up-data	yes	yes
Down-data	yes	yes
Voice	no	yes
Recovery beacon	no	yes
Flight log recorder	no	yes
Landing aids	no	yes
Reuse capability	components	total vehicle

This information indicates that the ESS, due to the absence of some systems and the simplification of others, will require fewer measurements and controls than the orbiter for inflight status evaluation and prelaunch checkout. In addition, the average shuttle orbiter mission is considerably longer than the ESS 24-hour mission. These facts indicate that the total amount of inflight "exception" data (resulting from failure and out-of-limits conditions) should be significantly less on the ESS.

Another factor which will help reduce the amount of data necessary for ESS subsystem evaluation will be the significant amount of ground and flight test data available from the shuttle program. These tests will have been completed and some operational flights will have been flown prior to the first ESS mission. The data available from all the shuttle activity will enable the ESS subsystem measurements to be reduced to the fewest number which provide the maximum information. The limits established for these measurements will have been refined to ensure the minimum out-of-limit flags. Both of these, less measurements and more refined limits, will reduce the amount of exception data during the ESS mission.

Since the orbiter will return to the operational site, the only data transmitted to the ground during the mission will be status information, primarily to identify the vehicle redundancy configuration. One of the design concepts for the ESS is that the avionics equipment will be recovered by the shuttle orbiter. The recorded information can then be recovered on the ground. However, it would be desirable to transmit this data to the ground during the mission, in the event the avionics is not recoverable or if some decision-making is necessary on the ground with regard to the mission performance (of the type performed by the orbiter crew). The 2-kbs data link to the TDRS should be adequate for transmittal of all the necessary ESS exception data to the ground. The switchable 51.2 kbs mode will be available for launch through staging and as a backup for data-dump purposes, when the on-orbit ESS has contact with one of the four MSFN stations (MILA, GOLDSTONE, MADRID, HONEYSUCKLE) which are planned to be in operation during the ESS time frame.

As stated previously, the orbiter navigation will be accomplished onboard utilizing the TDRS for position determination and the automatic star tracker for attitude information. Navigation studies have indicated that for very accurate position determination, the TDRS may be a marginal system. Further study will be necessary to define precise capabilities.

Since the orbiter requires the PRS for approach and landing, this system can be used for on-orbit navigation also. The problem that exists however, is being able to get sufficient coverage from the ground transponders located at the few alternate landing sites. If these locations do not provide adequate coverage, then additional costs will be incurred to provide ground transponders at appropriate locations other than alternate landing sites. This may present problems in additon to transponder costs if it is necessary to locate transponders at places where U.S. controlled facilities are not presently available. Therefore, the TDRS is preferable to the PRS for on-orbit position determination if the TDRS accuracy is acceptable.

The ESS does not require landing aids as previously stated. Therefore, the PRS system is not available for on-orbit navigation unless it is added specifically for that purpose. The VHF/FM transceiver is required for data transmission between the ESS and ground via TDRS, and this same equipment can be used for communications with TDRS for navigation. The most cost-effective approach, therefore, will obviously be to avoid the addition of the PRS and use the communication equipment already available onboard for navigation. This assumes, of course, that the accuracy using TDRS is acceptable. The MSFN stations previously identified can also be used for ground tracking, if necessary, as a backup when the ESS is visible to the MSFN antennas.

The ground checkout monitor and control system identified for the shuttle at KSC would be applicable for premate checkout, launch readiness checkout, and launch operations (including propellant loading) of the ESS. Some software changes would be necessary for ESS. The communication checkout equipment would also be applicable since the communication equipment used for ESS will be shuttle orbiter designs.

Maximum use of the shuttle servicing equipment designs will be used for ESS. Where different equipment is required for ESS, this will be defined as part of the Phase B study.

3.0 ESS SELECTED SYSTEM DEFINITION

The general specification for the ESS system, as determined by this evaluation, is as follows:

1. Mission Support System. Use TDRS for on-orbit support and the reduced MSFN for launch through staging and for on-orbit backup. The reduced MCC capability available during the shuttle operations time frame will support the ESS with minor software changes.

2. Communications. ESS up-data rate of 200 bps (information) and down-data at 2 kbs, via TDRS, will be used for orbital operations. The telemetry system will transmit 51.2 kbs data to the MILA MSFN station during launch and staging and will also be used for on-orbit data-dumps to MSFN stations, if necessary, when contact is available by switching from the low bit-rate to high bit-rate mode. Up-data can also be sent through the MSFN link if necessary.

3. Guidance, Navigation and Control. All ESS guidance and navigation calculations and all control functions will be performed onboard. A simple ranging generator can be added to the VHF/FM system for space station rendezvous.

4. Data and Control Management. A full DCM capability will be provided onboard. This system will include computer, multiplexers, stimuli generators, data buses, and the necessary software required for controls, data acquisition, and checkout. The DCM computer will also handle the GN&C computations. Maximum use will be made of shuttle orbiter DCM flight and ground software to minimize costs.

5. Real-Time Mission Planning and Operations. As much as possible of the real-time mission planning will be done onboard, using automated DCM computer programs. The Mission Control Center will perform the portion of the real-time mission planning that cannot be performed onboard. This operation will be as much like the shuttle as possible.

6. Vehicle/Ground Interface. A minimum number of connections will be made between the ESS and the support equipment. The primary electronic connection will be between the airborne data bus and the ground system used for monitor and control of vehicle servicing.

7. Checkout Support Equipment. The ESS checkout requirements are very similar to the shuttle orbiter because of equipment commonality between vehicles. The primary difference is that orbiter checkout will utilize cockpit controls and displays in support of checkout whenever the vehicle can be manned; while the ESS is totally dependent on the support equipment controls and displays. This will necessitate the use of additional existing ground control and display consoles normally used during turnaround operations for ESS checkout. The shuttle checkout monitor and control system at KSC will be a computer-controlled multifunction control and display system. This system can be used for ESS checkout with the possible addition of multifunction control and display consoles and appropriate software changes. Reduced software costs will be achieved by ensuring maximum software commonality between the shuttle orbiter and the ESS onboard computer and ground computer checkout programs.

8. Servicing Support Equipment. Maximum use will be made of the shuttle orbiter servicing equipment provided for KSC operations in order to reduce costs. Some unique ESS requirements will necessitate special support equipment, such as dc ground power rather than ac. These requirements will be satisfied by using existing equipment with modification and/or refurbishment where possible. If use of existing equipment for these unique ESS requirements is not cost effective, then new equipment will be provided.