SPACE SHUTTLE VEHICLE

DESCRIPTION AND REQUIREMENTS

DOCUMENT

SPACE SHUTTLE

AUXILIARY PROPULSION SYSTEM DESIGN STUDY

July 1, 1971

PROPULSION AND POWER DIVISION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Foreward

This document describes the space shuttle vehicle configurations and the vehicle/mission requirements which are to be used as the basis for the space shuttle auxiliary propulsion system design study. This study is being conducted by the Manned Spacecraft Center under contract NAS9-12013. The vehicle configurations and vehicle/mission requirements basically reflect phase [illegible] final vehicle configurations and mission requirements. The inclusion of a particular vehicle configuration or requirement in this document should not therefore be interpreted as indicating a choice or preference on the part of NASA, nor should these data be considered applicable to contracts other than the one listed above.

Acknowledgement is given to the industrial contractors who furnished data in support of this document.

TABLE OF CONTENTS

SECTION		PAGE
1.	General Requirements	1
2.	Reference Mission Requirement	2
	2.1 Design Mission (Easterly Launch)	3
	2.2 South Polar Reference Mission	9
	2.3 Resupply Reference Mission	9
	2.4 Ascent Abort Requirements	19
	2.5 Vehicle Acceleration Requirements	20
3.	System and Component Design Criteria	25
	3.1 Factors of Safety	25
	3.2 Materials	26
	3.2.1 Fluids and Mechanical Criteria	28
	3.2.2 Thermal Conditioning and Control	29
	3.3 Vehicle/System Exchange Ratios	30
4.	Vehicle Characteristics	32

List of Figures

Figures	Title	Page
2-1	Mission Requirements Summary	2
2-2	Delivery and Retrieval of OOS	4
2-3	Design Mission Easterly Launch - Booster	7
2-4	Typical Easterly Launch Mission Profile	8
2-5	Reference Mission South Polar - Orbiter	11
2-6	Reference Mission South Polar - Booster	13
2-7	Typical South Polar Launch Mission Profile	14
2-8	Reference Mission Resupply - Orbiter	15
2-9	Reference Mission Resupply - Booster	17
2-10	Typical Resupply Mission Profile	18
2-11	Orbiter OMS Ascent Abort Requirements For Easterly Launch and Resupply Missions	21
2-12	Orbiter OMS Ascent Abort Requirements For South Polar Mission	22
2-13	Orbiter Maneuvering Acceleration Requirements	23
2-14	Booster Maneuvering Acceleration Requirements	24
3-1	Aluminum Alloys with Low Resistance to Stress Corrosion Cracking	26
3-2	Steel and Nickel Alloys with Moderate Resistance to Stress Corrosion Cracking	27
3-3	Steel Alloys with Very Low Resistance to Stress Corrosion Cracking	27
3-4	Parametric Vehicle Sensitivities - Fixed Payload	31
4-1	Orbiter Mass Properties	33

Figures	Title	Page
4-2	Booster Mass Properties	34
4-3	Orbiter ACPS Thruster Locations	35
4-4	Booster ACPS Thruster Locations	36
4-5	General Arrangement - Booster	37
4-6	General Arrangement Siamese Tank Delta Wing Orbiter	38

SECTION I. General Requirements - The following general requirements shall be applied for RCS/OMS design.

1. The vehicle trajectory design load factors shall be 3g maximum along the vehicle longitudinal axis.

2. Systems shall be designed for a minimum of maintenance with ease of removal and replacement; maximum use of aircraft design practice will be used.

3. The reaction control system shall provide three-axis translation and three-axis attitude control capability for orbiter stages and three-axis attitude control for booster stages and shall be designed to minimise cross coupling which may result from normal operational modes or potential failure modes.

4. The space shuttle design shall include proper onboard provisions to quickly and easily place the space shuttle in a safe condition following landing.

5. Maximum use of existing standards for the selection, design, packaging, and integration of hardware should be employed, consistent with program operational requirements.

6. The RCS shall be capable of operating satisfactorily when subjected to normal-g, reduced-g, zero-g, or reversed-g environments, with no time limitation imposed for any of these conditions.

7. The RCS shall permit propellant fill and drain and pressurization and venting in either a vertical or horizontal booster orientation.

8. The reaction control system shall function independent of gravity field and vehicle attitude orientation.

9. The vehicle should be capable of loading fluid consumables within the 2-hour period immediately prior to launch.

10. The auxiliary propulsion system shall be designed to function for a minimum service life of 100 mission cycles over a 10-year period with cost effective refurbishment.

11. At least 7 days of self-sustaining lifetime shall be provided for the mission duration.

12. The APS shall be designed to fail safe after the failure of any two critical components. An exception to this will be the OMS operation in the abort mode. In this case the OMS shall be designed for fail safe operation after a single failure; i.e., assuming that the main engine failure constitutes the first system failure. Pressure vessels and fluid lines shall be considered exempt from the fail safe criteria, but shall be appropriately designed for the necessary reliable operation. Redundant paths, such as fluid lines, electrical wiring, connectors, and explosive trains, shall be located to ensure that an event which damages one line is not likely to damage the other.

2. Reference Mission Requirements - The Space Shuttle is designed to perform the three missions described in the following paragraphs. The Easterly launch mission is designated the design mission. However, the reference South Polar mission is primarily responsible for sizing both shuttle stages. The requirement to provide sufficient capability for a one pass orbiter abort following an engine failure at and/or after Orbiter-Booster separation is satisfied for each of the three missions of interest. The nominal insertion orbit for all missions is 50 n.m. perigee by 100 n.m. apogee. Figure 2-1 provides summary data for the three shuttle missions.

Figure 2-1

Mission Requirements Summary

Requirement	Missions		
	Design	Reference	
	Easterly	Polar	Resupply
• Inclination (°)	28.5	90	55
• Orbit Altitude (nm)	100	100	270
• OMS Capability (fps)	900	650	1500
• Required Payload (lb)	65,000	-	-
• Assumed Minimum Payload (lb)	-	40,000	25,000
• Mission Duration (Days)	7	7	7

2.1 Design Mission (Easterly Launch) - The Space Shuttle design mission consists of delivering and retrieving payloads in a 100 nm circular orbit with an inclination of 28.5 degrees, remaining in orbit up to 7 days, and returning to the launch site. The orbiter has the capability to deploy the payload and if required, retrieve it. Some missions may consist only of retrieving or servicing a previously launched payload. Payloads requiring insertion into orbits much higher than the nominal delivery altitude may be boosted by a orbit-to-orbit shuttle (OOS) which can also be carried by the orbiter. Typical mission sequence of events from lift-off to landing for the Orbiter and Booster are shown in Figures 2-2 and 2-3 respectively. The Orbiter is inserted into a 50 x 100 nm orbit which is circularised at apogee. The OOS is then checked, deployed and separated from the Orbiter. The OOS is activated and checked out prior to initiation of an Orbiter - OOS spacing burn. The OOS is then transferred to its mission orbit and the orbiter spacing burn is terminated. The orbiter remains on station for approximately 6 days and operates in a $\pm 20°$ deadband until the OOS returns to a 110 nm circular rendezvous orbit. During this time period routine crew functions are performed and 12 orbit maintenance burns are made to retain the 100 nm parking orbit. After the OOS descends to the rendezvous orbit the Orbiter maneuvers into position, deploys its docking mechanism and retrieves the OOS. The cross range capability of the delta wing Orbiter eliminates the need for pre-deorbit phasing. At the appropriate time the orbiter deorbits and returns to the launch site. The on-orbit ΔV values shown in Figure 2-2 are typical and are for translation maneuvers only. The anticipated requirement, is 491 fps nominal. A total ΔV capability of 900 fps will be provided. Additional propellant is provided for on-orbit attitude control and entry RCS. Figure 2-4 illustrates the altitude-time history and major events of this mission.

Figure 2-2

DESIGN MISSION EASTERLY LAUNCH - ORBITER

DELIVERY AND RETRIEVAL OF OOS

EVENT	TIME OF INITIATION DAYS HRS MIN SEC	Δt BETWEEN EVENTS DAYS HRS MIN SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
ASCENT				
• Booster Engine Ignition	- 00:00:00:08			
		00:00:00:08		
• Lift-Off	00:00:00:00		0	
		00:00:03:14.6		
• Booster Engine Cut-Off	00:00:03:14.6		209,204 ft	Imp ΔV = 15060
		00:00:00:00		
• Separation Initiation	00:00:03:14.6		209,204 ft	
		00:00:00:02.5		
• Orbiter Engine Ignition	00:00:03:17.1		212,973 ft	
		00:00:03:15.3		
• Orbiter Engine Shut-Down/Insert.	00:00:06:32.4		50/100 nm	
		00:00:43:45		
ON-ORBIT				
• Circularize	00:00:50:17		100/100 nm	91
		00:00:30:43		
• Deploy OOS (Rotate from Cargo Bay)	00:01:21:00			
		00:00:13:00		
• Separate OOS	00:01:34:00			
		00:00:06:00		
• OOS - Orbiter Spacing Burn #1 - Radial Down	00:01:40:00			10
		00:00:13:00		
• OOS - Ignition & Transfer to Mission Orbit	00:01:53:00			
		00:00:32:00		
• Terminate Spacing Burn #2 - Radial Up	00:02:25:00			10

Figure 2-2 Cont'd.

ON-ORBIT (Continued)

EVENT	TIME OF INITIATION DAYS:HRS:MIN:SEC	Δt BETWEEN EVENTS DAYS:HRS:MIN:SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
• Perform On-Orbit Activities as Required		00:09:45:00		
• Perform Orbit Maintenance Burns Twice per Day - 6 Days (TYP)				54
- Burn #1	00:12:10:00	00:00:45:00	98.5/101 nm	(4.5)
- Burn #2 (Circularize)	00:12:55:00	05:16:29:00	101/101 nm	(4.5)
• OOS Burn Into Rendezvous Orbit	06:05:24:00	00:00:49:00		
• Orbiter TPI	06:06:13:00	00:00:31:00	100/110 nm	32
• Initiate Braking	06:06:44:00	00:00:23:00	110/110 nm	44
• Dock	06:07:07:00	00:00:02:00	110/110 nm	
• Retrieve OOS - Stow in Cargo Bay	06:07:09:00			
DESCENT-ORBITER				
• De-Orbit-Initiate Burn	06:20:04:30	00:00:02:19	-10/110 nm	250
• De-Orbit-Terminate Burn	06:20:06:49	00:00:01:00		
• Maneuver to 30 degrees	06:20:07:49	00:00:11:40		

Figure 2-2 Cont'd.

DESCENT-ORBITER (Continued)

EVENT	TIME OF INITIATION DAYS:HRS:MIN:SEC	Δt BETWEEN EVENTS DAYS:HRS:MIN:SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
• Entry	06:20:19:29		400,000 ft	
		00:00:29:55		
• Initiate Transition Maneuver	06:20:49:24		155,000 ft	
		00:00:07:50		
• Complete Transition	06:20:57:14		48,000 ft	
		00:00:05:45		
• Land (straight-in-approach)	06:21:02:59			

TOTAL ON-ORBIT
ΔV = 491 fps
(900 IS AVAILABLE)

Figure 2-3

DESIGN MISSION EASTERLY LAUNCH - BOOSTER

	TIME OF INITIATION DAYS:HRS:MIN:SEC	TIME BETWEEN EVENTS DAYS:HRS:MIN:SEC	ALTITUDE - ft
DESCENT BOOSTER			
• Initiate Separation	00:03:14.6		209,204
		00:00:02.5	
• Separation	00:03:17.1		212,973
		00:00:57.9	
• Orientate to $\alpha = 60°$ $\beta = 0°$	00:04:15		255,000
		00:01:55	
• Orientate to $\beta = 90°$	00:06:10		135,337
		00:00:02	
• Initiate α Modulation	00:06:12		133,821
		00:00:26	
• Initiate β Modulation	00:06:38		104,683
		00:02:10	
• Start ABES	00:08:48		45,000
		00:00:40	
• Orientate to $\beta = 0°$	00:09:28		30,000
		00:00:50	
• Orientate to $\alpha = 11°$	00:10:18		16,500
		00:00:30	
• Start Cruise Bank (438 NM)	00:10:48		15,500
		01:30:00	
• Land	01:40:48		

TYPICAL EASTERLY LAUNCH

MISSION PROFILE

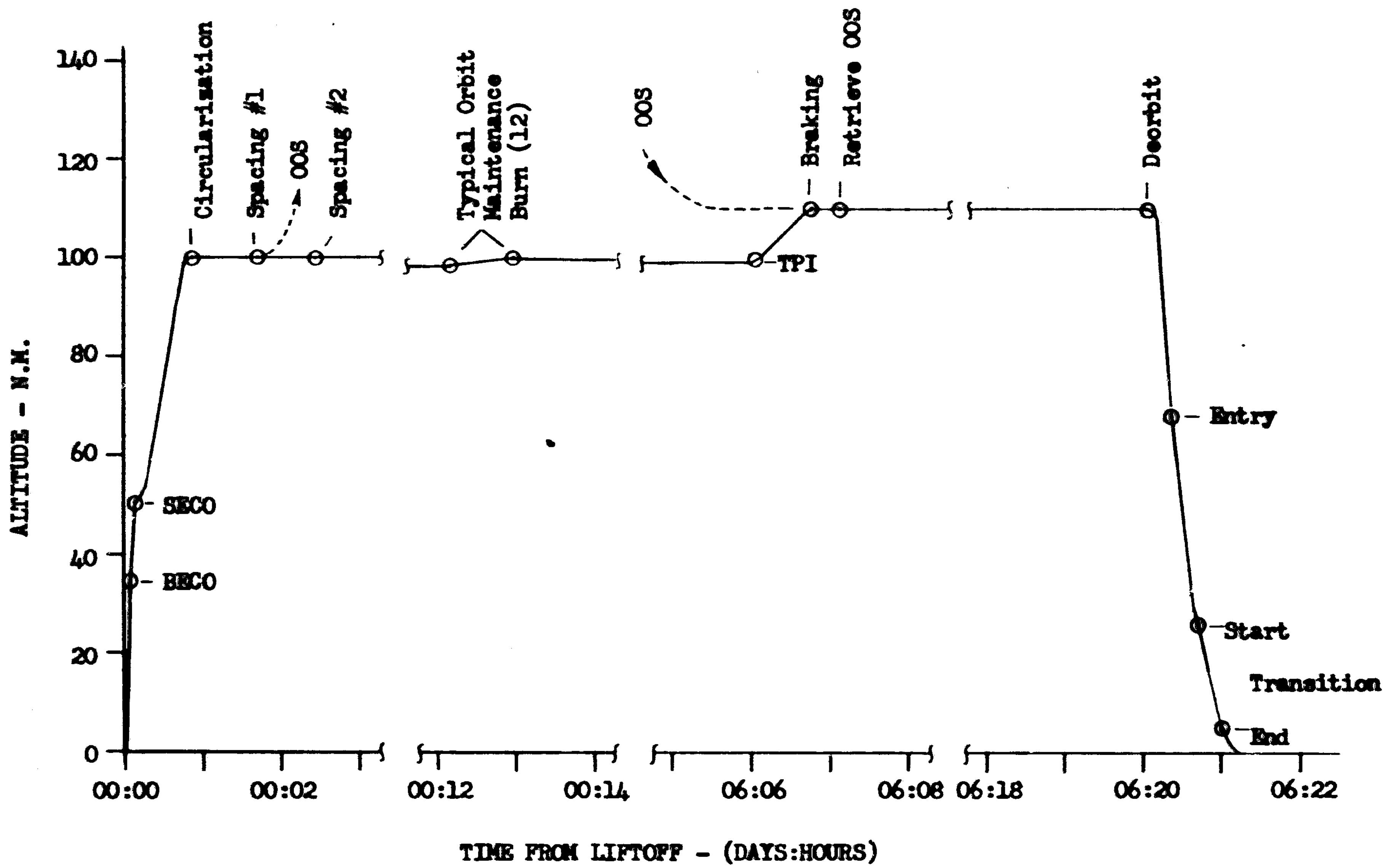


Figure 2-4

2.2 South Polar Reference Mission - The South Polar Reference Mission consists of launching the orbiter into an injection orbit of 50 x 100 nm, with a 90 degree inclination and circularizing at apogee utilizing the orbital maneuvering propulsion system. A variety of payloads will be delivered, serviced and/or retrieved. The orbiter remains in orbit for 7 days and operates in a ± 20° deadband prior to returning to the launch site. Typical mission sequence of events from lift-off to landing are shown in Figures 2-5 and 2-6 for the orbiter and booster. On-orbit activities will vary with each specific mission flight and are presently undefined. In addition to normal on orbit maneuvering functions, the OMS provides 950 fps ΔV augmentation in the nominal ascent operating mode. The ΔV allocations of Figure 2-5 are for on orbit maneuvers only and the total requirement is 650 fps. Additional propellant is carried for attitude control and entry RCS. Figure 2-7 illustrates major mission events and identifies significant ascent and entry parameters.

2.3 Resupply Reference Mission - The resupply reference mission consists of providing logistic support for a space station/space base in a 270 nm, 55 degree circular orbit. Logistic support will consist of periodic transportation of expendable supplies, experiments, data and passengers to and from the space station. The duration of each mission is 7 days. The resupply mission requires the orbiter to rendezvous and dock with the space station. Therefore, depending upon launch time, the orbiter may be required to phase in a parking orbit prior to rendezvous with the space station. Typical resupply mission sequence of events are shown in Figures 2-8 and 2-9 for the orbiter and booster respectively. Approximately 5 hours of phasing, which is part of the transfer/gross rendezvous maneuvers is considered for the orbiter. Upon reaching apogee of the 50 x 100 nm insertion orbit perigee is raised to 123 nm. Approximately 1/2 orbit later, the 100 nm perigee is raised to 241 nm and the Orbiter remains in a 123 x 241 nm orbit for 1 1/2 revolutions. At this time the orbit is changed to 241 x 250 nm and 1/2 orbit later perigee is raised to 260 nm. The orbit is circularized at 260 nm at the appropriate time and the Orbiter prepares for initiation of final rendesvous and docking maneuvers.

The cargo container is rotated and locked into a position 90° from its original position in the cargo bay for docking to the space station. The orbiter remains docked long enough to secure the cargo module to the station safely and permit transfer of passengers. The orbiter then separates and remains in a $\pm 20°$ deadband until cargo is transferred to the station and the return cargo is loaded into a returning module. The orbiter then redocks with the cargo module, separates from the station and returns to the launch site.

A typical mission will expend, as shown in Figure 2-8, approximately 1283 fps ΔV (nom). Approximately 100 to 160 fps is estimated for dispersion corrections. However, 1500 fps ΔV will be available for translation maneuvers. Additional propellant is provided for on-orbit attitude control and entry RCS. Figure 2-10 illustrates major mission events and identifies significant ascent and entry parameters.

Figure 2-5

REFERENCE MISSION

SOUTH POLAR - ORBITER

	TIME OF INITIATION DAYS: HRS: MIN: SEC	Δt BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
ASCENT				
• Booster Engine Ignition	- 00:00:00:08			
		00:00:00:08		
• Lift-Off	00:00:00:00		0	
		00:00:03:15 7		
• Booster Engine Cut-Off	00:00:03:15.7		213,179 ft	Imp ΔV = 15267
		00:00:00:00		
• Separation Initiation	00:00:03:15.7		213,179 ft	
		00:00:00:02.5		
• Orbiter Engine & OMS Ignition	00:00:03:18.2		216,831 ft	
		00:00:03:18.6		
• Orbiter Engine Shut-Down	00:00:06:36.8		303,375 ft	
		00:00:02:14.8		
• OMS Shut-Down/Insert	00:00:08:51.6		50/100 nm	
		00:00:43:40		
ON ORBIT				
• Circularize	00:00:52:32		100/100 nm	90
• On-Orbit Activities (TBD)		06:19:11:58		310
• Orbit Decay Correction - Two corrections per day				
DESCENT-ORBITER				
• De-Orbit-Initiate Burn	06:20:04:30		-10/100 nm	250
		00:00:02:19		
• De-Orbit-Terminate Burn	06:20:06:49			
		00:00:01:00		

DESCENT-ORBITER (Continued)

Figure 2-5 Cont'd.

EVENT	TIME OF INITIATION DAYS: HRS: MIN: SEC	Δt BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
• Maneuver to 30° α	06:20:07:49			
		00:00:09:40		
◦ Entry	06:20:17:29		400,000 ft	
		00:00:31:50		
• Initiate Transition Maneuver	06:20:49:19		153,000 ft	
		00:00:07:50		
◦ Complete Transition	06:20:57:09			
		00:00:05:45		
• Land	06:21:02:54		48,000 ft	

TOTAL ON-ORBIT
ΔV = 650 fps

Figure 2-6

REFERENCE MISSION SOUTH POLAR - BOOSTER

EVENT	TIME OF INITIATION DAYS: HRS: MIN: SEC	Δt BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE - FT
DESCENT BOOSTER			
• Initiate Separation	00:03:15.7		213,179
		00:00:02.5	
• Separation	00:03:18.2		216,831
		00:00:56.8	
• Orientate to $\alpha = 60°$ $\beta = 90°$	00:04:15		259,163
		00:01:55	
• Orientate to $\beta = 90°$	00:06:10		135,337
		00:00:02	
• Initiate α Modulation	00:06:12		133,821
		00:00:26	
• Initiate β Modulation	00:06:38		104,683
		00:02:10	
• Start ABES	00:08:48		45,000
		00:00:40	
• Orientate to $\beta = 0°$	00:09:28		30,000
		00:00:50	
• Orientate to $\alpha = 11°$	00:10:18		16,500
		00:00:30	
• Start Cruise Back (438 NM)	00:10:48		15,500
		01:30:00	
• Land	01:40:48		0

TYPICAL SOUTH POLAR LAUNCH

MISSION PROFILE

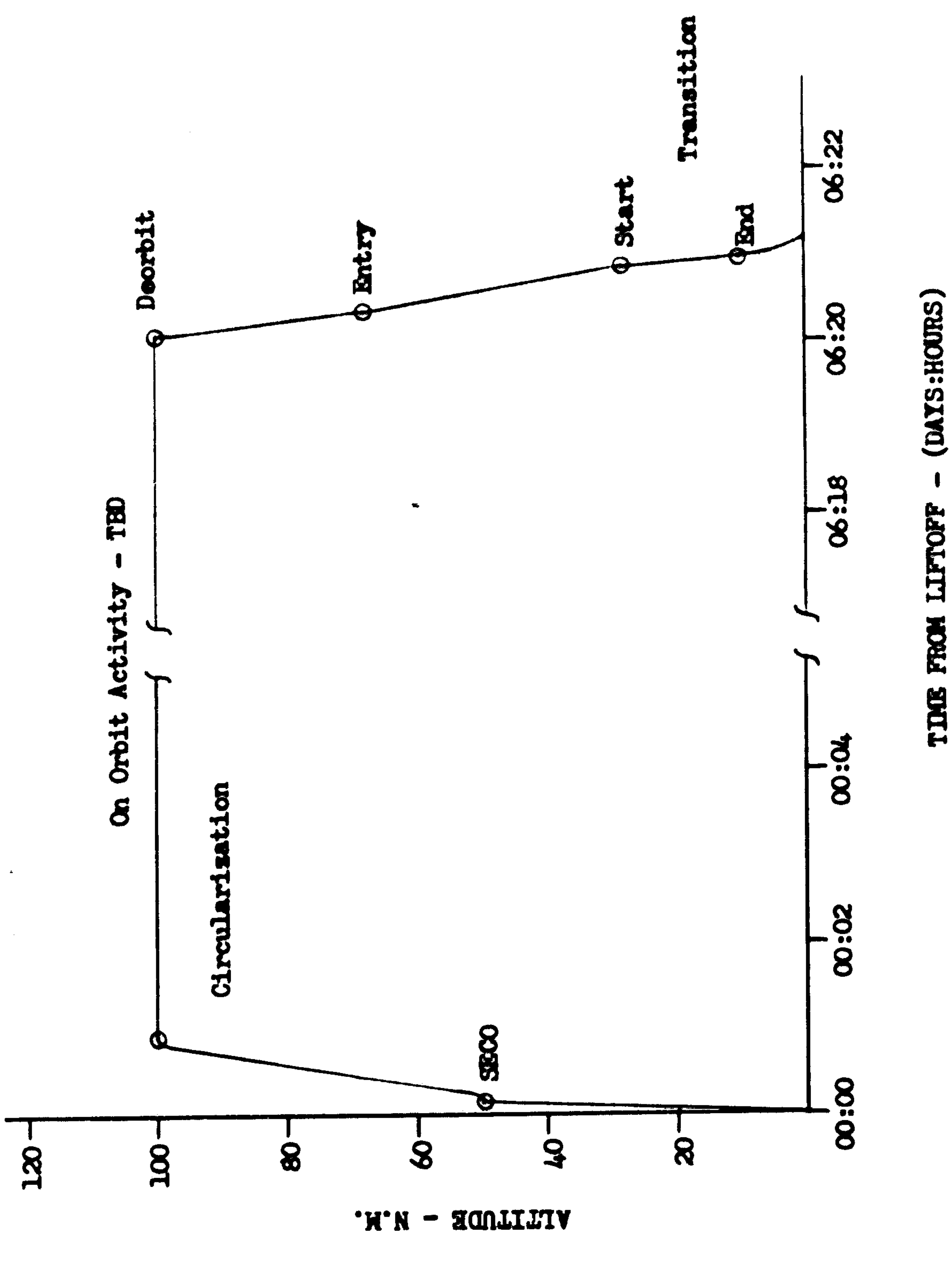


Figure 2-7

Figure 2-8

REFERENCE MISSION

RESUPPLY - ORBITER

EVENT	TIME OF INITIATION DAYS: HRS: MIN: SEC	Δt BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
ASCENT				
• Booster Engine Ignition	-00:00:00:08	00:00:00:08		
• Lift-Off	00:00:00:00	00:00:03:15.2	0	
• Booster Engine Shut-Down	00:00:03:15.2	00:00:00:00	211,201 ft	Imp ΔV = 15,169
• Separation Initiation	00:00:03:15.2	00:00:00:00	211,201 ft	
• Orbiter Engine Ignition	00:00:03:17.7	00:00:03:16.7	214,930 ft	
• Orbiter Engine Shut-Down/Insert	00:00:06:34.4	00:00:43:40	100/50 nm	
ON-ORBIT				
• N_{C_1} (Phasing)	00:00:50:14	00:00:45:00	123/100 nm	133
• N_{C_2} (Phasing)	00:01:35:14	00:02:16:12	241/123 nm	248
• N_{C_3} (Phasing)	00:03:51:26	00:00:45:00	250/241 nm	224
• NCC (Corrective Combination)	00:04:36:26	00:00:45:00	260/250 nm	33
• N_S12 (Coelliptic)	00:05:21:26	00:00:45:00	260/260 nm	18
• TPI	00:06:06:26	00:00:35:59	270/260 nm	22
• Braking	00:06:42:25	00:00:12:04	270/270 nm	45
• Deploy Cargo Container	00:06:54:29	00:00:25:00	270/270 nm	

Figure 2-8 (cont'd)

ON-ORBIT (Continued)

EVENT	TIME OF INITIATION DAYS: HRS: MIN: SEC	TIME BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE	ON-ORBIT TOTAL ΔV fps
• Docking	00:07:19:29		270/270 nm	10
		00:03:00:00		
• Separation	00:10:19:29		270/270 nm	10
---------- On Station ----------		06:00:00:00		
• TPI	06:10:19:29		270/270 nm	26
		00:00:51:18		
• Braking	06:11:10:47		270/270 nm	54
		00:00:37:15		
• Docking	06:11:48:02		270/270 nm	10
		00:03:00:00		
• Separation	06:14:48:02		270/270 nm	10
		00:00:15:00		
• Stow Cargo Container	06:15:03:02		270/270 nm	
		00:00:15:00		
• Position Update	06:15:18:02		270/270 nm	
DESCENT-ORBITER				
• De-orbit-Initiate Burn	06:20:40:28		270/270 nm	440
		00:00:04:08		
• De-orbit-Terminate Burn	06:20:44:36			TOTAL 1283 AVAIL. (1500)
		00:00:01:00		
• Orient to 34° α	06:20:45:36			
		00:00:28:00		
• Entry	06:21:13:36		400,000 ft	
		00:00:25:25		
• Initiate Transition Maneuver	06:21:34:01		159,000 ft	
		00:00:07:50		
• Terminate Transition Maneuver	06:21:46:51		48,000 ft	
		00:00:11:40		
• Land (straight-in-approach)	06:21:58:31			

Figure 2-9 REFERENCE MISSION RESUPPLY - BOOSTER

EVENT	TIME OF INITIATION DAYS: HRS: MIN: SEC	Δt BETWEEN EVENTS DAYS: HRS: MIN: SEC	ALTITUDE - FT
• Liftoff	00:00:00		0
		00:03:15.2	
• Initiate Separation	00:03:15.2		211,201
		00:00:02.5	
• Separation	00:03:17.7		214,930
		00:00:57.3	
• Orientate to $\alpha = 60°$ $\beta = 0°$	00:04:15		257,000
		00:01:55	
• Orientate to $\beta = 90°$	00:06:10		135,337
		00:00:02	
• Initiate α Modulation	00:06:12		133,821
		00:00:26	
• Initiate β Modulation	00:06:38		104,683
		00:02:10	
• Start ABES	00:08:48		45,000
		00:00:40	
• Orientate to $\beta = 0°$	00:09:28		30,000
		00:10:18	
• Orientate to $\alpha = 11°$	00:10:18		16,500
		00:00:30	
• Start Cruise Back (438 NM)	00:10:48		15,500
		00:30:00	
• Land	01:40:48		0

TYPICAL RESUPPLY MISSION PROFILE

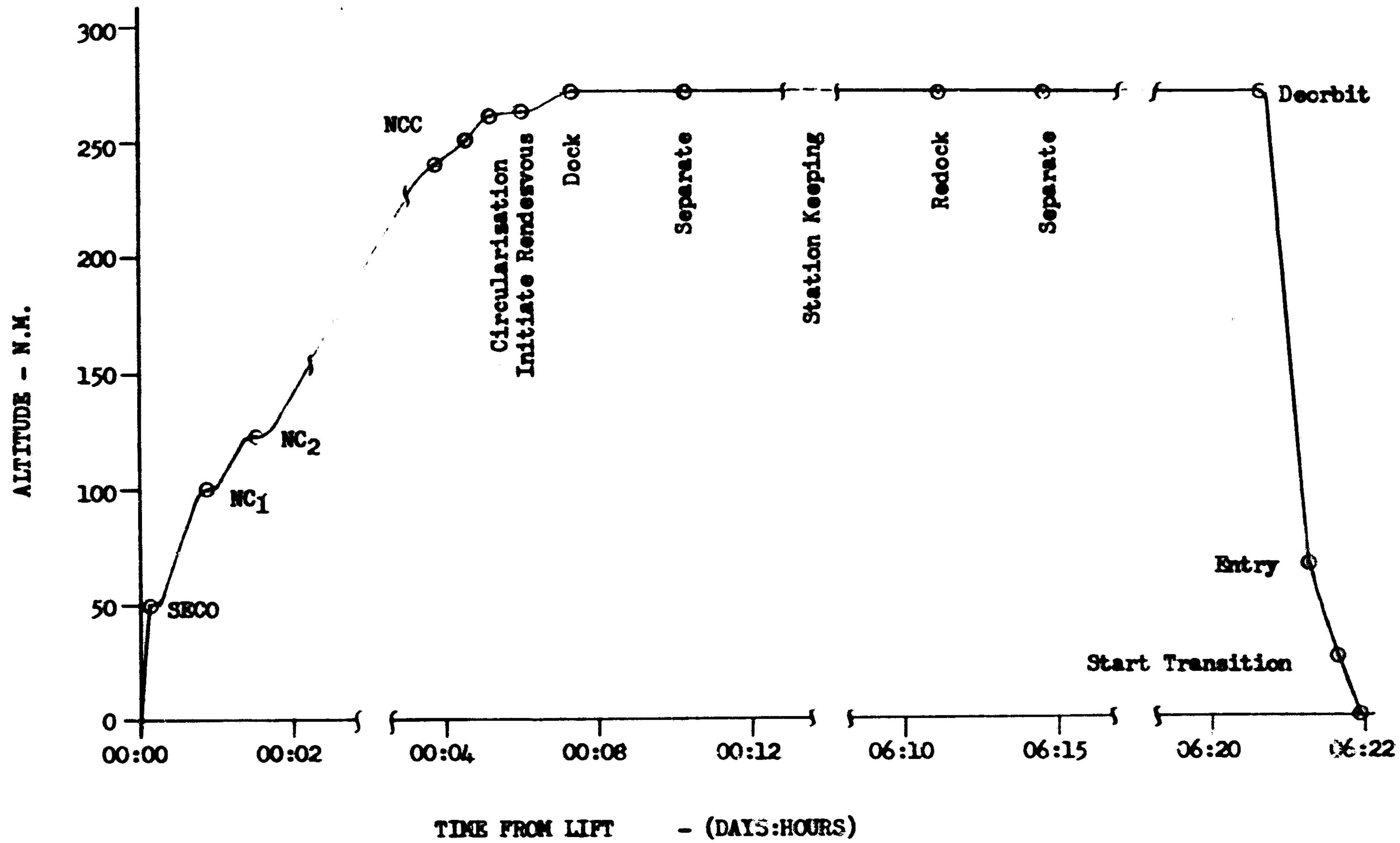


Figure 2-10

2.4 Ascent Abort Requirements - A major requirement for the Orbit Maneuvering Propulsion System will be to provide for safe entry in the event of a main engine failure during ascent. In this mission abort situation the remaining orbiter main engine will be operated at 109% of its nominal thrust level. However, total ascent thrust will still be appreciably reduced and the increased gravity losses incurred must be made up by the orbit maneuver system. Two operating modes are feasible, i.e., the OMS can be burned after main engine shutdown (series) or during main engine firing (parallel). Figures 2-11 and 2-12 provide definition of the abort ΔV augmentation required of the OMS as a function of OMS thrust level for the three missions to be considered.

2.5 Vehicle Acceleration Requirements - The translation and rotational acceleration requirements for the shuttle orbiter and booster are provided in figures 2-13 and 2-14 respectively. Also provided in these figures are the attitude limits during the various mission phases. The acceleration requirements are to be interpreted as follows for system design:

Fail Safe - Systems shall provide in excess of the safe acceleration levels after any failure or any two failures

Design - Systems shall provide acceleration levels above the design minimum under normal operating conditions (i.e., no failure).

Figure 2-11

ORBITER OMS ASCENT ABORT REQUIREMENTS
FOR
EASTERLY LAUNCH AND RESUPPLY MISSIONS

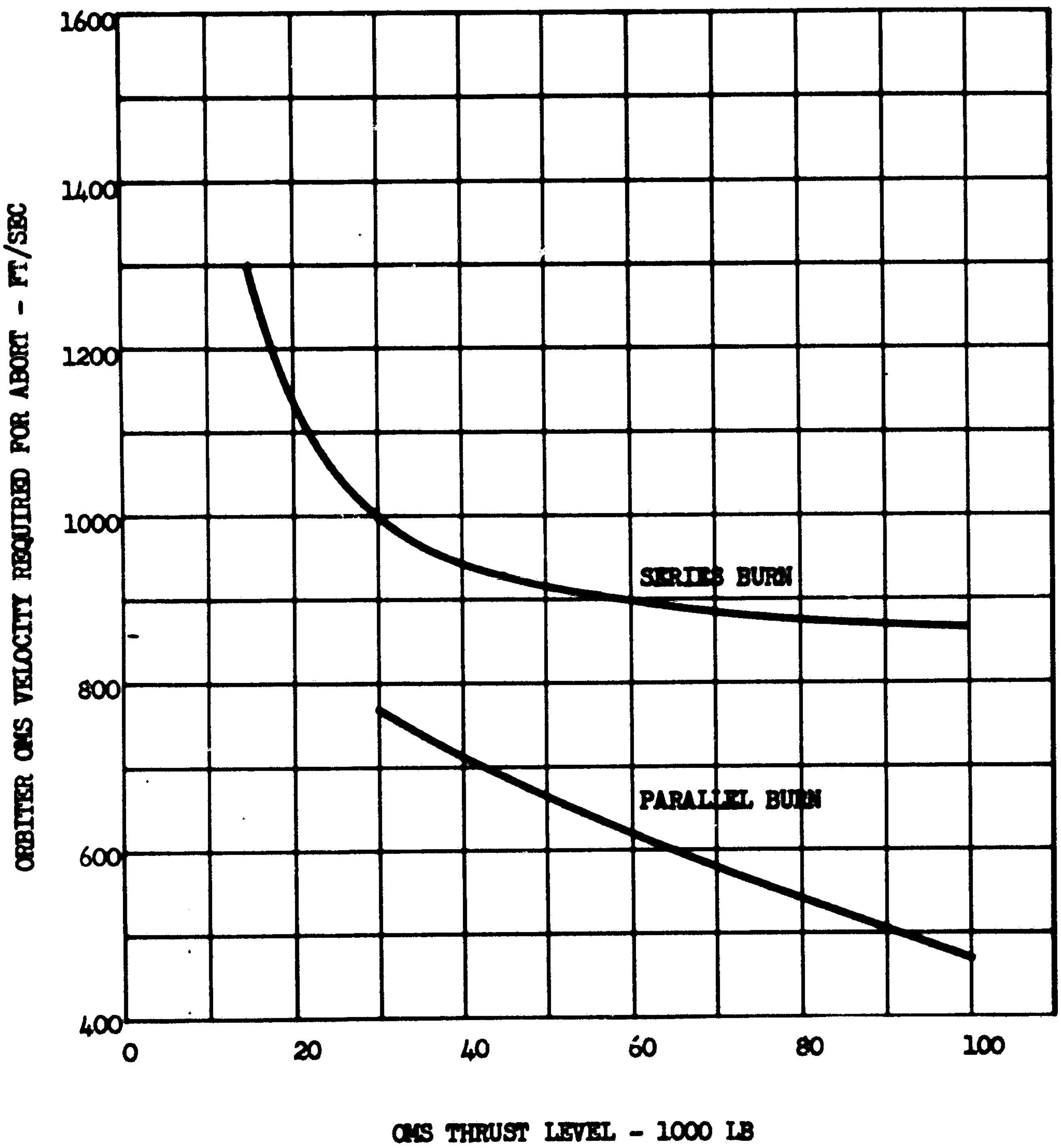


FIGURE 2-12

ORBITER OMS ASCENT ABORT REQUIREMENTS
FOR
SOUTH POLAR MISSION

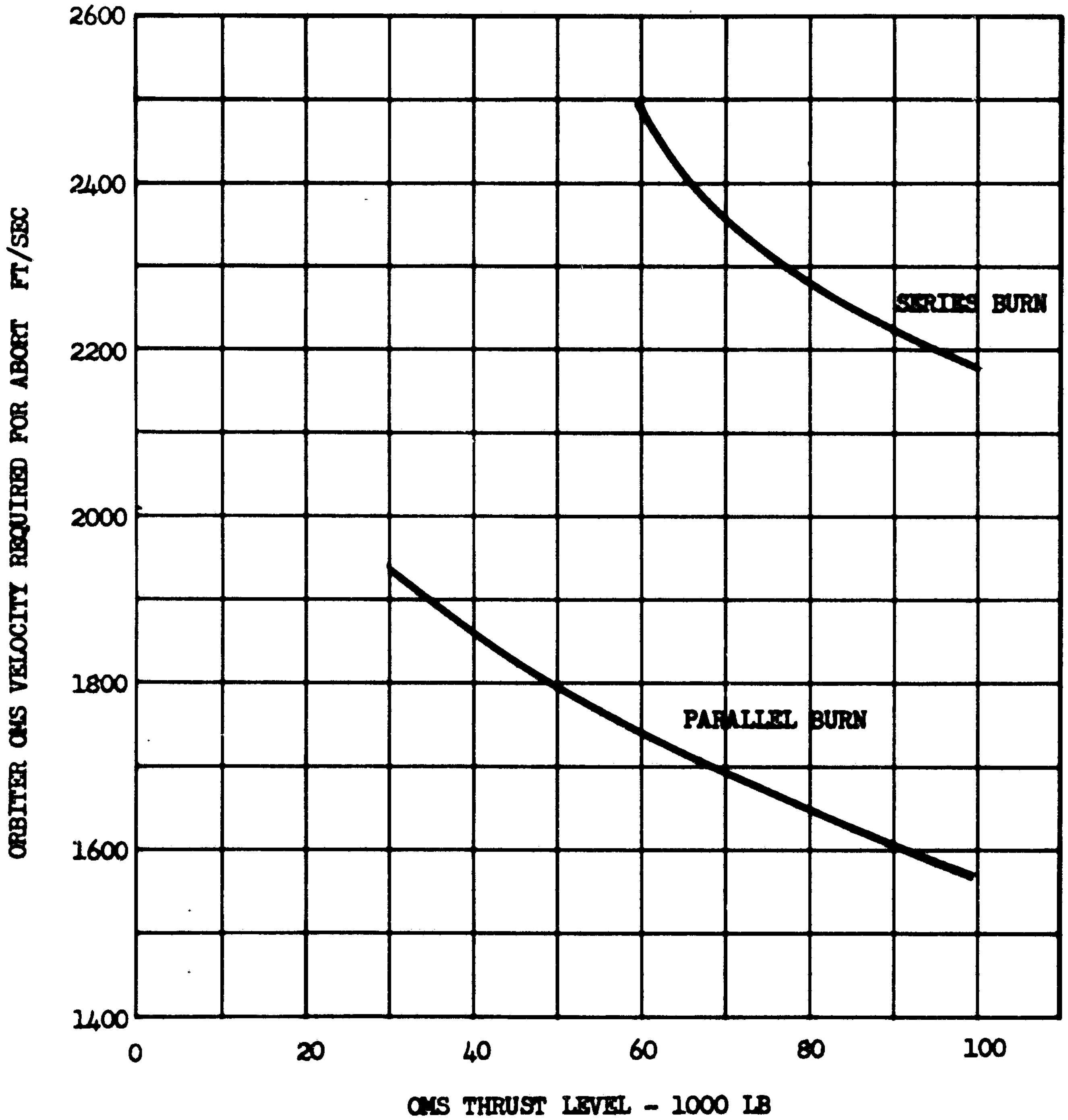


Figure 2-13 ORBITER MANEUVERING ACCELERATION REQUIREMENTS

MISSION PHASE		ASCENT			ON-ORBIT			ENTRY			TRANSITION		
		-X	+X	±Y,Z	-X(a)	+X	+Y,Z	-X	+X	±Y,Z	-X	+X	±Y,Z
TRANSLATION ACCELERATION ft/sec^2	SAFE	1.0(OMS)	N/R +		0.6(OMS) 0.2(APS)	0.0	0.0		N/R +			N/R +	
	DES MIN	1.5(OMS)			1.2(OMS) 0.4(APS)	0.4	0.2						
		P	Y	R	P	Y	R	P	Y	R	P	Y	R
ANGULAR ACCELERATION deg/sec^2	SAFE			(b)	0.3	0.3	0.3	0.3	0.8	1.0			
	DES MIN	N/R +			0.5	0.5	0.5	0.5	1.2	1.5	TBD	TBD	TBD
ATTITUDE LIMITS deg	FINE	N/R +		1.0	0.5	0.5	0.5	1.0	2.0	2.0			
	COURSE	N/R +		N/R +	20.	20.	20.	N/R +	N/R +	N/R +			

\+ NO REQUIREMENT

(a) FAIL SAFE DEORBIT BACKUP SHALL BE PROVIDED BY APS; DEORBIT MANEUVER SHALL NOT EXCEED 5 MINUTES DURATION

(b) ROLL CONTROL TORQUE OF 40,000 ft-lb (MIN) REQUIRED FOR FAILED MAIN ENGINE

Figure 2-14

BOOSTER MANEUVERING ACCELERATION REQUIREMENTS

MISSION PHASE		POST-SEPARATION			ORIENTATION			ENTRY(a)			TRANSITION(a)		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
TRANSLATION ACCELERATION ft/sec^2	SAFE	NO			NO			NO			NO		
	DES MIN	REQUIREMENT			REQUIREMENT			REQUIREMENT			REQUIREMENT		
		P	Y	R	P	Y	R	P	Y	R	P	Y	R
ANGULAR ACCELERATION deg/sec^2	SAFE	0.12	0.12	0.12	0.12	0.12	0.12	NO			NO		
	DES MIN	0.30	0.30	0.30	0.30	0.30	0.30	REQUIREMENT			REQUIREMENT		
ATTITUDE LIMITS deg	FINE	2.0	2.0	2.0	2.0	2.0		NO			NO		
	COURSE	N/R	N/R	N/R	N/R	N/R		REQUIREMENT			REQUIREMENT		

(a) CONTROL PROVIDED BY AERODYNAMIC SURFACES

3.0 System and Component Design Criteria

3.1 Factors of Safety

Safety factors should be based on limit loads and stress conditions and on material properties described in the "A" allowable values of MIL-HDBK-5A or equivalent values based on probability and confidence.

a. Factors of safety for applied or resultant loads, general structure.

The following factors of safety shall be applied to loads resulting from inertia, dynamic response, engine thrust, thermal conditions, and other miscellaneous conditions not specifically covered elsewhere. These factors of safety shall be the minimum acceptable for 100 mission cycles.

Yield factor = 1.1

Ultimate factor = 1.4 (Prelaunch through entry transition)

= 1.5 (Entry transition to prelaunch)

b. Factors of Safety for Pressure Systems

The following minimum factors of safety shall be applied to loads resulting from unit pressure conditions:

Proof factor = 1.5

Ultimate factor = 2.0

c. Factors on Operational Lifetime Cycles

When only typical fatigue allowables are available, the component shall be capable of withstanding 10 times the predicted number of load cycles. When sufficient fatigue data are available to establish statistical minimum guaranteed fatigue allowables, the component shall be capable of withstanding three times the predicted number of load cycles.

3.2 Materials

Materials used in the manufacture of the APS shall be of high quality suitable for the purpose and shall conform to applicable specifications. All materials employed must have proven capability to be fabricated to the shape and form (including weldability) to satisfy the design requirements.

Materials known to be susceptible to stress corrosion cracking shall not be used in a configuration/application conducive to stress corrosion cracking. Materials known to be susceptible to stress corrosion cracking, as listed in Figures 3-1, 3-2, and 3-3, shall not be used witnout prior approval by the procuring activity.

Figure 3-1 ALUMINUM ALLOYS WITH LOW RESISTANCE TO STRESS CORROSION CRACKING*

Wrought Alloys		Castings	
Alloy	Temper	Alloy	Temper
2014	All Tempers	195, B195	-T6
2024	T3, T351, T36, T4	220	-T4
2219	T31, T351, T37	Turnalloy 7	-T6
7001	T6, T651	40E	As Cast
7075	T6, T651		
7079	T6, T651		
7178	T6, T651		

* If sheet material, unmachined extrusions, or unmachined plate material is required, use of material listed above is permissible if high-strength material is necessary.

Figure 3-2 STEEL AND NICKEL ALLOYS WITH MODERATE RESISTANCE TO STRESS CORROSION CRACKING*

Alloy	Temper
Low Alloy Steel	150 to 180 ksi Y.S.
Maraging Steel	200 ksi Y.S.
400 Series Stainless Steel	All Tempers
PH14-8 Mo Stainless Steel	SRH950 to 1050
PH15-5 Mo Stainless Steel	H900 to 1000
PH13-8 Mo Stainless Steel	H900 to 1000
17-4PH Stainless Steel	H900 to 1000
AM 355 Stainless Steel	>SCT -900FH

*Alloys and heat treatments listed above may be used if it can be shown that there are no sustained tensile stresses (residual or imposed).

Figure 3-3

STEEL ALLOYS WITH VERY LOW RESISTANCE TO STRESS CORROSION CRACKING

Alloy	Temper
17-7PH Stainless Steel	All Except CH900
PH15-7 Mo Stainless Steel	All Except CH900
AM 355 Stainless Steel	SCT900 FH
H-11 Steel	All Tempers
Vascojet 1000	All Tempers
Low-Alloy Steels	180 ksi Y.S.
18 Ni Maraging Steel	>200 ksi Y.S.

(a) Hydrogen Embrittlement

Materials known to be susceptible to embrittlement when exposed to gaseous hydrogen shall not be used in a configuration/application conducive to hydrogen embrittlement.

(b) Compatibility

All material used shall be selected on the basis of having maximum compatibility with the environment with which it is used, with primary importance placed on material-propellant compatibility and the use of nonflammable materials wherever possible. Any material used internally in the oxidizer system shall be LOX compatible.

3.2.1 Fluids and Mechanical Criteria

(a) Fluid Velocity

Fluid line sizes shall be selected on the basis of design velocities that will result in an acceptable compromise between the excessive pressure drop produced by too-small tubings and the weight and cost of too-large lines. Gas velocities shall be limited to Mach 0.3 or less, except where higher values are specifically justified and approved.

(b) Flange Seal Connectors

Mechanically separable seal connectors in tubing or ducting greater than 1 in. in diameter shall be bolted-type flanges, unless otherwise justified and approved. All flanges in tubing or ducting will incorporate redundant seals.

(c) Component Integration and Packaging

Flight components shall be limited to those required for flight operations, except for components that are required for onboard checkout and servicing. Components integration, packaging, and simplicity of checkout shall be considered where advantages in maintainability, serviceability, replaceability, weight, and cost could be realized.

3.2.2 Thermal Conditioning and Control

1. Thermal Control

Passive-type thermal control shall be employed to the maximum extent possible.

2. Thermal Protections

Thermal protection requirements identified shall be included in the system or component design and corresponding weights included in the overall system weight.

3.3 Vehicle/System Exchange Ratios - Figure 3-4 provides typical stage and gross lift-off weight exchanges for use in system design trade studies. The data presented are a compilation of results obtained from vehicle sizing studies and reflect all known penalties including factors such as landing engine fuel for cruise back range and changes to ascent and entry drag.

Figure 3-4

PARAMETRIC VEHICLE SENSITIVITIES - FIXED PAYLOAD +

VARIABLE	EASTERLY LAUNCH			RESUPPLY MISSION			SOUTH POLAR MISSION			SENSITIVITY UNITS
	INERT WGT		GROSS WGT (GLOW)	INERT WGT		GROSS WGT (GLOW)	INERT WGT		GROSS WGT (GLOW)	
	BOOSTER	ORBITER		BOOSTER	ORBITER		BOOSTER	ORBITER		
APS INERT WGT										
- BOOSTER	1.5	0.07	6.1	1.6	0.07	6.4	1.6	0.07	6.5	LB/LB
- ORBITER	2.1	2.59	34.9	2.0	2.7	34.0	2.3	2.8	37.7	LB/LB
VEH. BASE AREA										
- ORBITER	30.6	37.8	510	28.0	37.8	476	31.2	37.8	510	LB/FT^2
APS TANK VOL.										
- BOOSTER	0.21	0.01	0.85	0.22	0.01	0.88	0.21	0.01	0.87	LB/FT^3
- ORBITER	1.69	2.1	28.1	2.0	2.7	34.1	2.2	2.6	35.4	LB/FT^3

+ VEHICLE SYSTEM RESIZED TO MAINTAIN FIXED PAYLOAD

4. Vehicle Characteristics - The orbiter stage of the shuttle system is a delta wing, high cross range configuration and the booster is a single body, swept wing, canard configuration. Figures 4-1 and 4-2 present mass properties for the two stages. Figures 4-3 and 4-4 show profile sketches of the orbiter and booster respectively indicating general vehicle dimensions and RCS thruster locations. Figures 4-5 and 4-6 show vehicle inboard profiles indicating general equipment locations.

Figure 4-1 ORBITER MASS PROPERTIES

DESIGN-EASTERLY LAUNCH		STAGING	INSERTION	ON-ORBIT	ENTRY
Weight (lb)		860,442	331,780	319,187	277,291
Center of Gravity (in)	X	+1063	+1465	+1485	+1481
	Y	0	0	0	0
	Z	+257	+303	+306	+298
Moment of Inertia (Slug-ft^{2}x10^{-6})					
	I_{XX}	2.55	1.96	1.94	1.84
	I_{YY}	42.24	15.25	14.06	12.86
	I_{ZZ}	42.66	15.58	14.39	13.23
SOUTH POLAR					
Weight (lb)		853,407	302,075	290,012	278,376
Center of Gravity (in)	X	+1067	+1470	+1491	+1486
	Y	0	0	0	0
	Z	+253	+295	+298	+298
Moment of Inertia (Slug-ft^{2}x10^{-6})					
	I_{XX}	2.45	1.88	1.86	1.84
	I_{YY}	43.77	14.77	13.60	12.99
	I_{ZZ}	44.32	15.16	13.99	13.37
RESUPPLY					
Weight (lb)		845,988	317,149	293,197	276,367
Center of Gravity (in)	X	+1063	+1486	+1498	+1489
	Y	0	0	0	0
	Z	+250	+286	+289	+288
Moment of Inertia (Slug-ft^{2}x10^{-6})					
	I_{XX}	2.56	2.07	2.03	2.01
	I_{YY}	42.90	15.34	13.59	12.73
	I_{ZZ}	43.67	15.93	14.16	13.29

Figure 4-2

BOOSTER MASS PROPERTIES

Design - Easterly Launch*

		Mission Phase	
	Lift Off	Staging	Start of Cruise
Weight (lb)	3,756,180	721,280	699,292
Center of Gravity (in) X	+2071	+3021	+3015
Y	0	0	0
Z	+404	+423	+424
Moment of Inertia (Slug $ft^2 x 10^{-6}$)			
I_{XX}	9.45	9.38	9.38
I_{YY}	439.87	118.32	115.45
I_{ZZ}	444.00	122.52	119.65

*Applicable to Resupply and South Polar Missions

FIGURE 4-3
ORBITER ACPS THRUSTER LOCATIONS

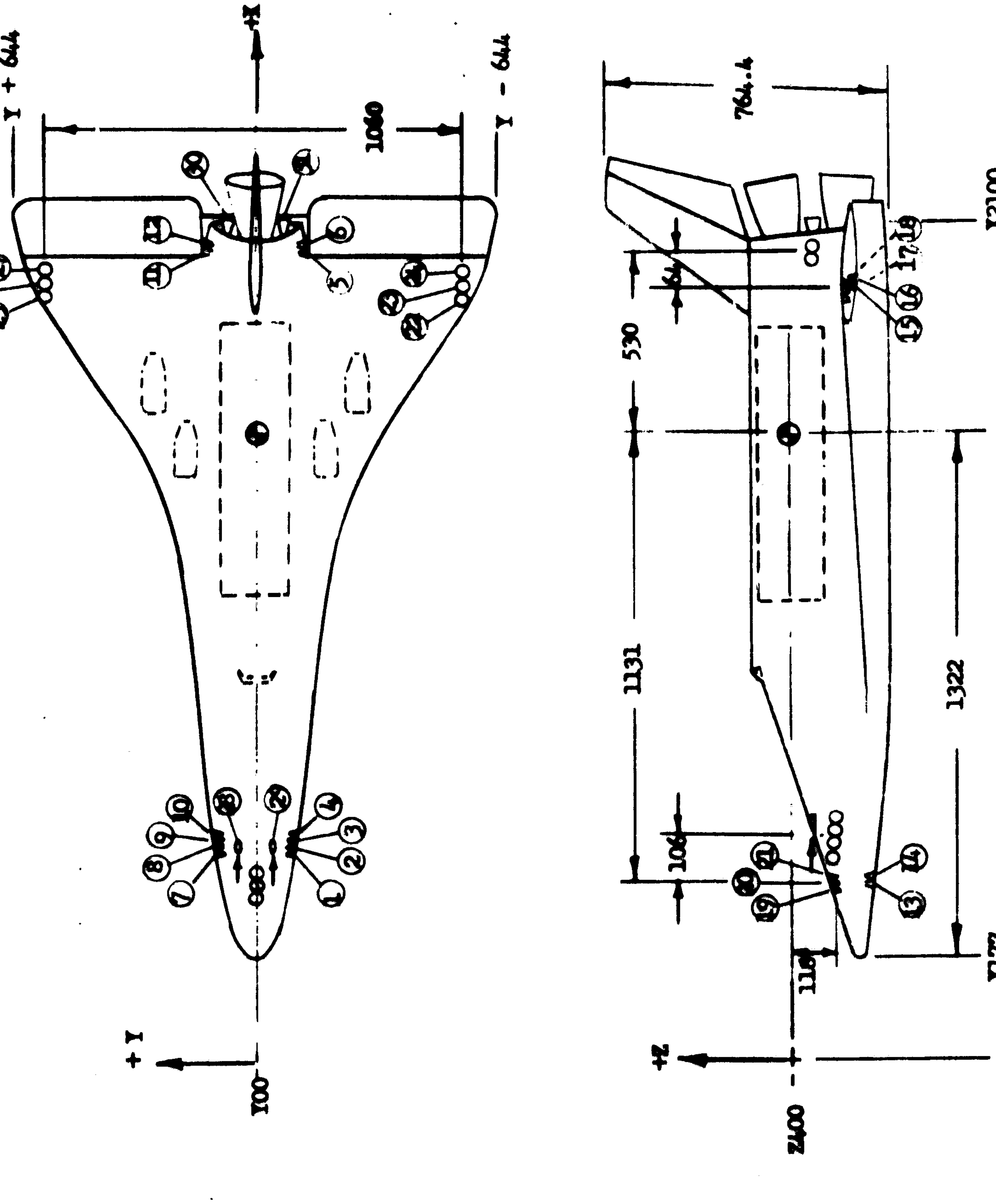
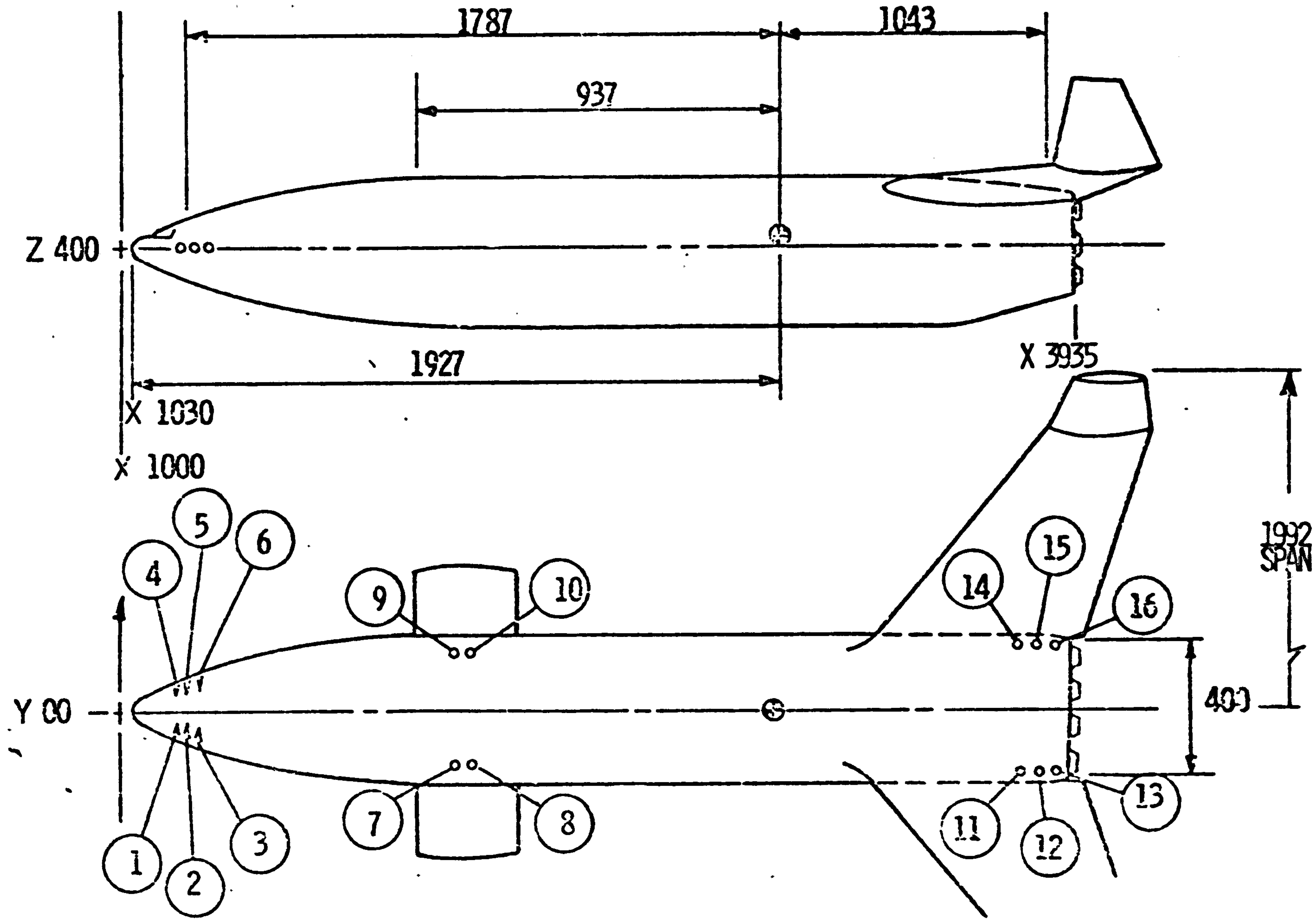
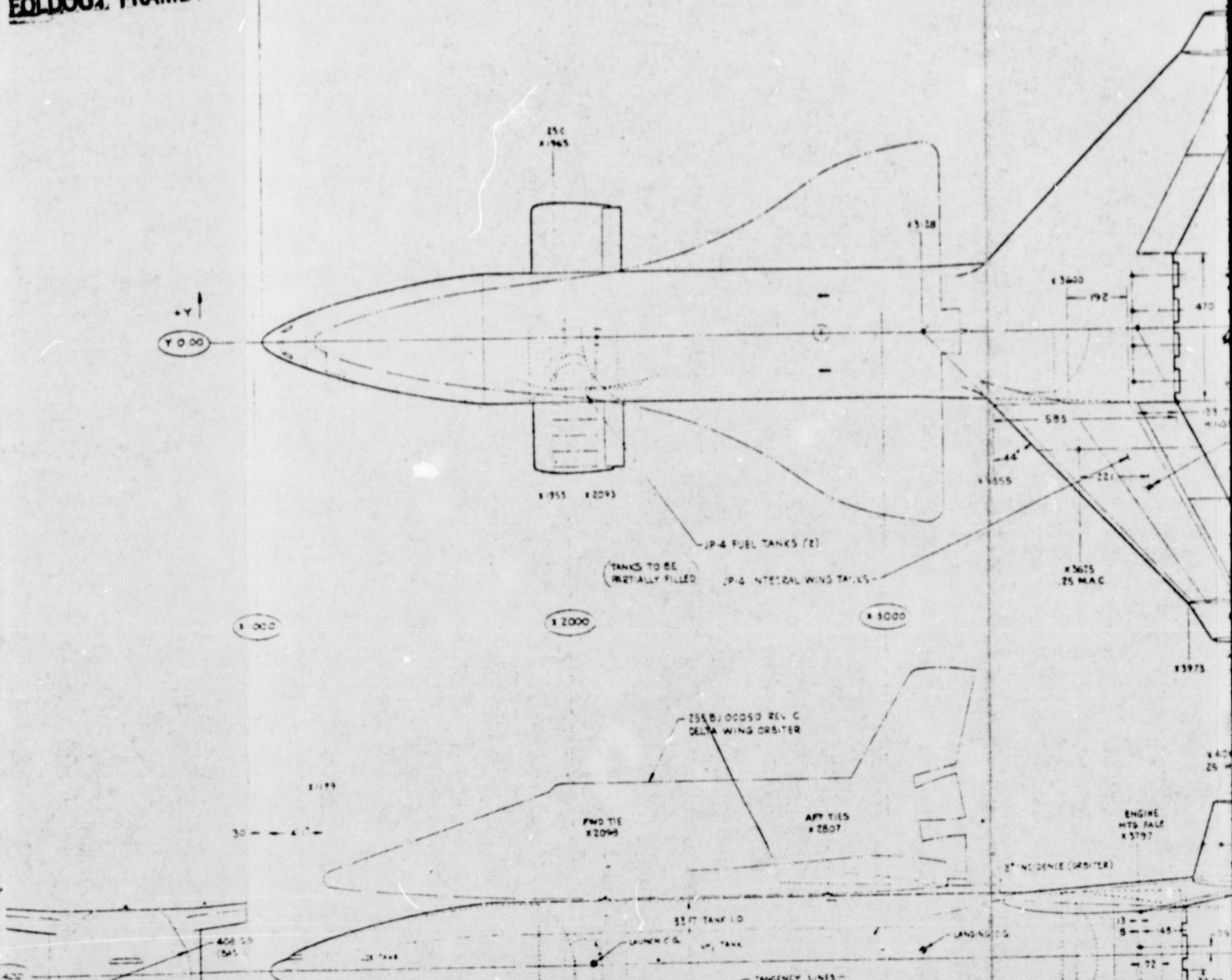


FIGURE 4-4

BOOSTER ACPS THRUSTER LOCATIONS

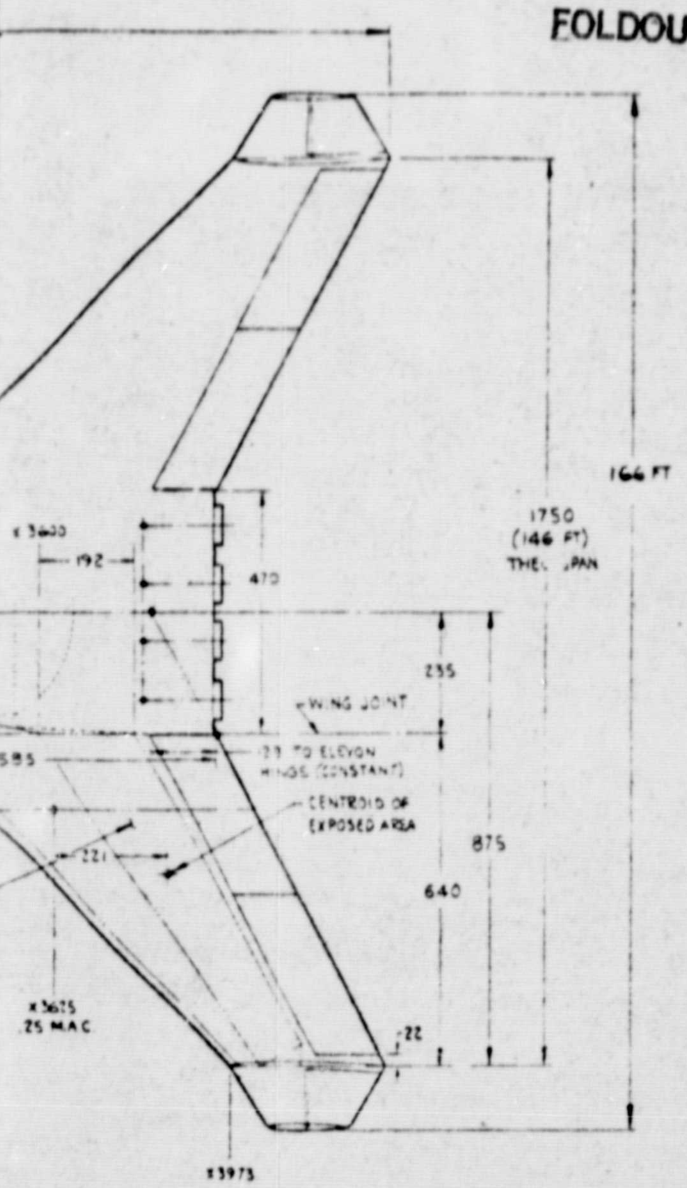


FOLDOUT FRAME 1



GENERAL ARRANGEMENT - BOO

FOLDOUT FRAME 2



GEOMETRIC DATA

WING

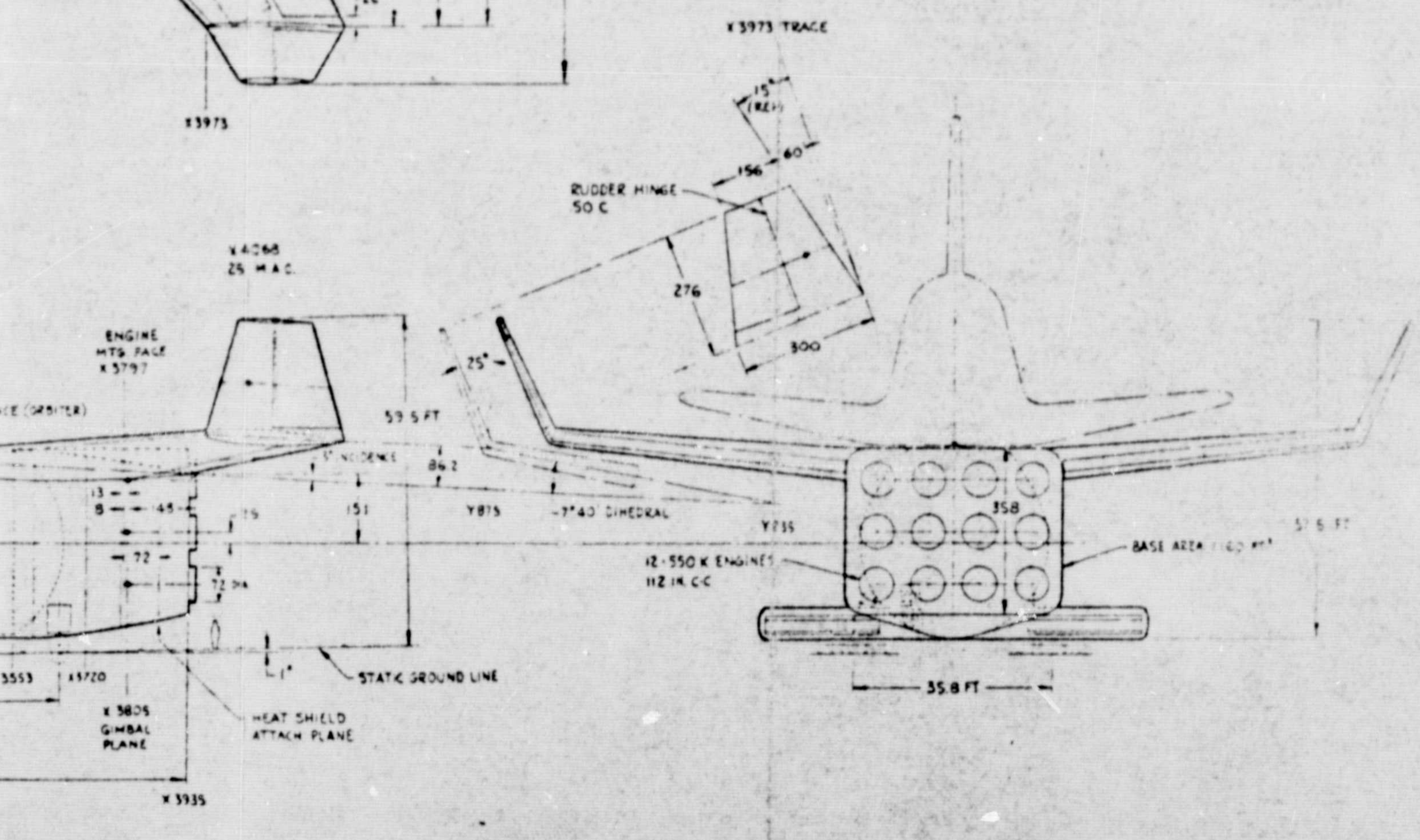
THEO. AREA	6020 FT^2
EXP. AREA (Y 204 TO Y 875)	4190 FT^2
ASPECT RATIO	3.54
TAPER RATIO	.435
CHORD AT ℄	690 IN
CHORD AT TIP (Y 875)	300 IN
M.A.C. (Y 380)	520 IN
AIRFOIL (CONSTANT)	NACA 0010.7-64

VERTICALS (VALUES FOR ONE)

AREA (TRUE)	438 FT^2
AREA (SIDE PROJECTED)	397 FT^2
ASPECT RATIO	1.21
TAPER RATIO	.520
M.A.C.	236 IN
AIRFOIL (CONSTANT)	NACA 0003-64

CANARD

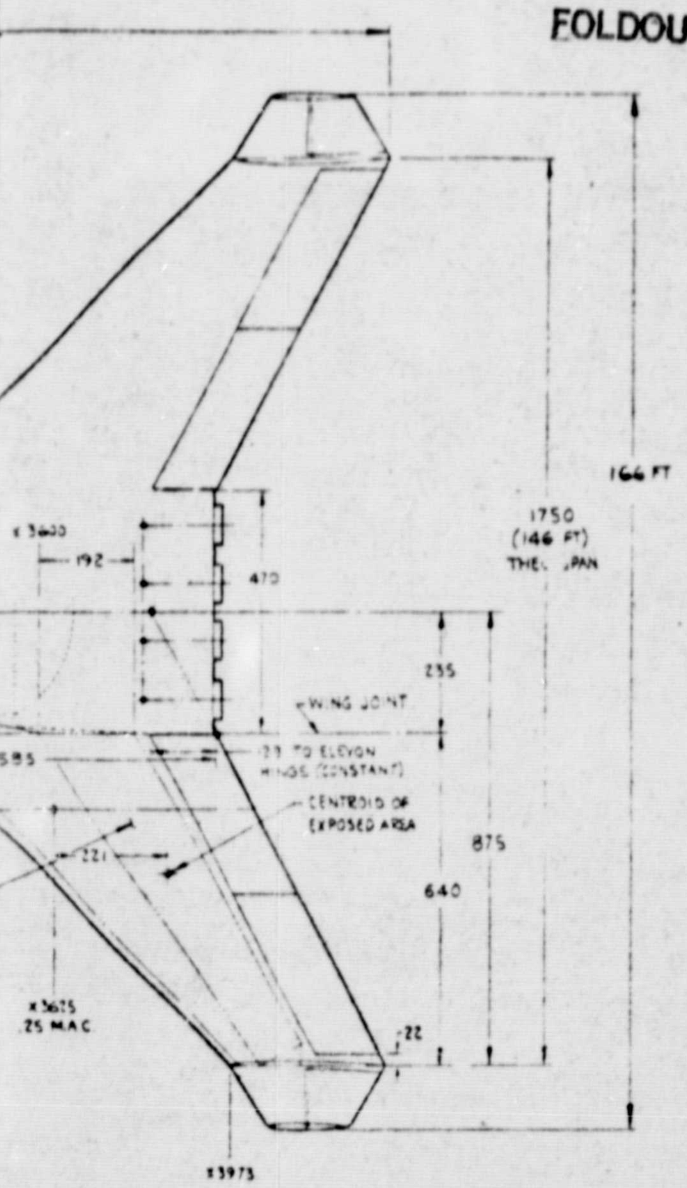
THEO. AREA	1660 FT^2
EXP. AREA	1215 FT^2
ASPECT RATIO	3.0
CHORD (INCL. FLAP)	23.625 FT
AIRFOIL (360 IN THEO. CHORD)	NACA 63-018



...NT - BOOSTER

Figure 4-5

FOLDOUT FRAME 2



GEOMETRIC DATA

WING

THEO. AREA	6020 FT^2
EXP. AREA (Y204 TO Y875)	4190 FT^2
ASPECT RATIO	3.54
TAPER RATIO	.435
CHORD AT ℄	690 IN
CHORD AT TIP (Y 875)	300 IN
M.A.C. (Y 380)	520 IN
AIRFOIL (CONSTANT)	NACA 0010.7-64

VERTICALS (VALUES FOR ONE)

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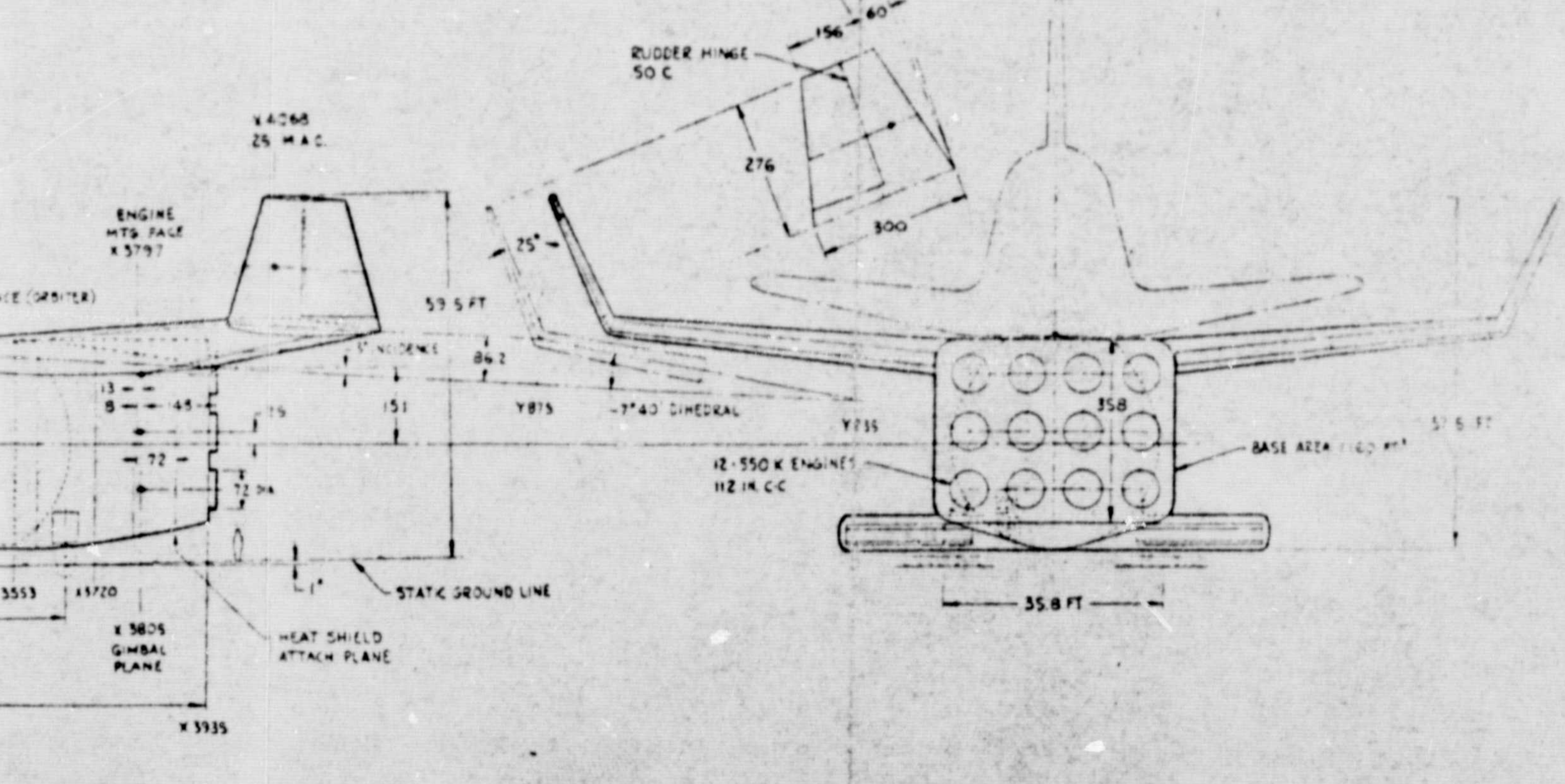
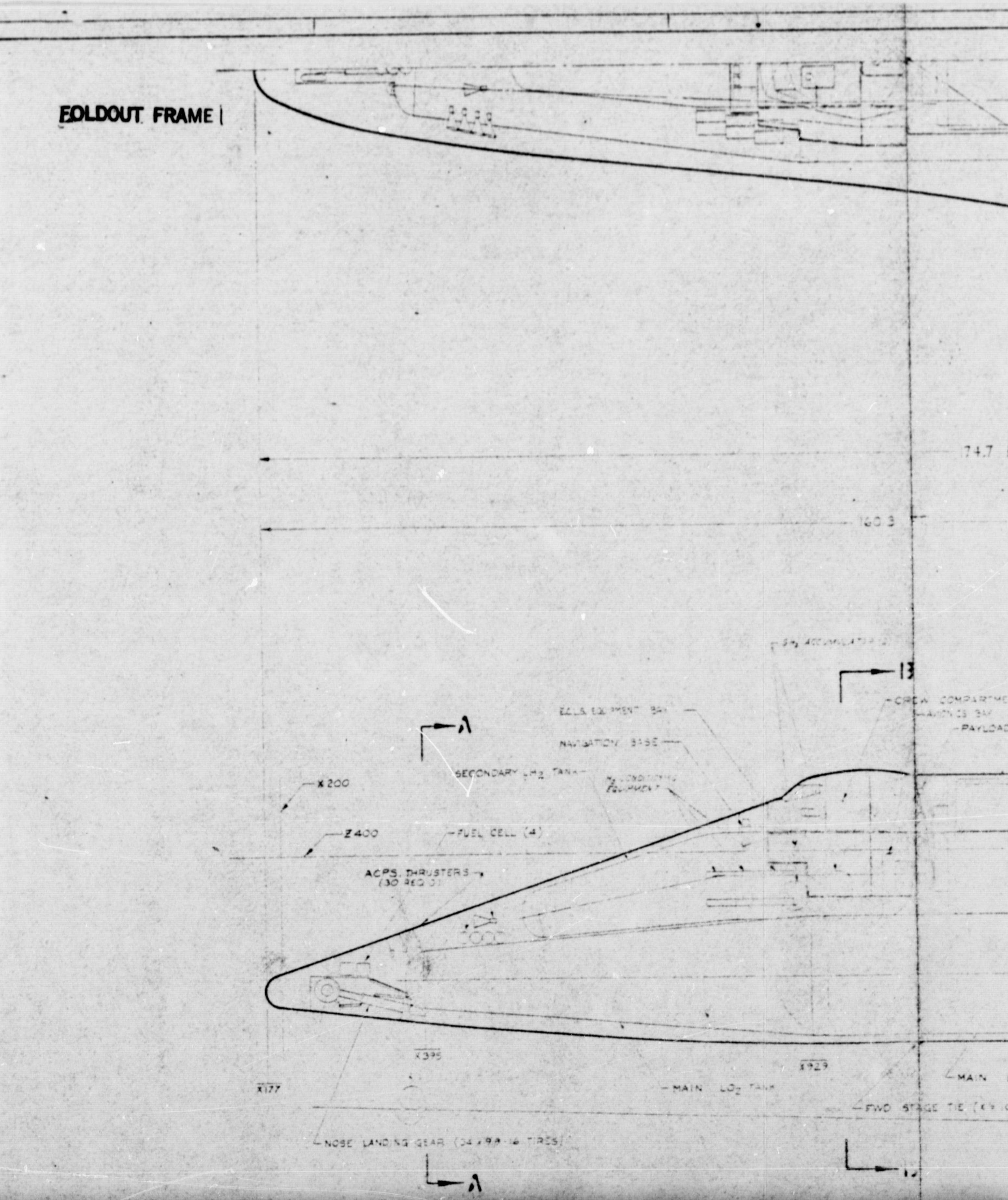
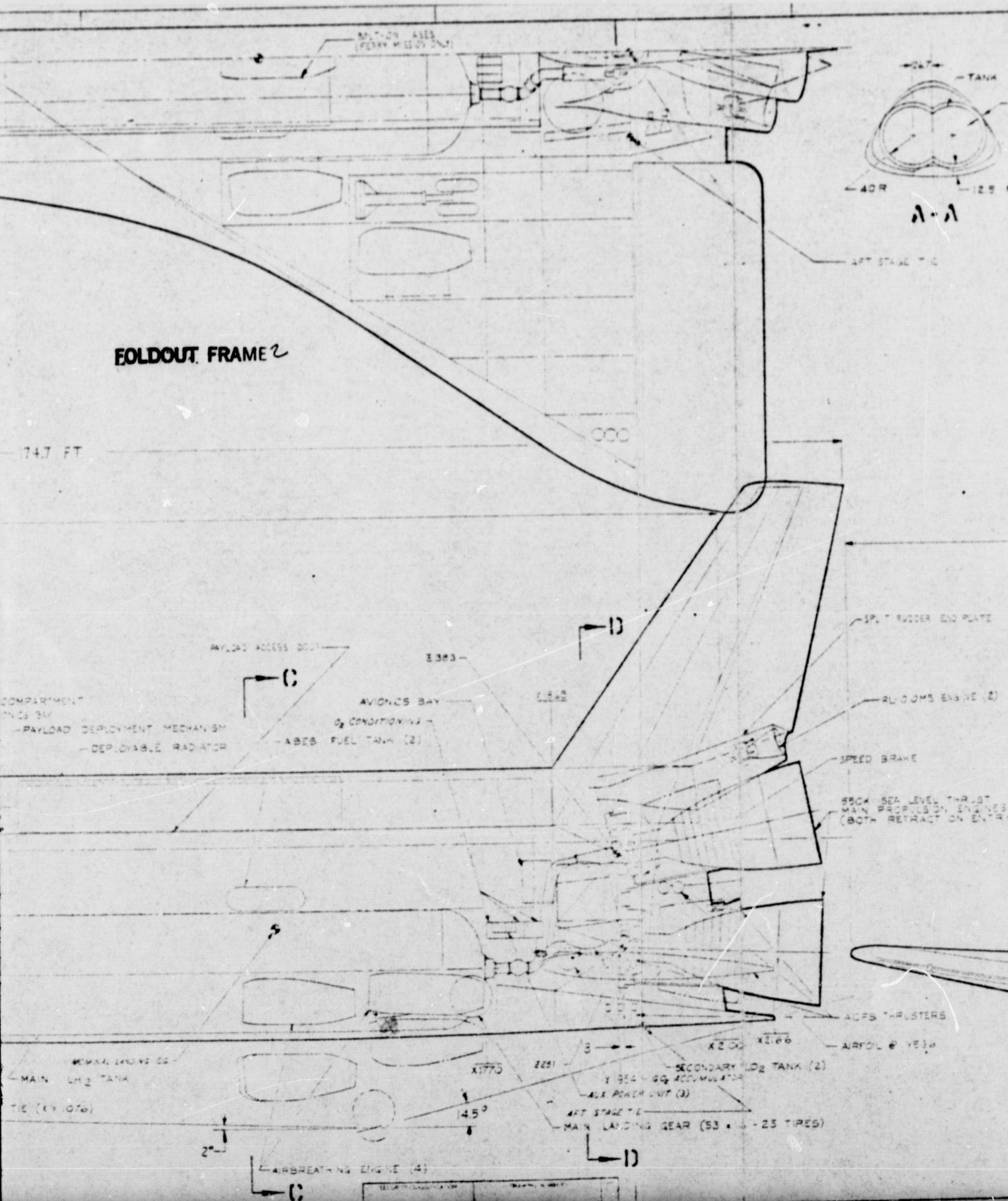


...IT- BOOSTER

Figure 4-5

FOLDOUT FRAME 1




FOLDOUT FRAME 2
A-A
TANK
40 R
AFT STAGE TIE
174.7 FT
SPLIT RUDDER END PLATE
PAYLOAD ACCESS DOOR
AVIONICS BAY
PAYLOAD DEPLOYMENT MECHANISM
DEPLOYABLE RADIATOR
ABES FUEL TANK (2)
SPEED BRAKE
ACPS THRUSTERS
MAIN LH2 TANK
SECONDARY LO2 TANK (2)
AUX POWER UNIT (3)
MAIN LANDING GEAR
14.5°
2°
AIRBREATHING ENGINE (4)
C
D

FOLDOUT FRAME 3

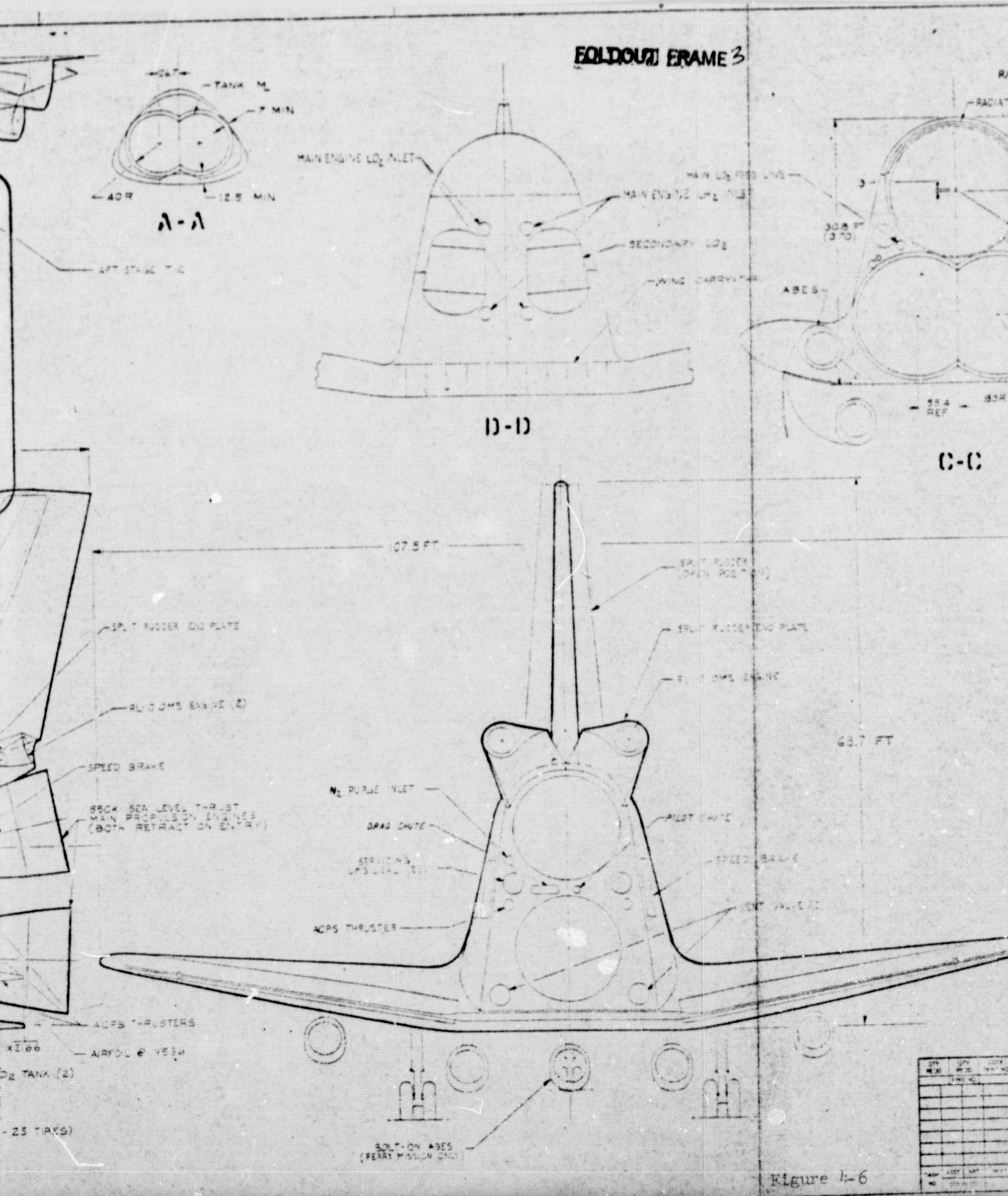


Figure 4-6

FOLDOUT FRAME 4

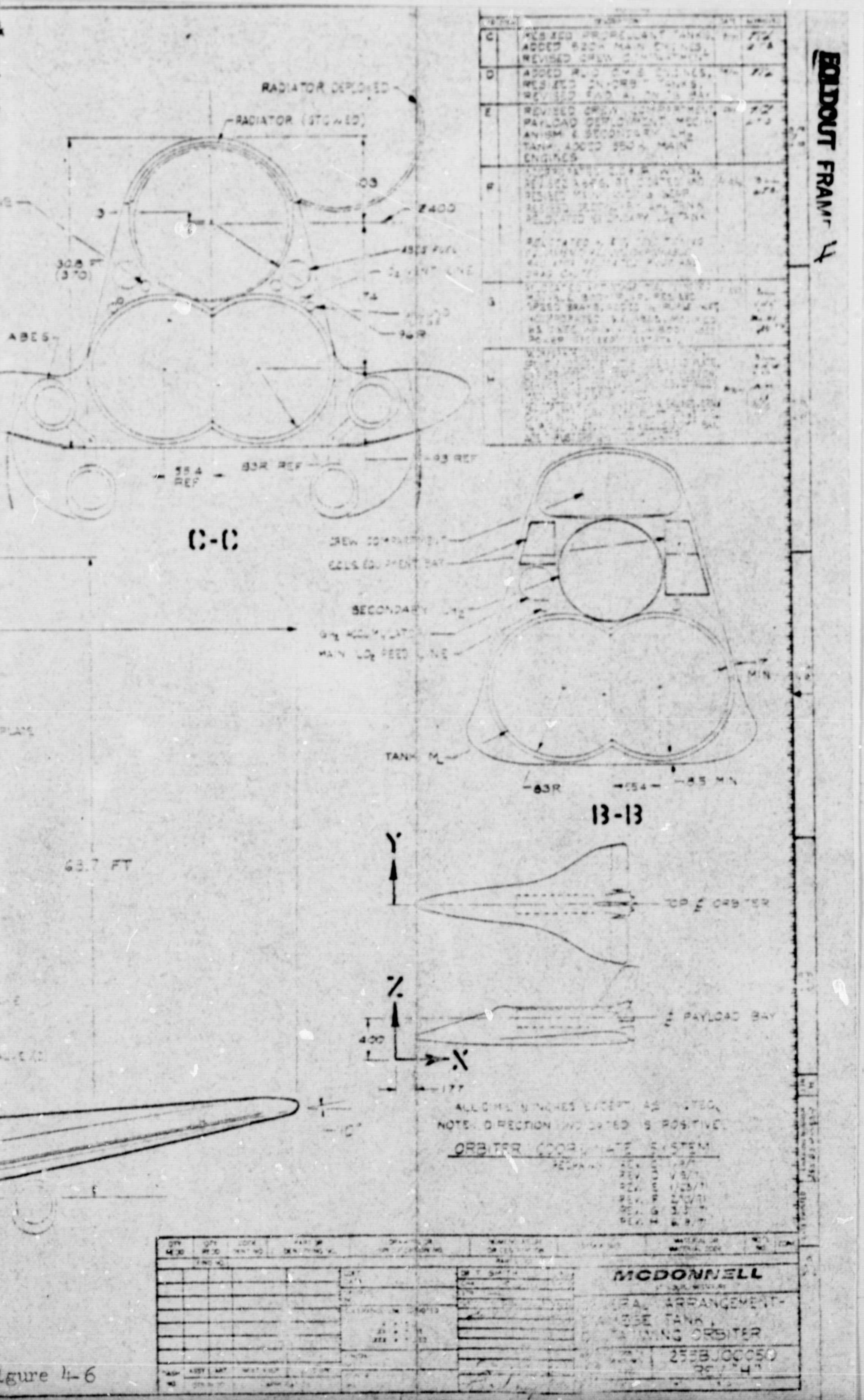


Figure 4-6