

# Launch Vehicle Systems

- Performance of current launch vehicles
  - Space Launch System
  - Atlas V
  - Falcon 9 / Falcon Heavy / Starship
- Case Study: Saturn V
  - Data is from SA-503 Saturn V Flight Manual, MSFC-MAN-503, NASA TM-X-72151, November 1968
  - Trajectory and dynamics
  - Onboard systems
  - Ground systems

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<http://spacecraft.ssl.umd.edu>

# Space Launch System



322 ft.

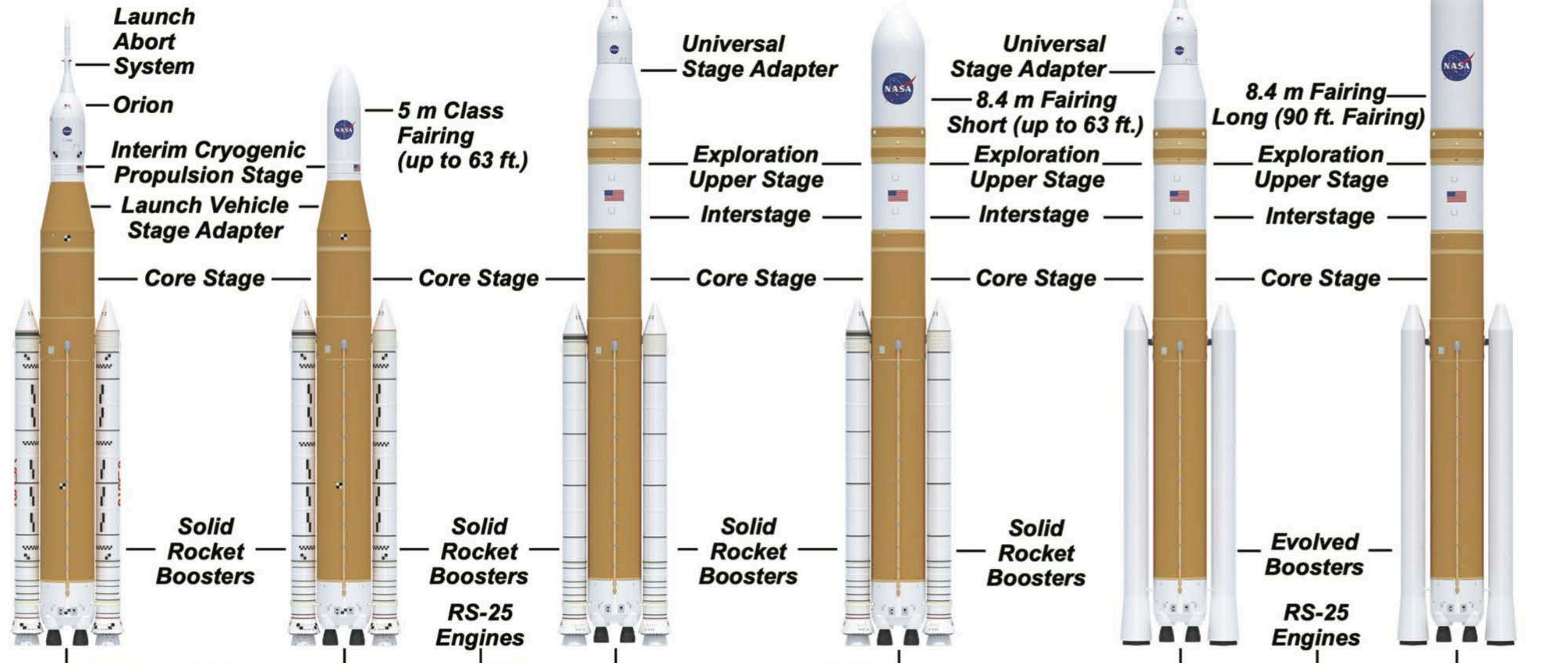
Up to 313 ft.

366 ft.

328 ft.

366 ft.

355 ft.



SLS Block 1

SLS Block 1 Cargo

SLS Block 1B Crew

SLS Block 1B Cargo

SLS Block 2 Crew

SLS Block 2 Cargo

> 27 t (59k lbs)

> 27 t (59k lbs)

38 t (84k lbs)

42 t (92k lbs)

> 43 t (94k lbs)

> 46 t (101k lbs)

Payload to TLI/Moon

# RANGE OF PAYLOAD ENCAPSULATION



Block 1B



Enclosure	5.4m PLF	5.1m PLF	8.4m USA	8.4m USA PLF	8.4m PLF, Short	8.4m PLF, Long	10m PLF
Type	5m PPL	5m PPL	8.4m CPL	8.4m PPL	8.4m PPL	8.4m PPL	10m PPL
Length	55.8 ft 17.0 m	62.7 ft 19.1 m	32.8 ft 10.0 m	47.2 ft 14.4 m	62.7 ft 19.1 m	90 ft 27.4 m	90 ft 27.4 m
Diameter	17.7 ft 5.4 m	16.7 ft 5.1 m	27.6 ft 8.4 m	27.6 ft 8.4 m	27.6 ft 8.4 m	27.6 ft 8.4 m	32.8 ft 10.0 m
Internal Diameter	15.1 ft 4.6 m	15.1 ft 4.6 m	24.6 ft 7.5 m	24.6 ft 7.5 m	24.6 ft 7.5 m	24.6 ft 7.5 m	29.9 ft 9.1 m
Available Volume	7,740 ft <sup>3</sup> 219.2 m <sup>3</sup>	9,030 ft <sup>3</sup> 255.7 m <sup>3</sup>	10,100 ft <sup>3</sup> 286.0 m <sup>3</sup>	11,260 ft <sup>3</sup> 319 m <sup>3</sup>	18,970 ft <sup>3</sup> 537 m <sup>3</sup>	31,950 ft <sup>3</sup> 905 m <sup>3</sup>	46,610 ft <sup>3</sup> 1,320 m <sup>3</sup>



Block 2



COTS: Commercial Off-the-Shelf CPL: Co-manifested Payload PPL: Primary Payload PLF: Payload Fairing

www.nasa.gov/sls

# SLS COST TO DESTINATION

B1 B1B B2



## Representative Timeline

🚀 Crew
▽ Block 1
▽ Block 1B
▽ Block 2

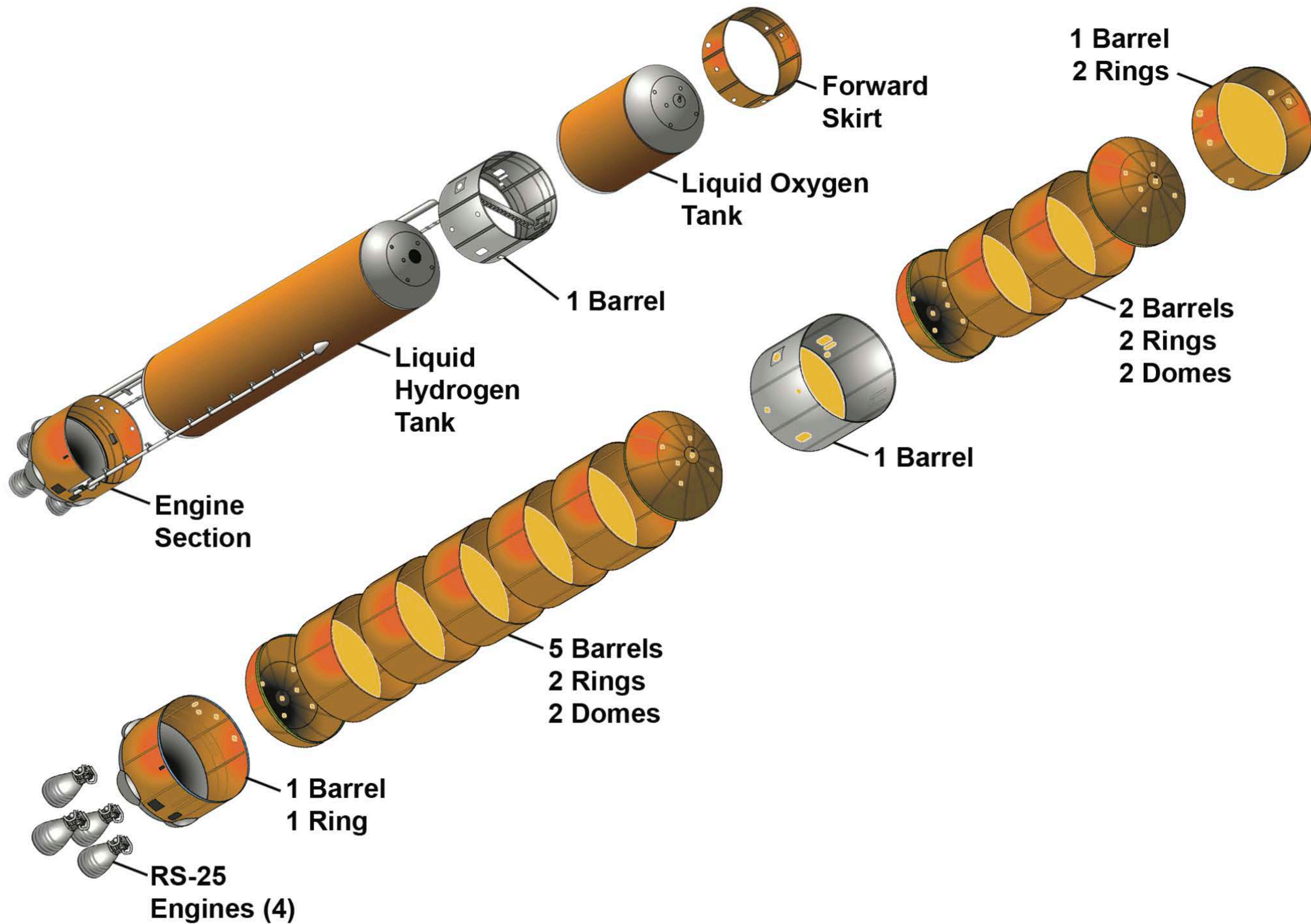
Launch Date	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SLS Opportunity	EM-1 ▽			EM-2 ▽ Europa	EM-3 ▽	EM-4 ▽	EM-5 ▽	EM-6 ▽	EM-7 ▽	EM-8 ▽	EM-9 ▽	EM-10 ▽	

- Plan to fly at least 1 crewed SLS per year**
  - System has capability to fly up to 3 SLS's per year
- Orion Co-manifested Payloads cost limited to launch vehicle integration activities**
  - More volume than Shuttle Payload Bay
  - Up to 10 mT of payload to cis-lunar space
- Multiple payload combinations possible**
  - New 8.4m class (w/COTS separation systems)
  - ELV 5m class (w/COTS separation systems)
  - ESPA ring class (w/COTS separation systems)
  - Up to 27U Cubesats (w/COTS dispenser systems)



Largest existing 5m fairing

Orion Co-manifested Payload (8.4m USA)



# SPACE LAUNCH SYSTEM



# SOLID ROCKET BOOSTERS

National Aeronautics and Space Administration



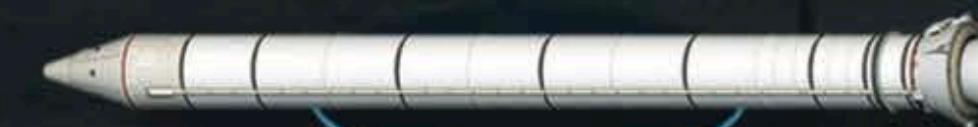
## WHAT ARE THEY AND WHAT DO THEY DO?

Two SLS Solid Rocket Boosters operate in parallel with the core stage's main engines for the first two minutes of the rocket's flight, providing the additional thrust needed for the launch vehicle to escape the gravitational pull of the Earth.

Each SLS Solid Rocket Booster has **3** assemblies:



The boosters tower **17 stories high...** Taller than the Statue of Liberty from base to torch. In fact, the NASA "worm" logo itself is **28 ft** tall.



Assembled, each booster weighs more than...

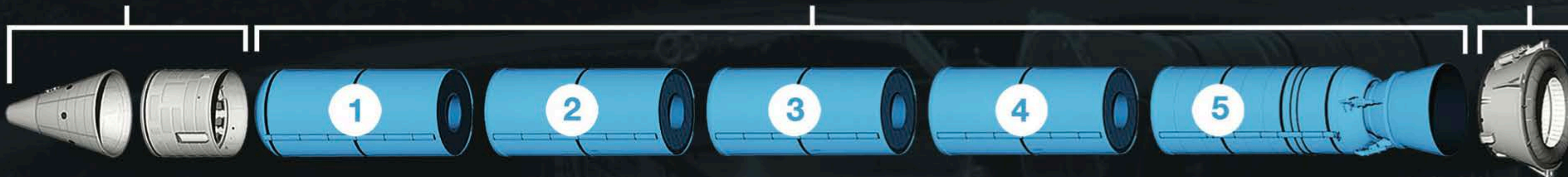


**1.6 Million pounds.**

### FORWARD ASSEMBLY

### MOTOR ASSEMBLY

### AFT ASSEMBLY



- **The forward assembly** includes the nose cap and the forward skirt. The forward skirt houses the electronics and has the critical connection point that carries most of the forces to the rocket during launch.

- **The motor assembly** has five segments filled with propellant the consistency of a pencil eraser.

- **The aft, or rear, assembly** contains the aft skirt and the thrust vector control system, which moves the nozzle to steer the vehicle.



Boosters are designed by engineers to be **FAST & POWERFUL.** **2 MINUTES OF PURE AWESOME** provides more than **75% OF TOTAL THRUST** at liftoff.



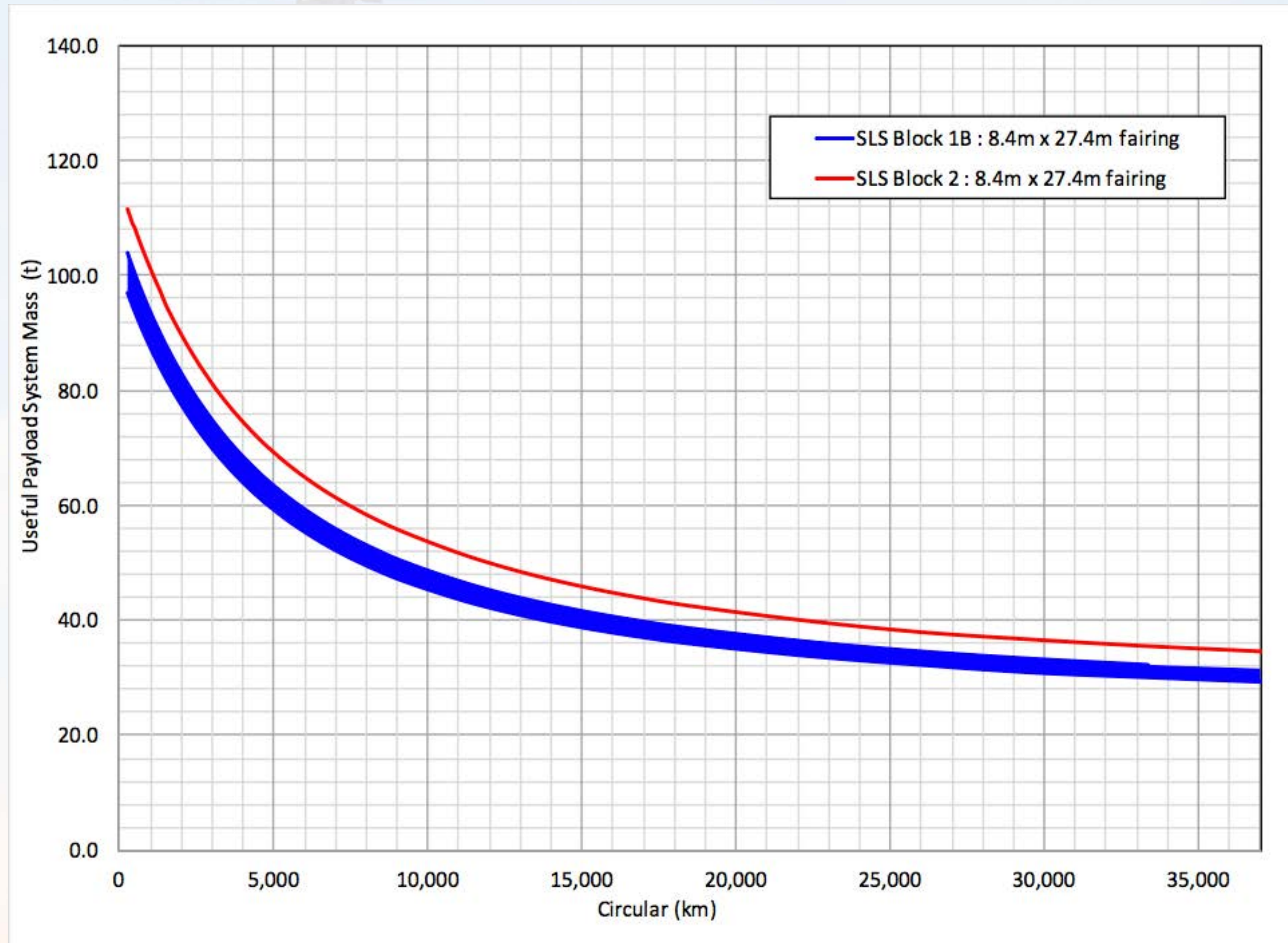
**EACH BOOSTER** burns **6 TONS** of solid propellant **EVERY SECOND** and generates a **MAX THRUST OF 3.6 MILLION POUNDS.**

# CORE STAGE MANUFACTURING

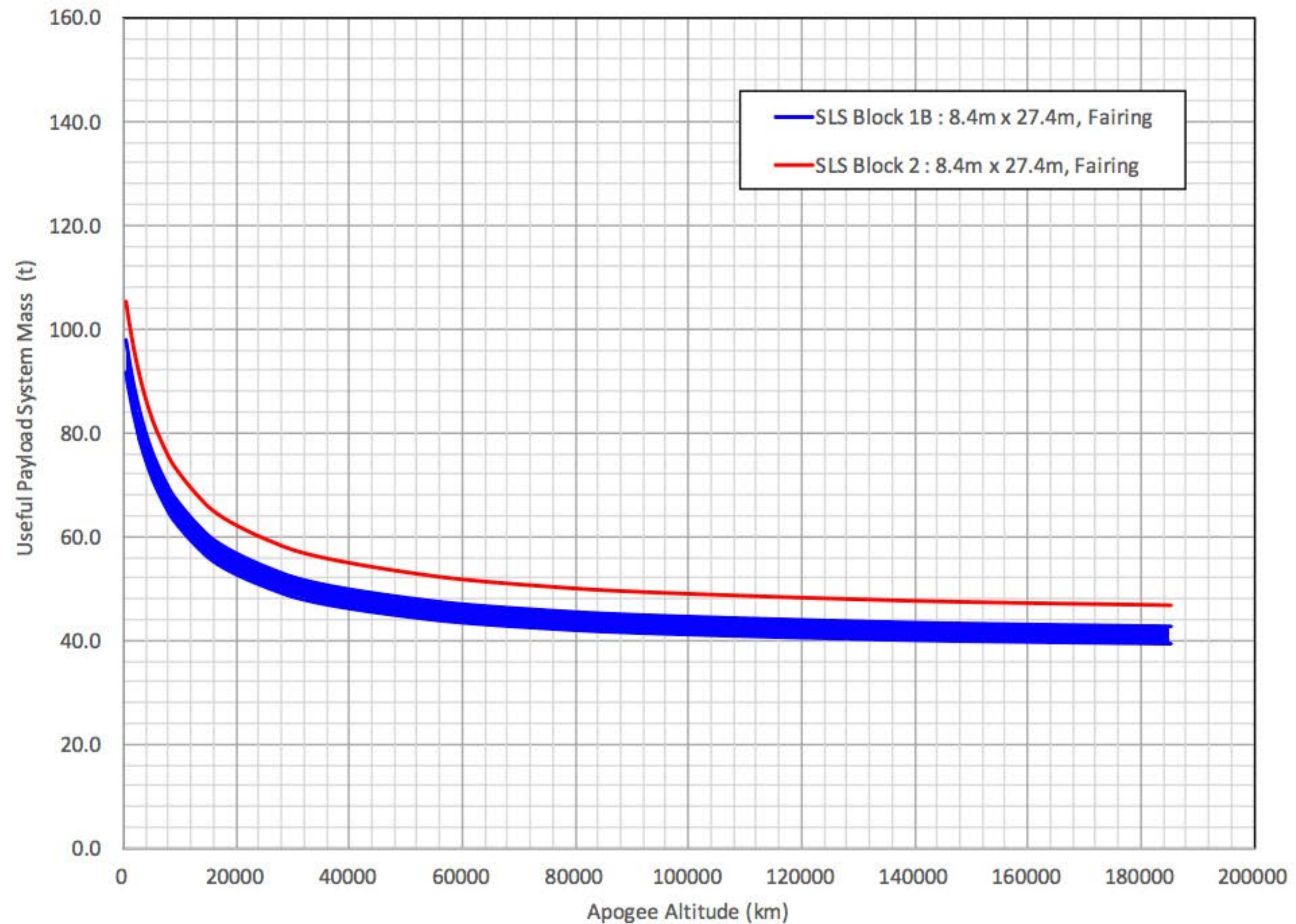




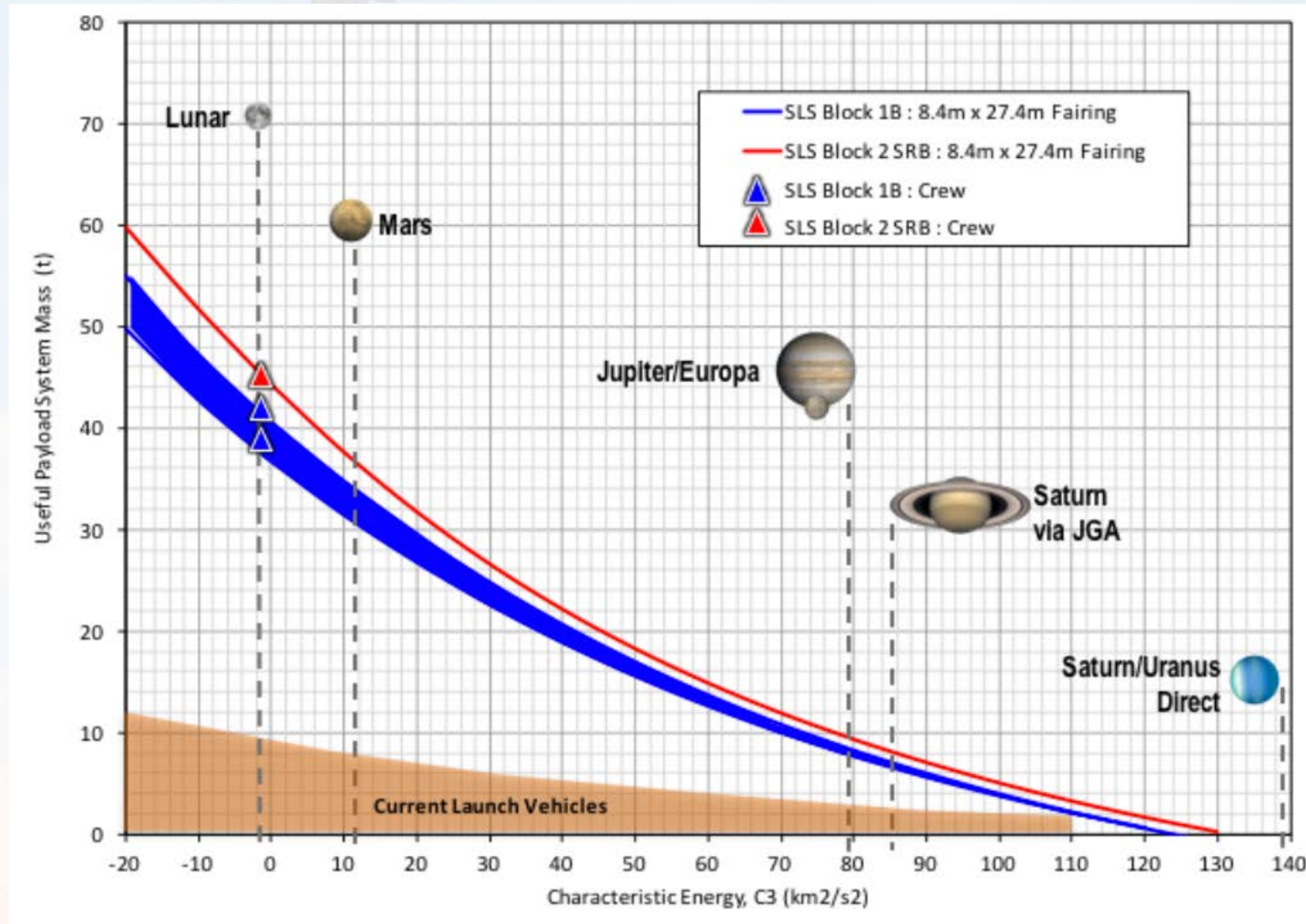
# SLS 1B/2 Circular Orbit Payload



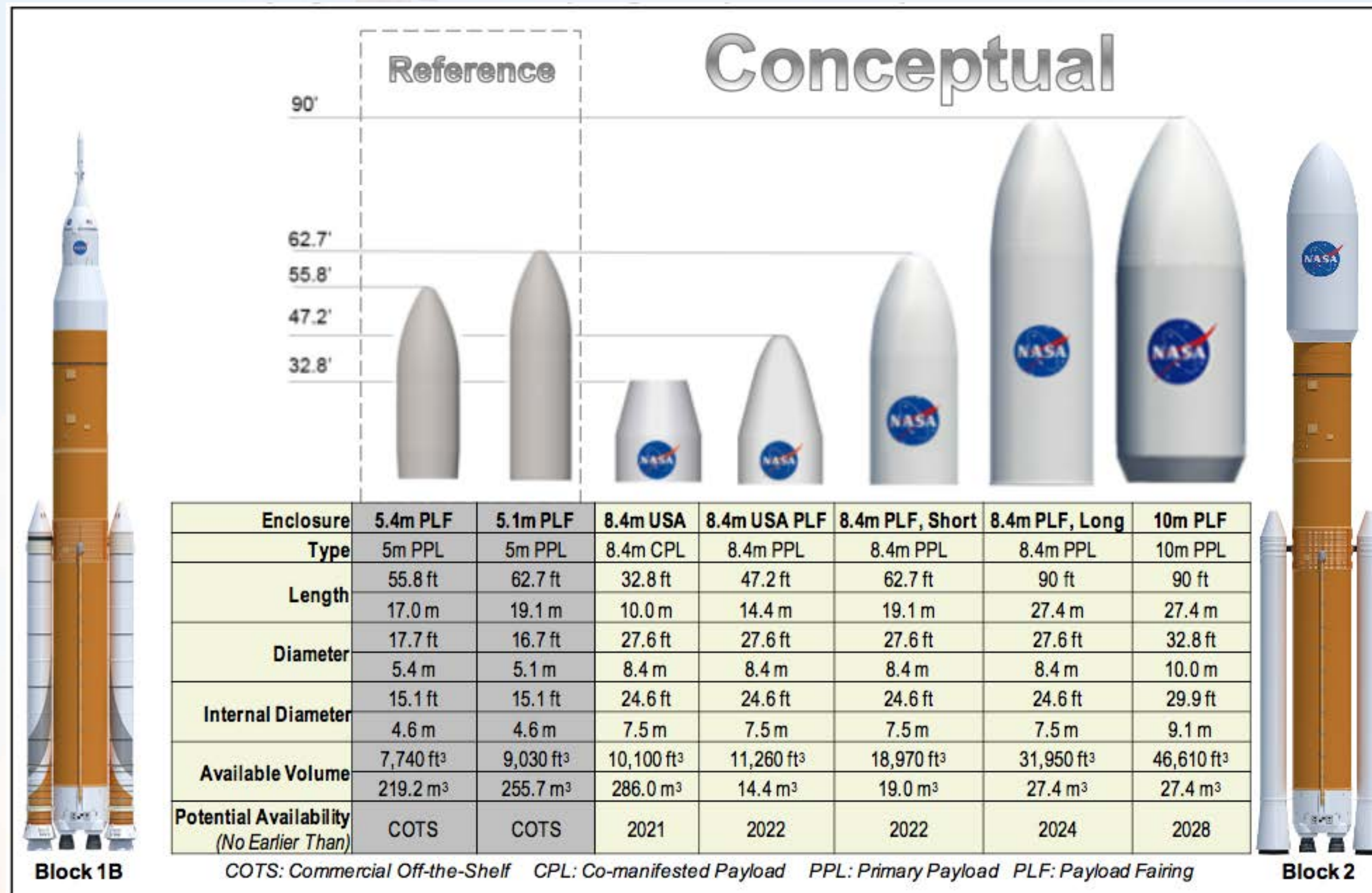
# SLS 1B/2 Elliptical Orbit Payload



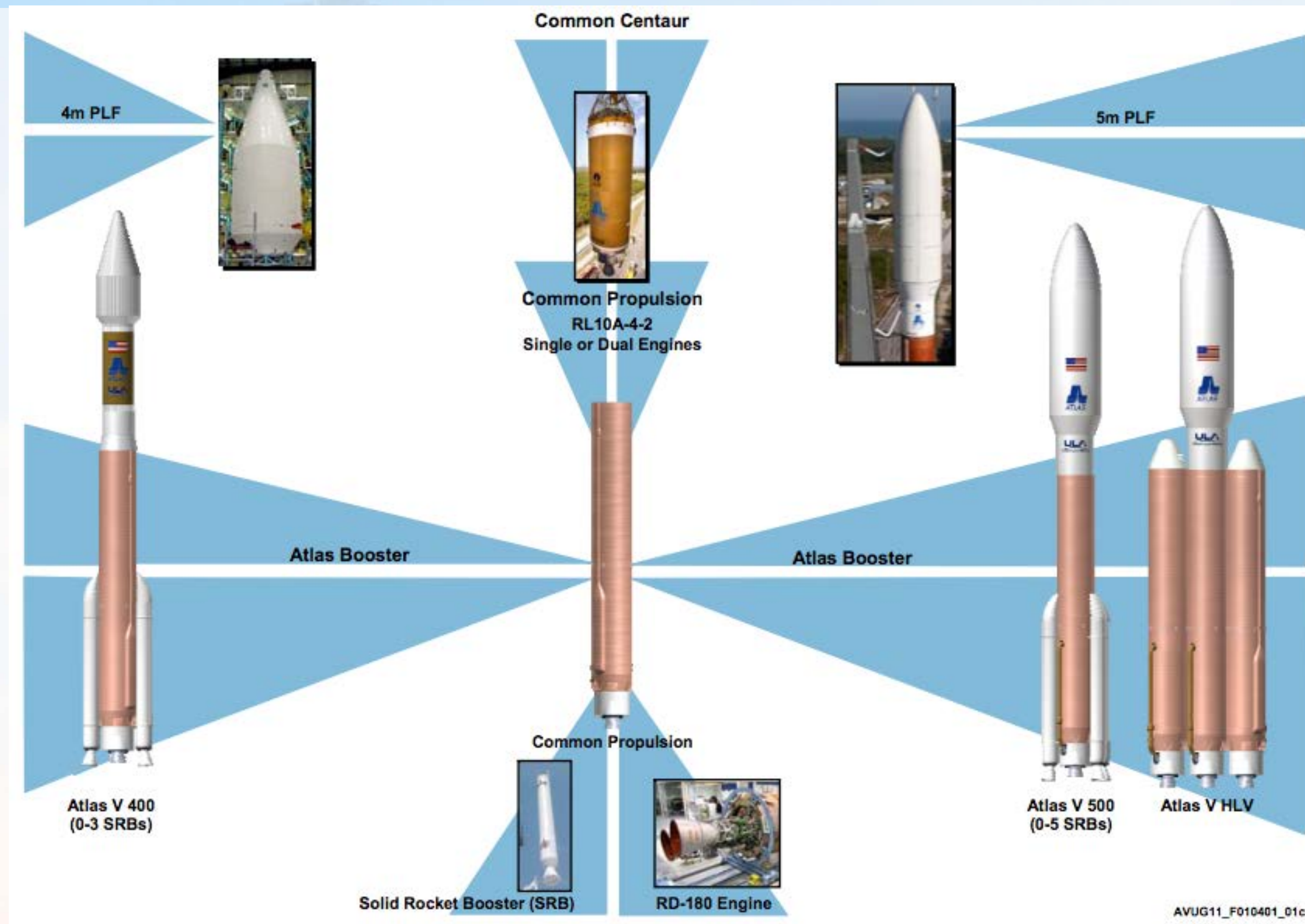
# SLS 1B/2 Planetary Injection Payload



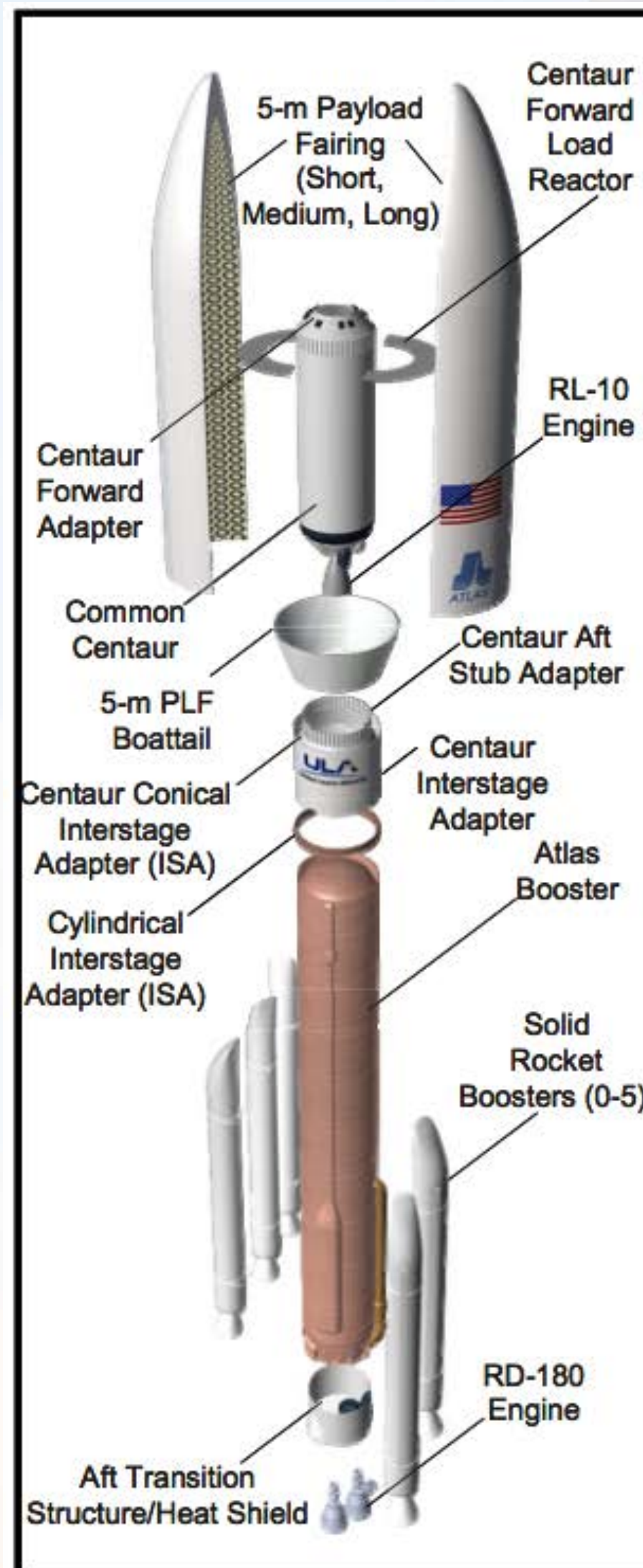
# SLS 1B/2 Payload Fairings



# Atlas V Common Vehicle Elements



# Atlas V (5m fairing) "Baseball Card"



**PAYLOAD FAIRING (PLF)**

Features	5-m Short	5-m Medium	5-m Long
Diameter:	5.4-m (213-in)	5.4-m (213-in)	5.4-m (213-in)
Length:	20.7-m (815-in)	23.4-m (921-in)	26.5-m (1043-in)
Mass:	3,524-kg (7,769-lbs)	4,003 kg (8,825 lbs)	4,379 kg (9,654 lbs)

**Subsystems**

- Fairing: Bisector; Sandwich Construction with Graphite Epoxy Face Sheets & an Aluminum Honeycomb Core
- Boattail: Fixed, Composite Sandwich Const
- Separation: Vertical Separation by a Linear Piston & Cylinder Activated by a Pyrotechnic Cord; Horizontal Separation by an Expanding Tube Shearing a Notched Frame, Activated by a Pyrotechnic Cord

**COMMON CENTAUR**

**Features**

- Size: 3.05-m (120-in) Dia x 12.68-m (499-in) Length with Extended Nozzle
- Inert Mass: 5X1: 2,247 kg (4,954 lbs); 5X2: 2,462 kg (5,429 lbs)
- CFLR: 275 kg (607 lbs)
- Propellant: 20,830-kg (45,922-lbs) LH2 & LO2
- Guidance: Inertial

**Subsystems**

- Structure: Pressure Stabilized Stainless Steel Tanks Separated by Common Ellipsoidal Bulkhead
- Propulsion:
  - Model: RL 10A-4-2
  - Thrust: 99.2 kN (22,300 lbf) (SEC); 198.4 kN (44,600 lbf) (DEC)
  - ISP: 450.5 s
- (SEC) One Electromechanically Actuated 51-cm Columbiu Fixed Nozzle; Four 27-N Hydrazine Thrusters; Eight 40.5-N Lateral Hydrazine Thrusters
- (DEC) Two Hydraulically Actuated 51-cm Columbiu Extendible Nozzles; Eight 40-N Lateral Hydrazine Thrusters; Four 27-N Hydrazine Thrusters
- Pneumatics: Common with Atlas V 400/500 Series
- Avionics: Common with Atlas V 400/500 Series
- Insulation: Foam with Optional Radiation Shields

**SOLID ROCKET BOOSTERS (SRB)**

Zero-to-Three Ground-Lit

Size: 158-cm (62.2-in) Dia. x 20-m (787-in) Length

Mass: 46,697 kg (102,949 lbs) (Including SRB Attach Kit, SRB Nose Fairing & Instrumentation)

Thrust: 1688.4 kN (379,550 lbf) (Each)

Vac ISP: 279.3 s

Nozzle Cant: 3°

**500 SERIES CENTAUR INTERSTAGE ADAPTER (C-ISA)**

**Features**

- Size: 3.83-m (151-in) Dia x 3.81-m (150-in) Length
- Mass: 5X1: 2,212 kg (4,876.6 lbs); 5X2: 2,227 kg (4,909.7 lbs) (Includes ISA, Aft Stub Adapter & Boattail)

**Subsystems**

- Structure: Composite Sandwich (Aluminum Core/Graphite Epoxy Face Sheets)

**ATLAS BOOSTER CYLINDRICAL INTERSTAGE ADAPTER**

**Features**

- Size: 3.83-m (151-in) Dia x 0.32-m (12.6-in) Length
- Mass: 285 kg (628 lbs)

**Subsystems**

- Structure: Aluminum Machined Rolled-Ring Forging

**ATLAS BOOSTER**

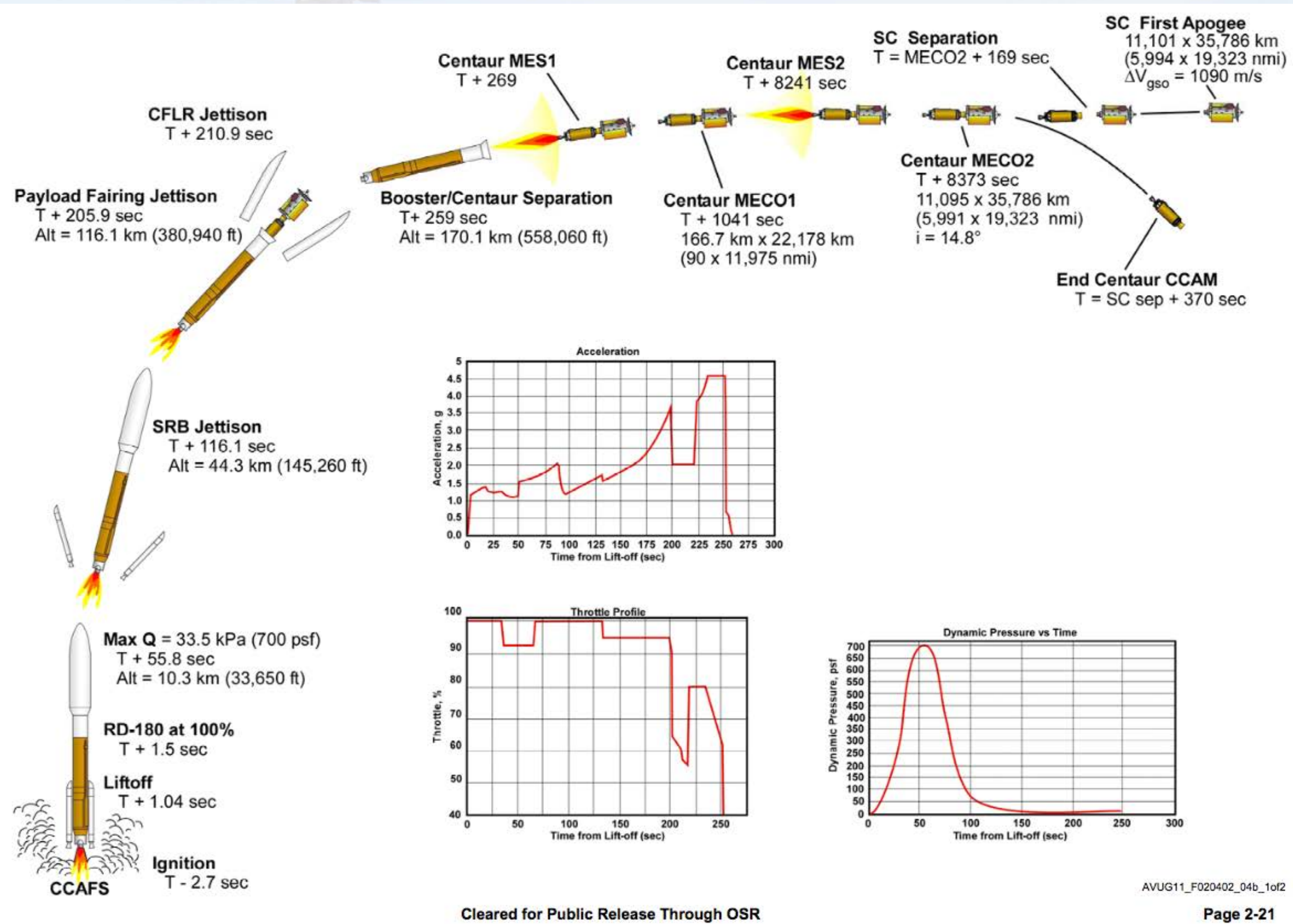
**Features**

- Size: 3.81-m (150-in) Dia x 32.46-m (1278-in) Length
- Propellant: 284,089-kg (626,309 lbs) LO2 & RP-1
- Inert Mass: 21,351 kg (47,071 lbs)
- Guidance: From Upper Stage

**Subsystems**

- Structure: Structurally Stable Aluminum Isogrid Tanks; Integrally Machined Aft Transition Structure; Composite Heat Shield
- Separation: 8 Retro Rockets
- Propulsion: Pratt & Whitney/NPO Energomash RD-180 Booster Engine (2 Chambers); SL 100% Thrust = 3,827 kN (860,309 lbf), ISP = 311.3 s; Vac 100% Thrust = 4,152 kN (933,369 lbf) ISP = 337.8 s
- Pneumatics: Helium for Tank Pressurization, Computer-Controlled Pressurization System
- Hydraulics: Fluid —Integral with Engine Provides Gimbal Control
- Avionics: Flight Control, Flight Termination, Telemetry, Redundant Rate Gyros, Electrical Power

# Atlas V 521 Ascent Profile



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Cleared for Public Release Through OSR

Page 2-21

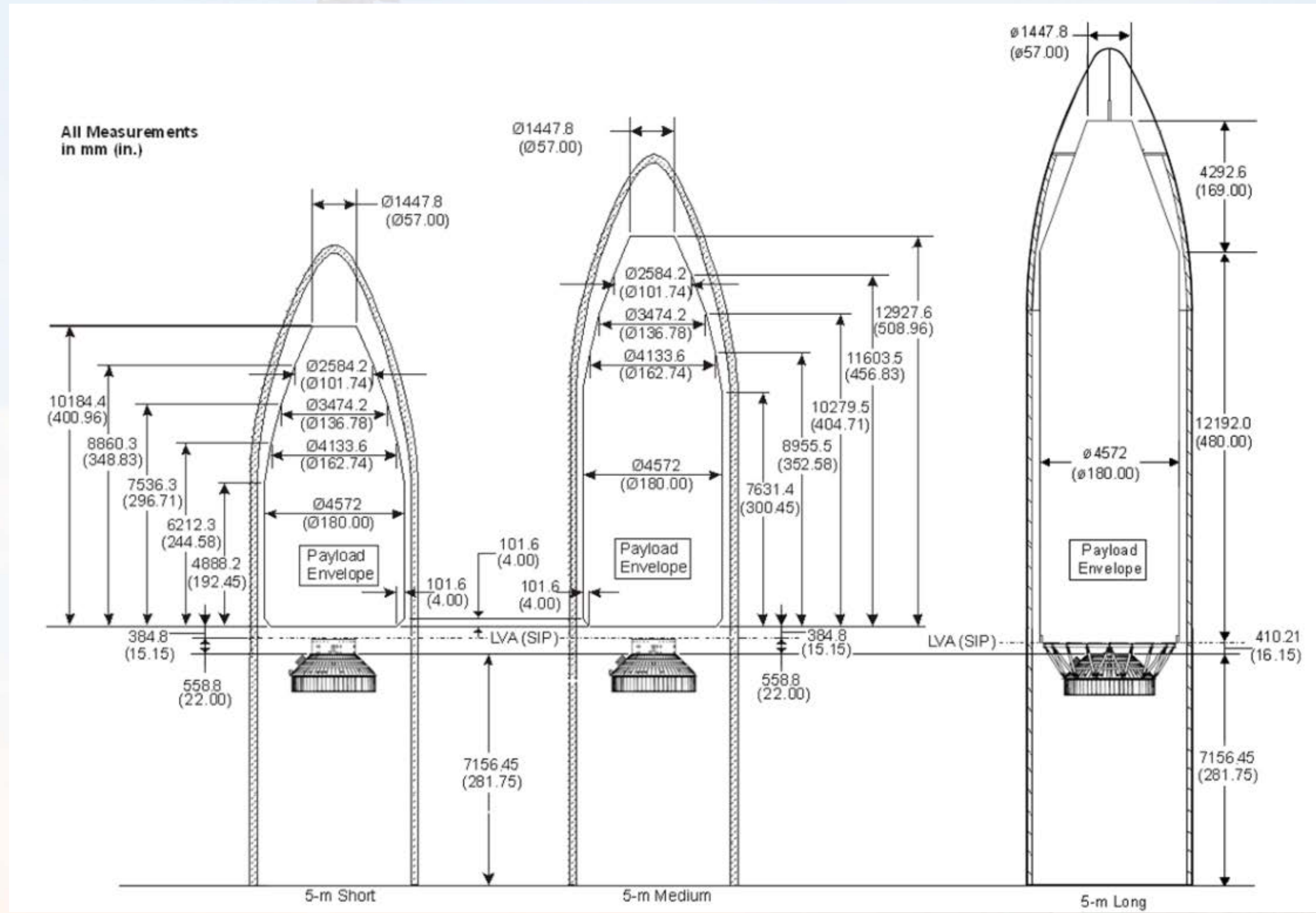
# Atlas V Performance Summary

Orbit Type ( $\Delta V$ to GSO)	400 Series				500 Series					HLV	
	Number of Solid Rocket Boosters										N/A
	0	1	2	3	0	1	2	3	4	5	
	Payload Systems Weight (PSW), kg (lb)										
GTO (1804 m/s)	4,750 (10,470)	5,950 (13,110)	6,890 (15,180)	7,700 (16,970)	3,775 (8,320)	5,250 (11,570)	6,475 (14,270)	7,475 (16,470)	8,290 (18,270)	8,900 (19,620)	13,000 (28,660)
GTO (1500 m/s)	3,460 (7,620)	4,450 (9,810)	5,210 (11,480)	5,860 (12,910)	2,690 (5,930)	3,900 (8,590)	4,880 (10,750)	5,690 (12,540)	6,280 (13,840)	6,860 (15,120)	--
GSO	--	--	--	--	--	--	2,632 (5,802)	3,192 (7,037)	3,630 (8,003)	3,904 (8,608)	6,454 (14,229)
LEO $i=28.5$ deg	9,797* (21,598)	12,150* (26,787)	14,067* (31,012)	15,718* (34,653)	8,123 (17,908)	10,986 (24,221)	13,490 (29,741)	15,575 (34,337)	17,443 (38,456)	18,814 (41,478)	29,400* (64,816)*
LEO Sun-sync	7,724 (17,028)	8,905 (19,633)	10,290 * (22,687)	11,704 * (25,803)	6,424 (14,163)	8,719 (19,223)	10,758 (23,717)	12,473 (27,498)	14,019 (30,908)	15,179 (33,464)	--
<b>Atlas V 400 Series</b>					<b>Atlas V 500 Series and HLV</b>						
<ul style="list-style-type: none"> <li>All Performance is SEC</li> <li>Quoted Performance is with 4-m EPF</li> </ul>					<ul style="list-style-type: none"> <li>All Performance is SEC</li> <li>Quoted Performance is with 5-m Short PLF</li> <li>HLV LEO Performance is DEC</li> <li>HLV Quoted Performance is with 5-m Long PLF</li> </ul>						
* For 400 series, PSW above 9,072 kg (20,000 lb) may require mission-unique accommodations. For 500 series and HLV, PSW above 19,051 kg (42,000 lb) may require mission-unique accommodations.											





# Atlas V 5m Payload Fairing Envelopes



# Falcon 9/Heavy Configurations

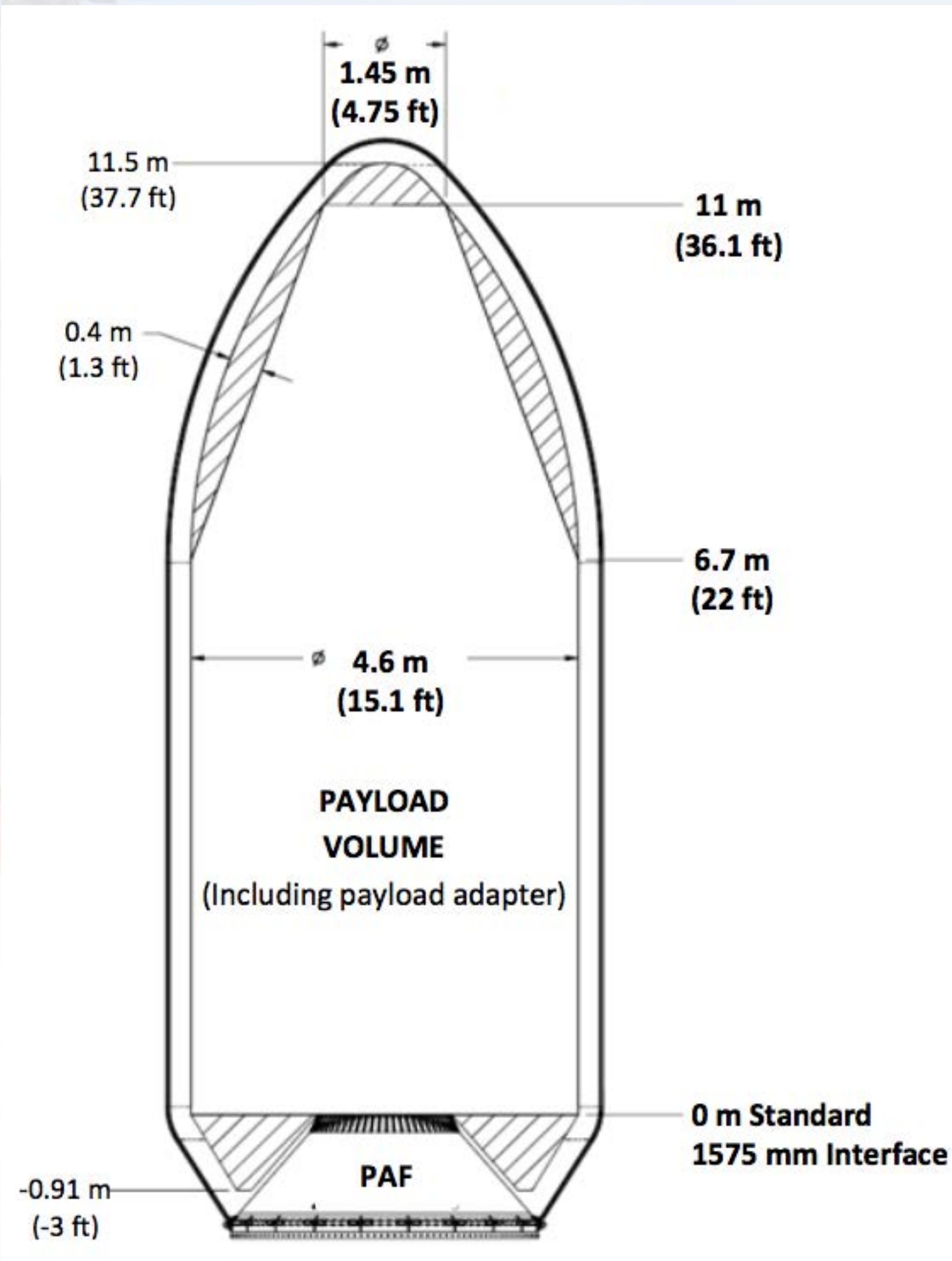
Falcon 9  
5.2 m (17 ft) fairing



Falcon Heavy  
5.2 m (17 ft) fairing



# Falcon 9 Payload Fairing



# Falcon 9/FH Performance

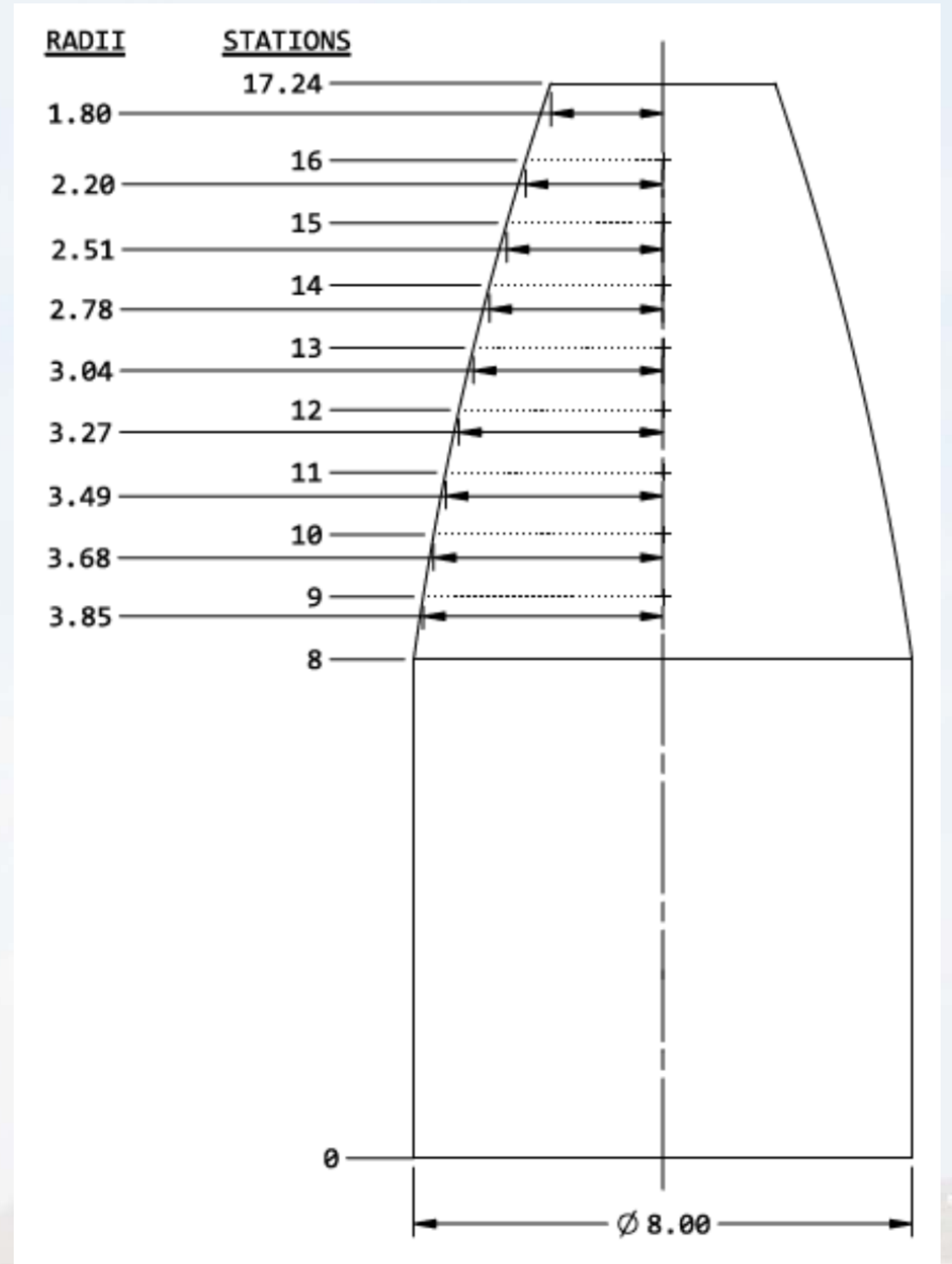
## TECHNICAL OVERVIEW

<u>HEIGHT</u>	<u>MASS</u>	<u>PAYLOAD TO LEO</u>	<u>PAYLOAD TO MARS</u>
70 m 229.6 ft	549,054 kg 1,207,920 lb	22,800 kg 50,265 lb	4,020 kg 8,860 lb
<u>DIAMETER</u>	<u>STAGES</u>	<u>PAYLOAD TO GTO</u>	
3.7 m 12 ft	2	8,300 kg 18,300 lb	

## TECHNICAL OVERVIEW

<u>HEIGHT</u>	<u>STAGES</u>	<u>BOOSTERS</u>	<u>PAYLOAD TO LEO</u>	<u>PAYLOAD TO MARS</u>
70 m 229.6 ft	2	2	63,800 kg 140,660 lb	16,800 kg 37,040 lb
<u>TOTAL WIDTH</u>	<u>MASS</u>	<u>PAYLOAD TO GTO</u>	<u>PAYLOAD TO PLUTO</u>	
12.2 m 39.9 ft	1,420,788 kg 3,125,735 lb	26,700 kg 58,860 lb	3,500 kg 7,720 lb	

# Starship Payload Accommodations



# Starship Payload Capabilities (2022)

<b>Orbit</b>	<b>Mass-to-Orbit Single Launch</b>	<b>Mass-to-Orbit Prop Transfer (t)</b>
<b>LEO<sup>1</sup></b>	100+	100+
<b>GTO<sup>2</sup></b>	21	100+
<b>Lunar Surface</b>	N/A	100+
<b>Mars Surface</b>	N/A	100+

<sup>1</sup>Up to 500-km circular orbit at up to 98.9-deg inclination

<sup>2</sup>Assumes 185 x 35,786 km orbit at 27-deg inclination with 1800 m/s  $\Delta V$  to go



# Starship Payload Capabilities (2024)

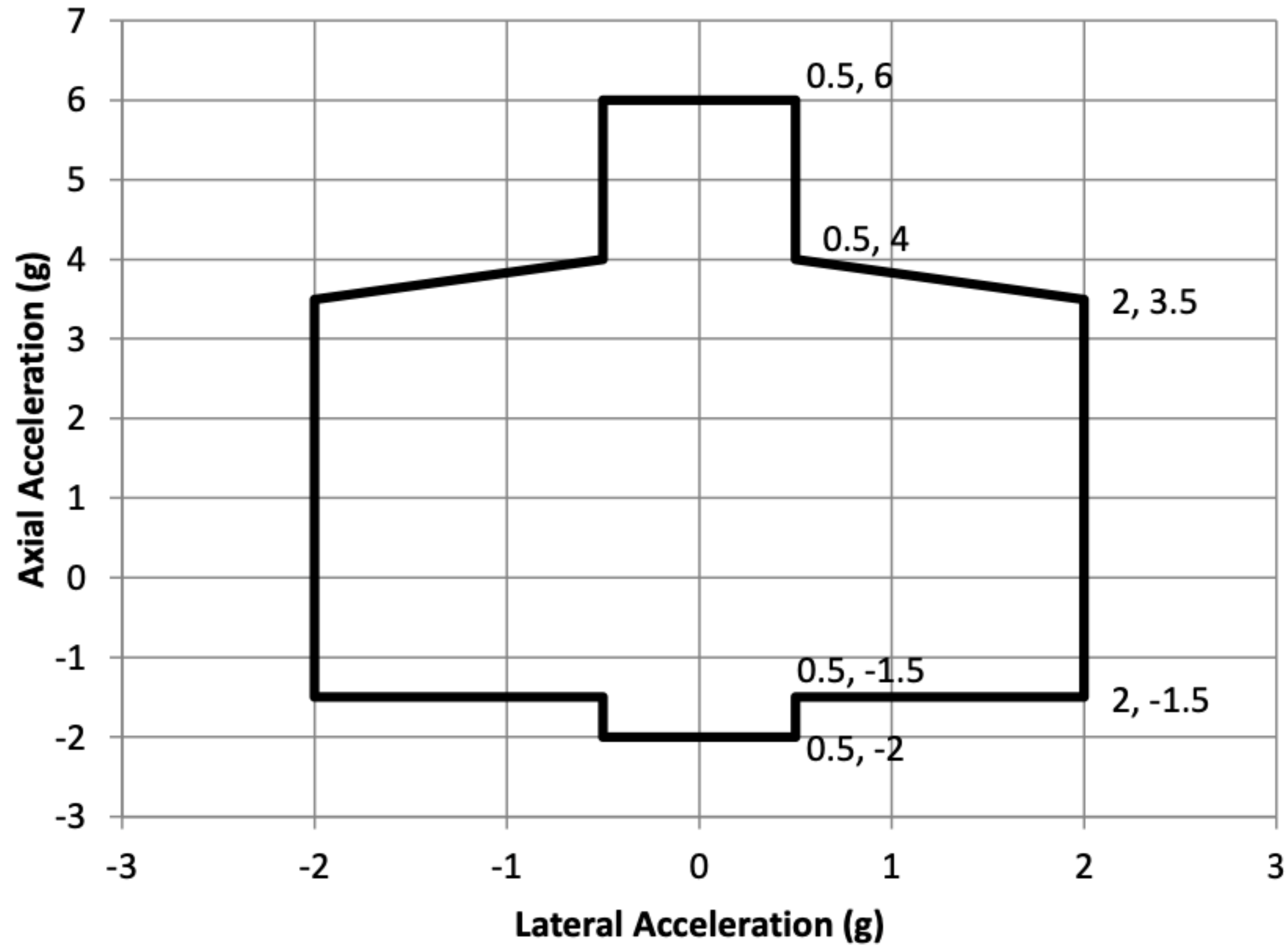
## PERFORMANCE

FULLY REUSABLE

	FLIGHT 3	STARSHIP 2	STARSHIP 3
PAYLOAD TO ORBIT (t)	N/A	100+	200+
BOOSTER PROP LOAD (t)	3300	3650	4050
SHIP PROP LOAD (t)	1200	1500	2300
BOOSTER LIFTOFF THRUST (tf)	7130	8240	10000
SHIP INITIAL THRUST (tf)	1250	1600	2700
SHIP SL ENGINES	3	3	3
SHIP VAC ENGINES	3	3	6
BOOSTER HEIGHT (m)	71	72.3	80.2
SHIP HEIGHT (m)	50.3	52.1	69.8
TOTAL HEIGHT (m)	121.3	124.4	150

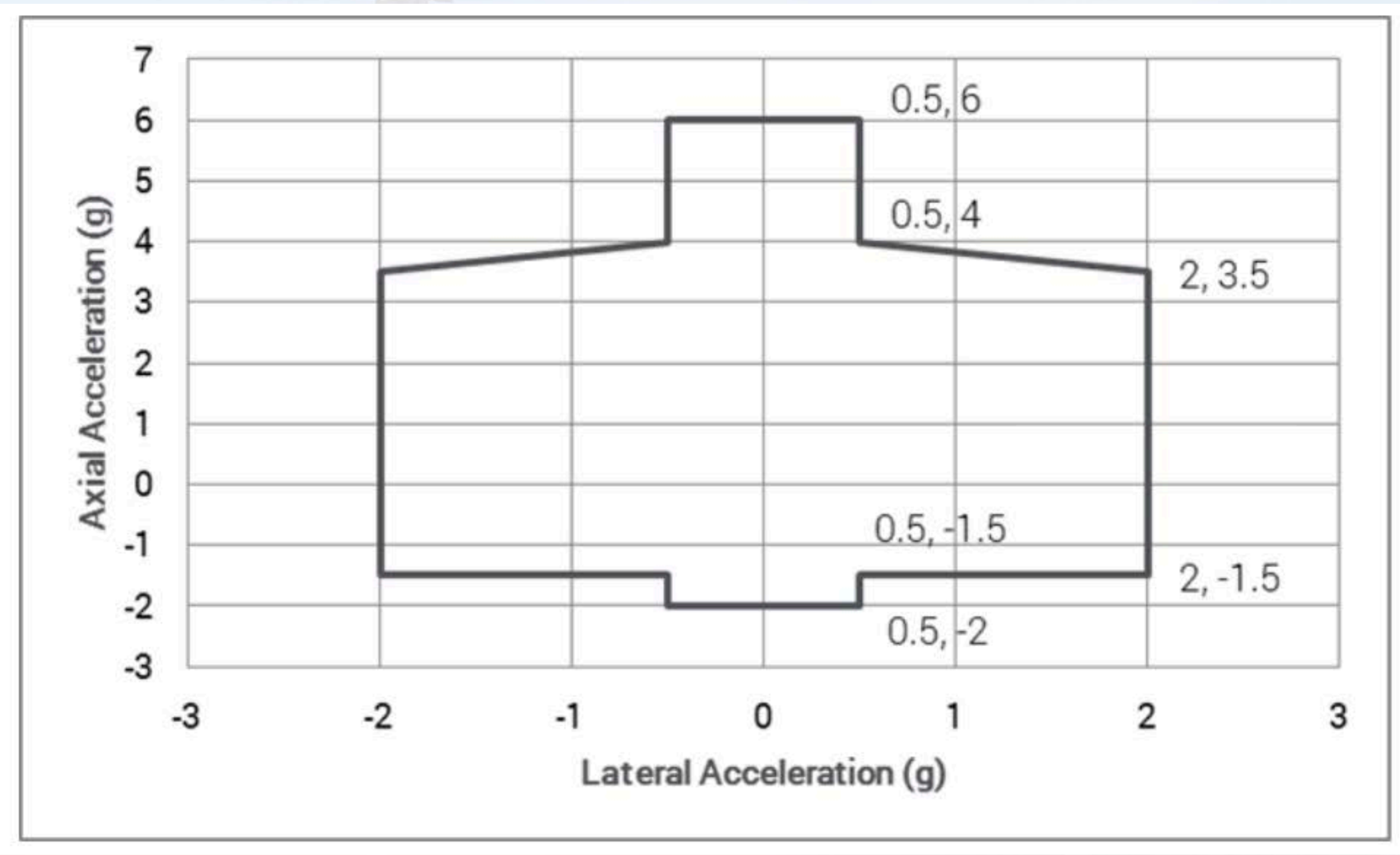


# Falcon 9/Falcon Heavy Acceleration Loads

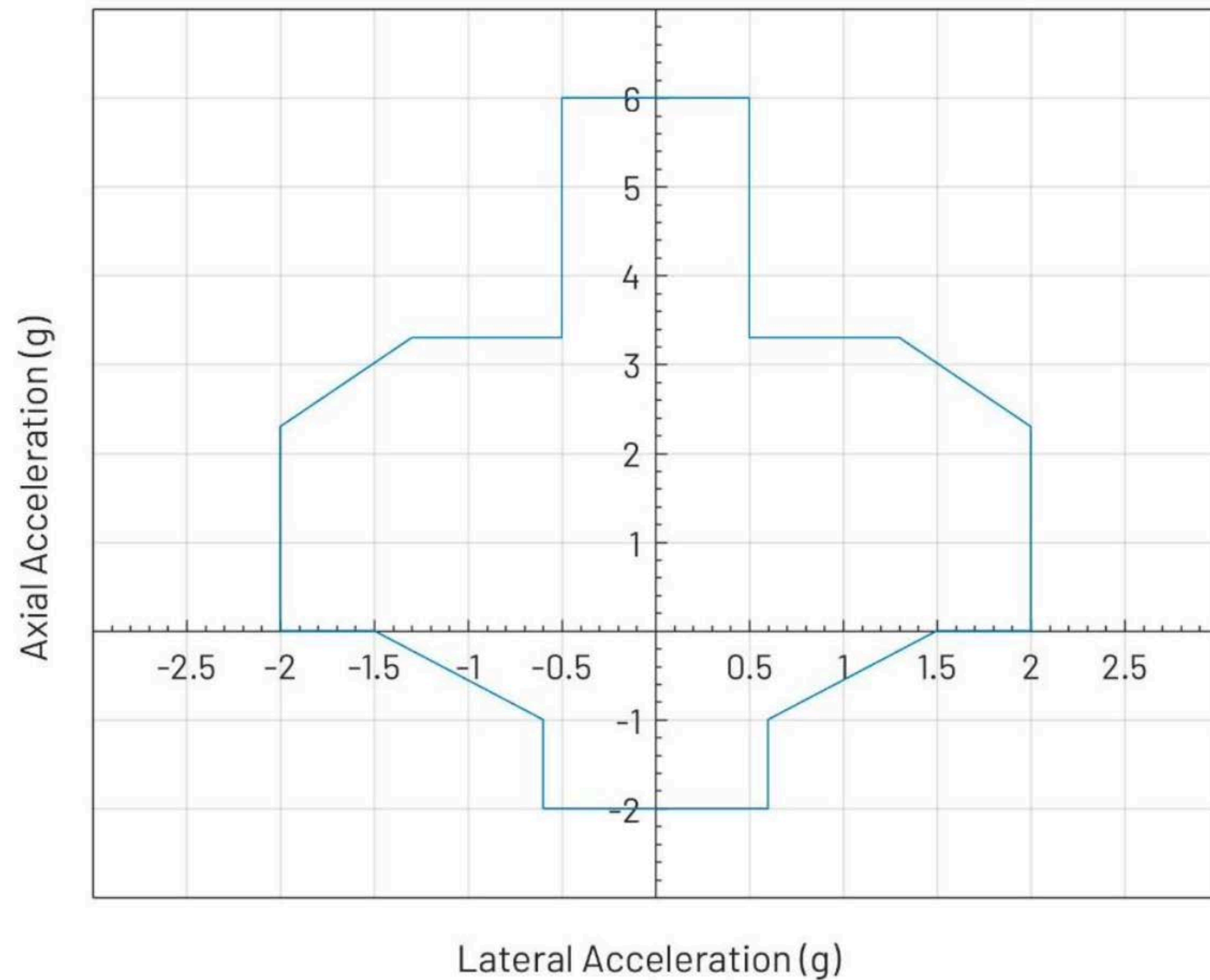




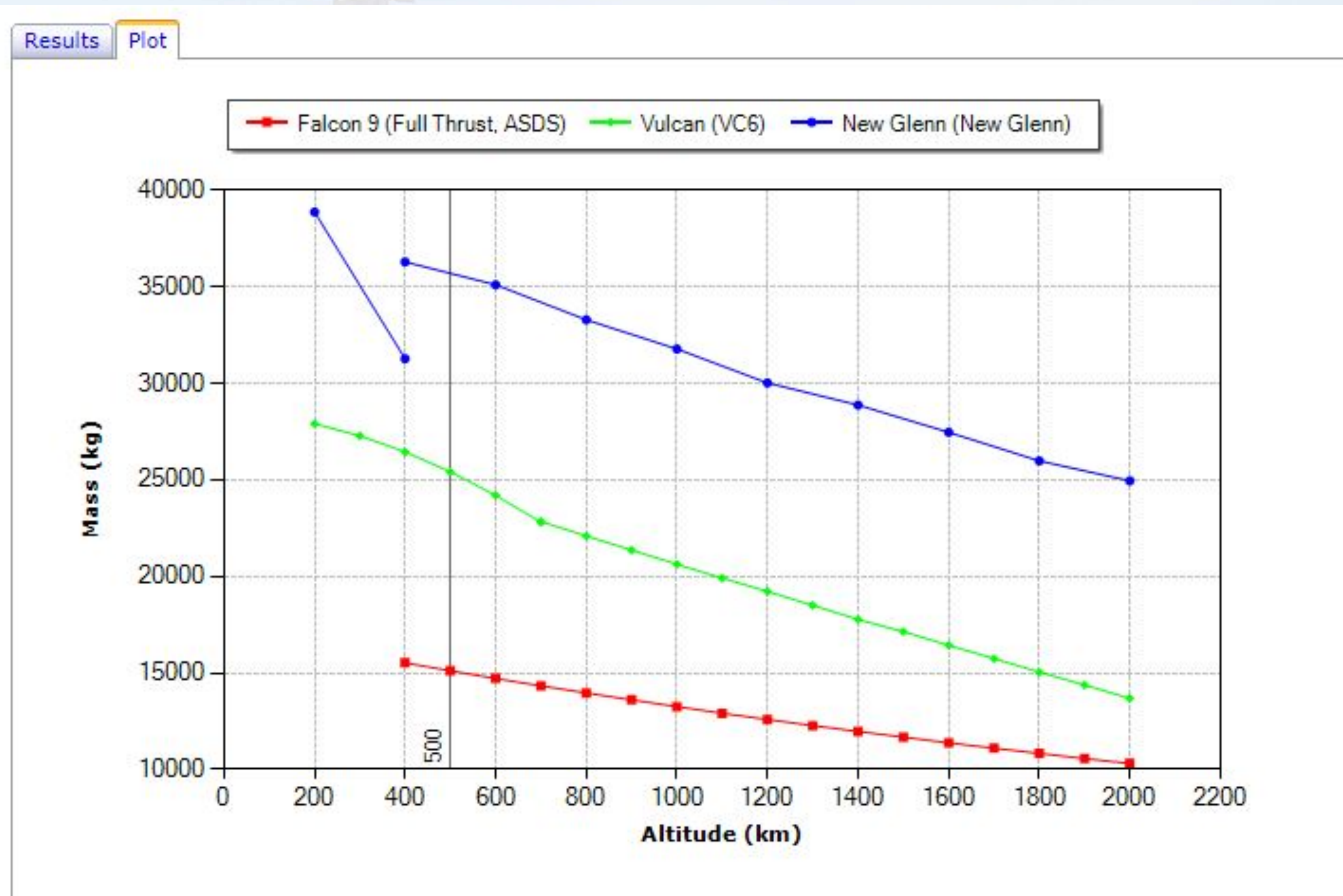
# Starship Acceleration Loads



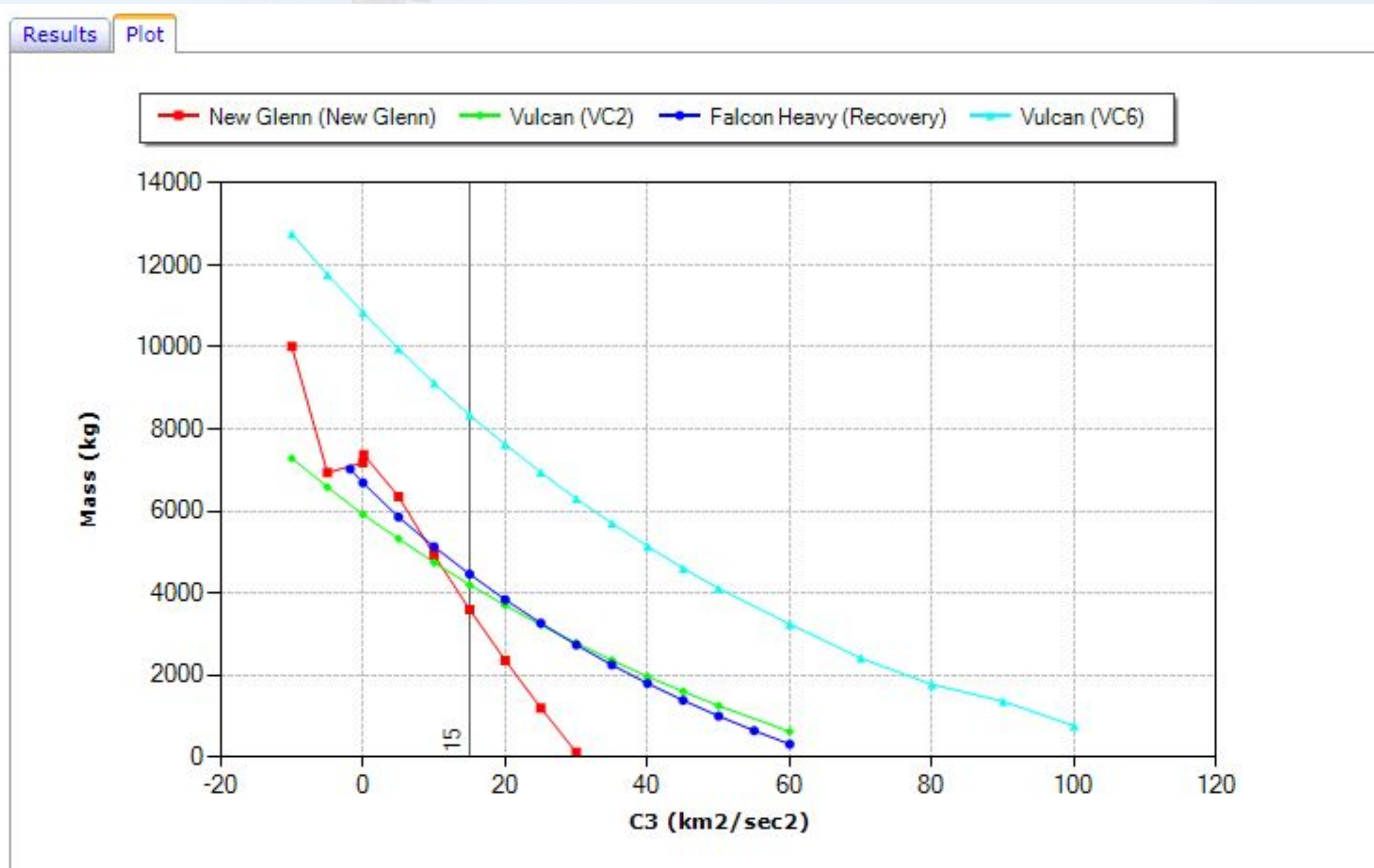
# New Glenn Acceleration Loads



# Comparative Performance to LEO



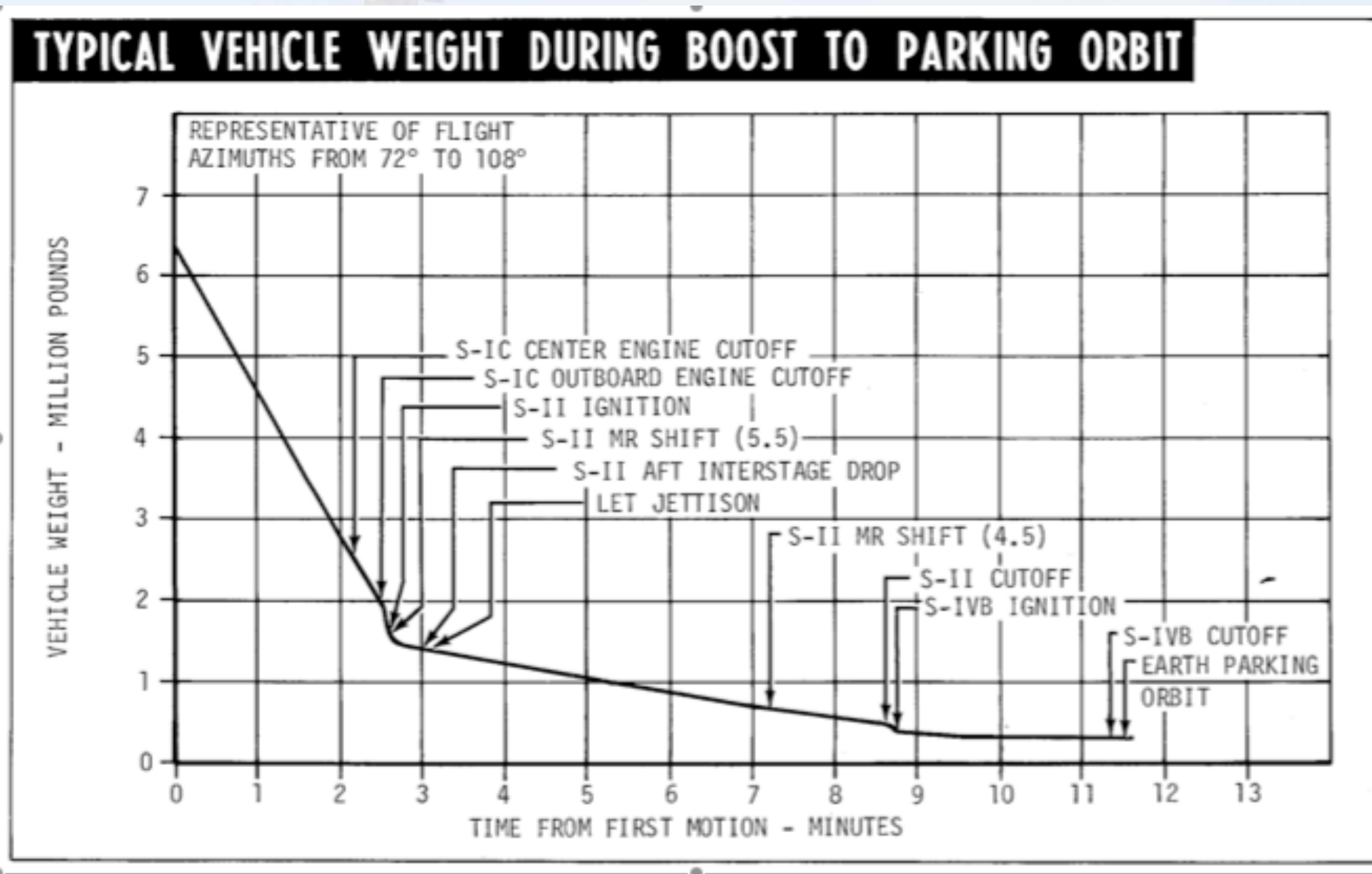
# Comparative Performance to C3=15



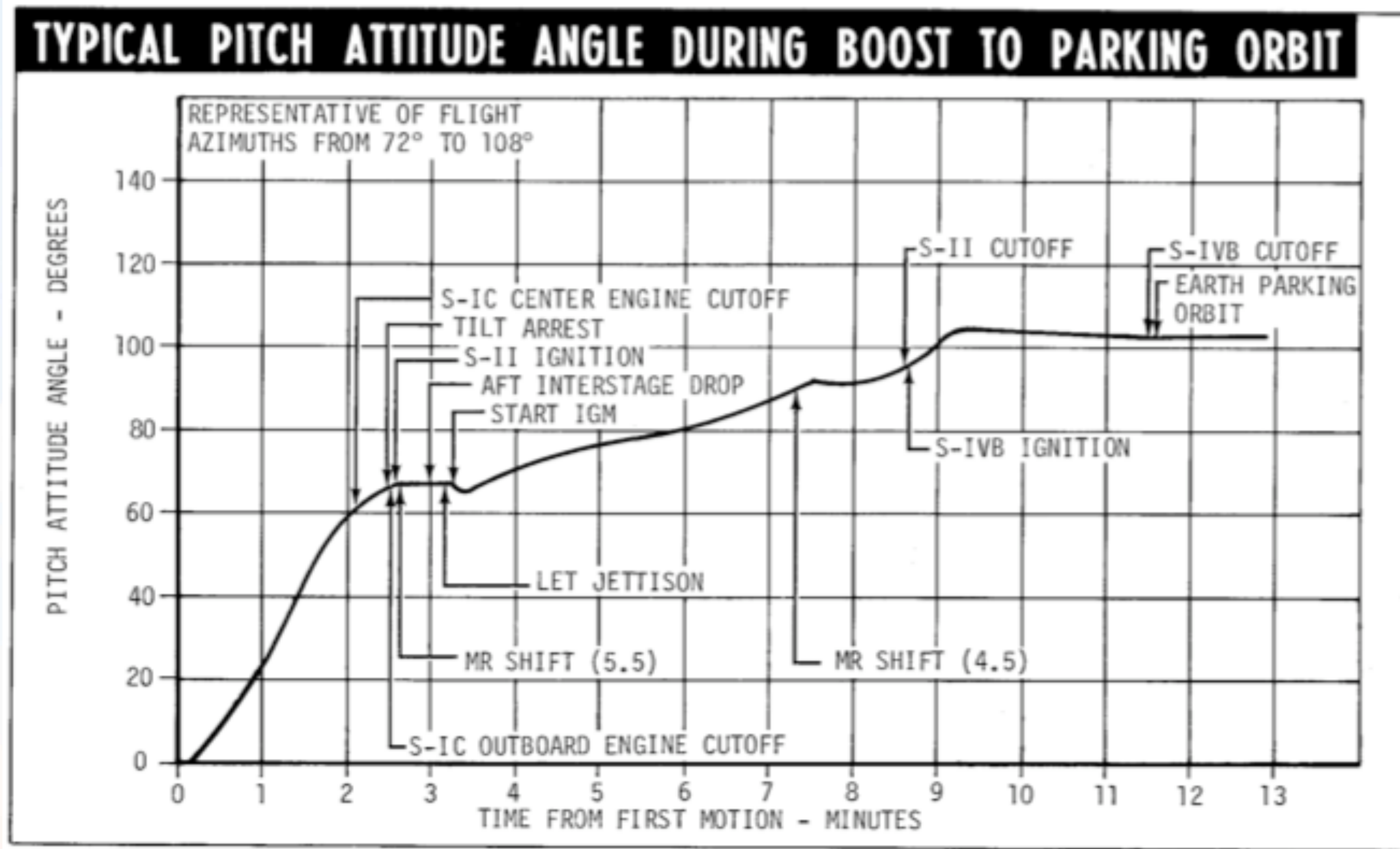
# Saturn V Design in Detail



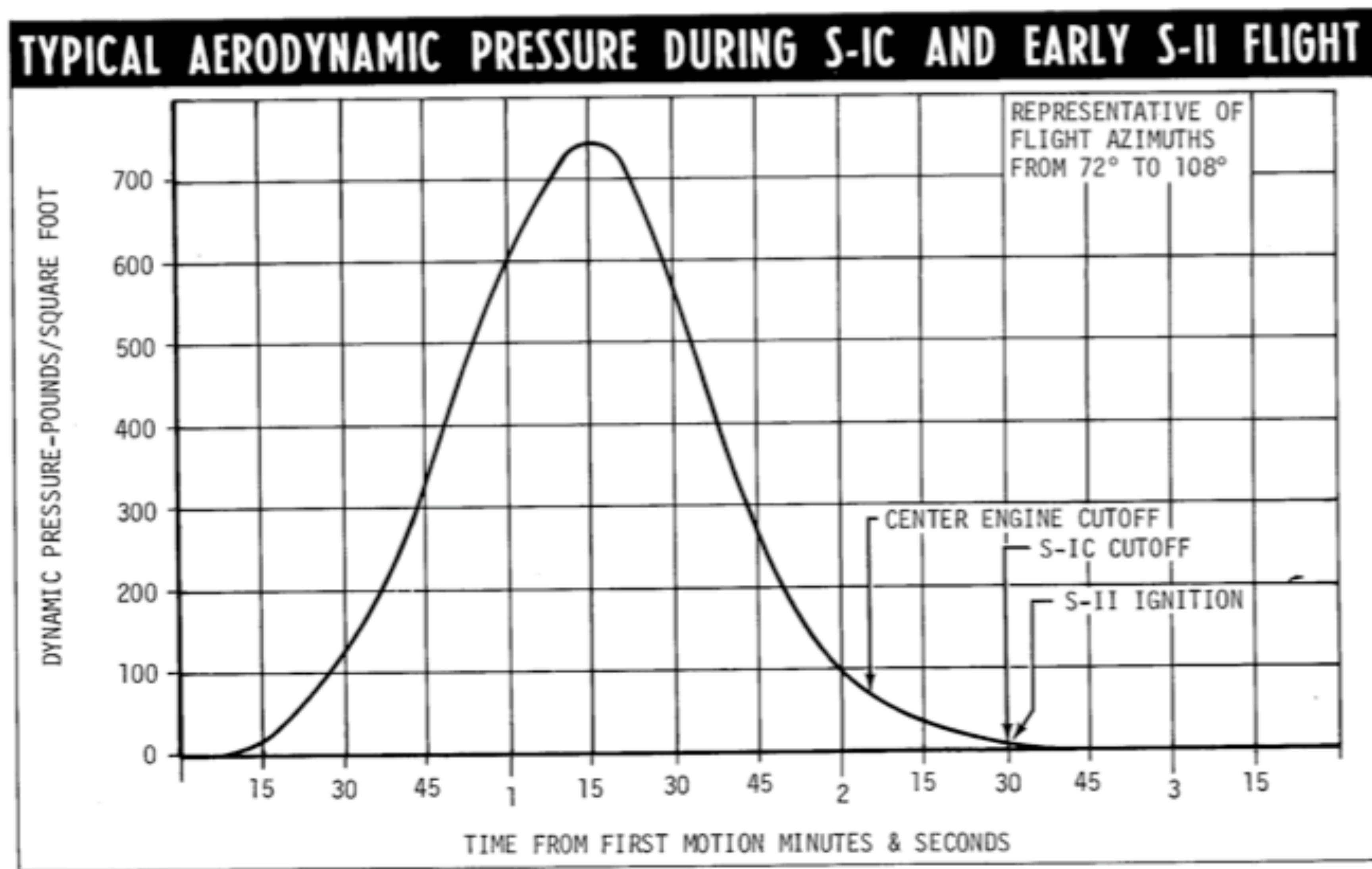
# Mass Changes During Launch



# Pitch Attitude Angle During Launch

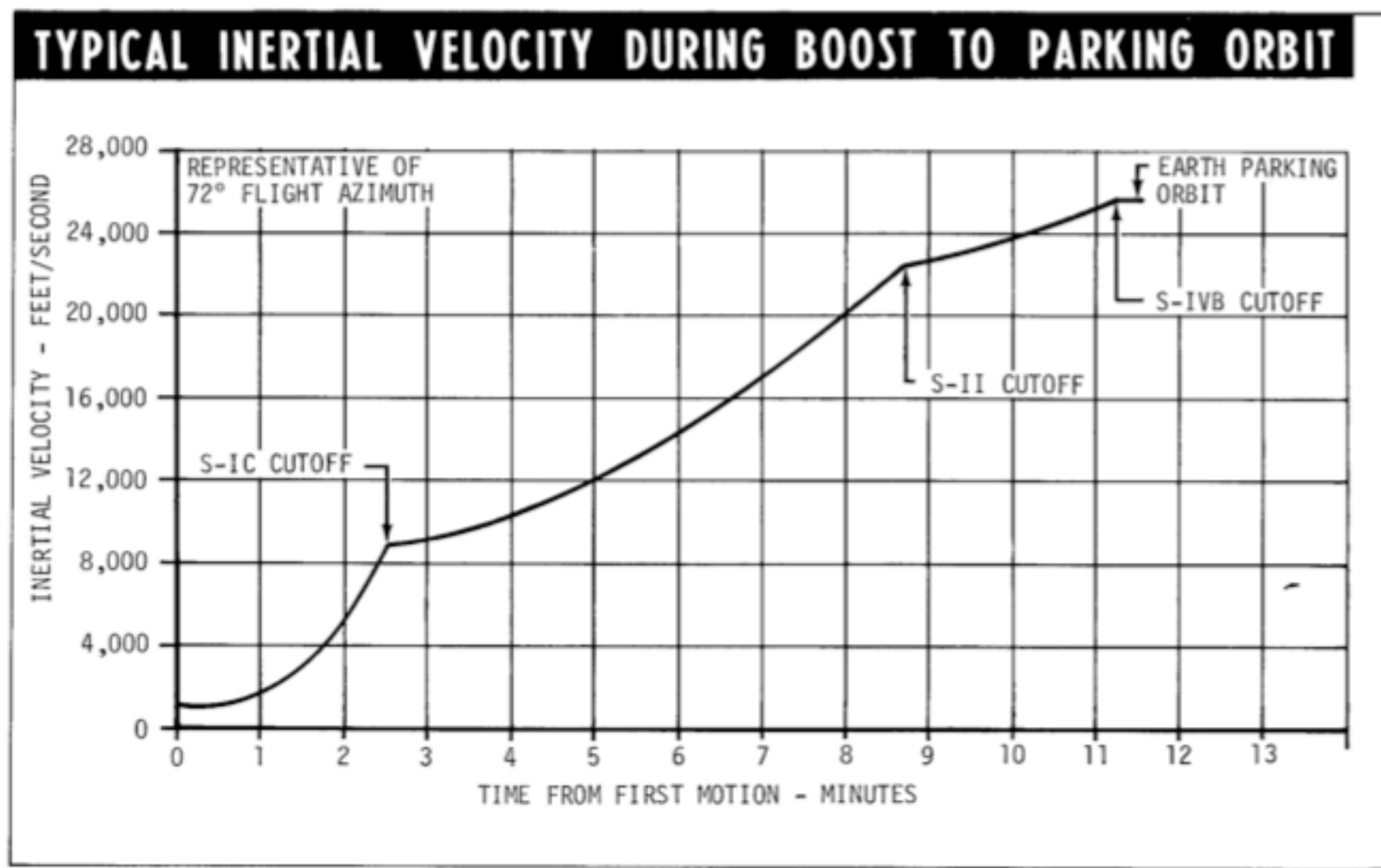


# Aerodynamic Pressure During Launch

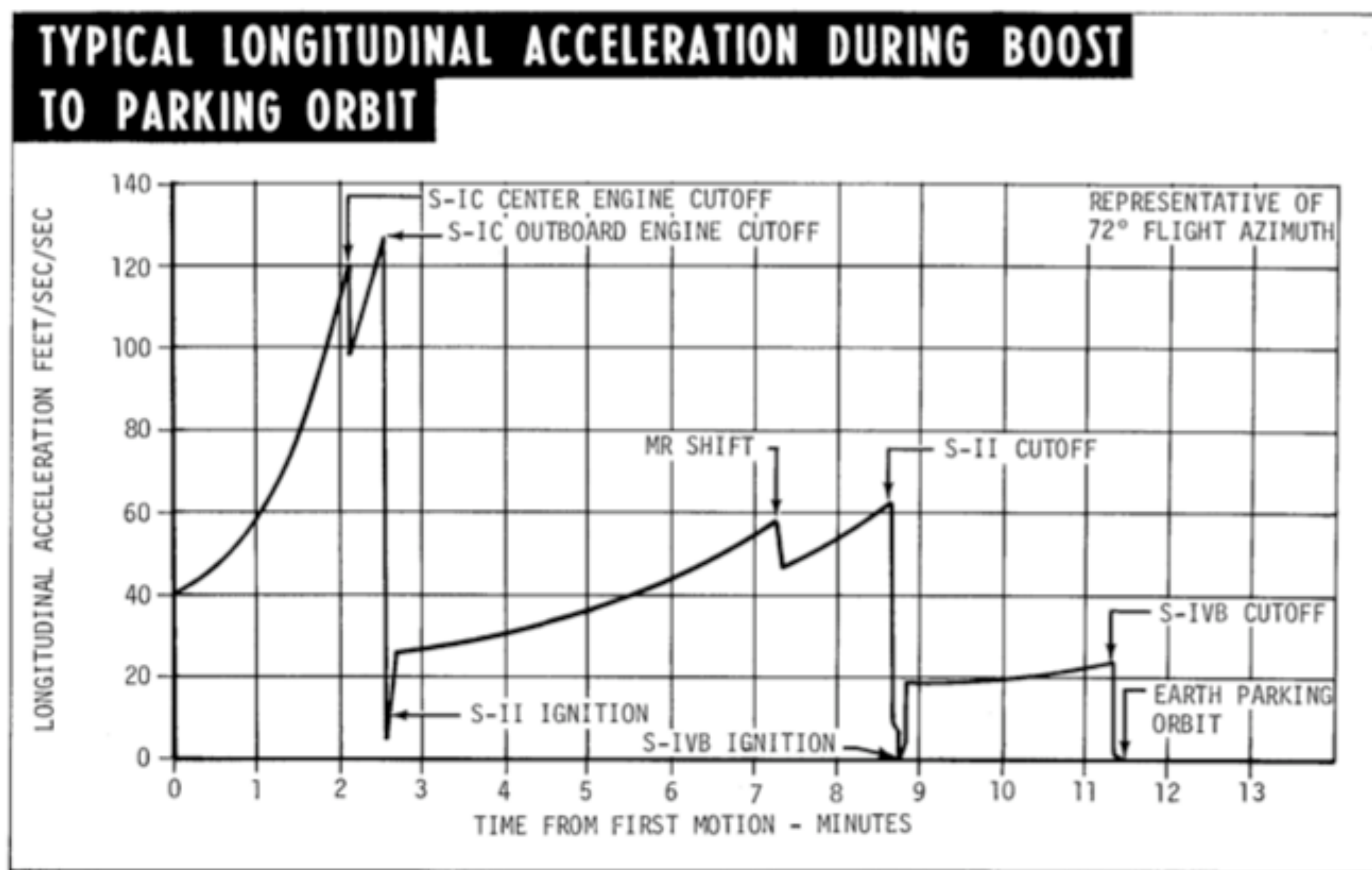




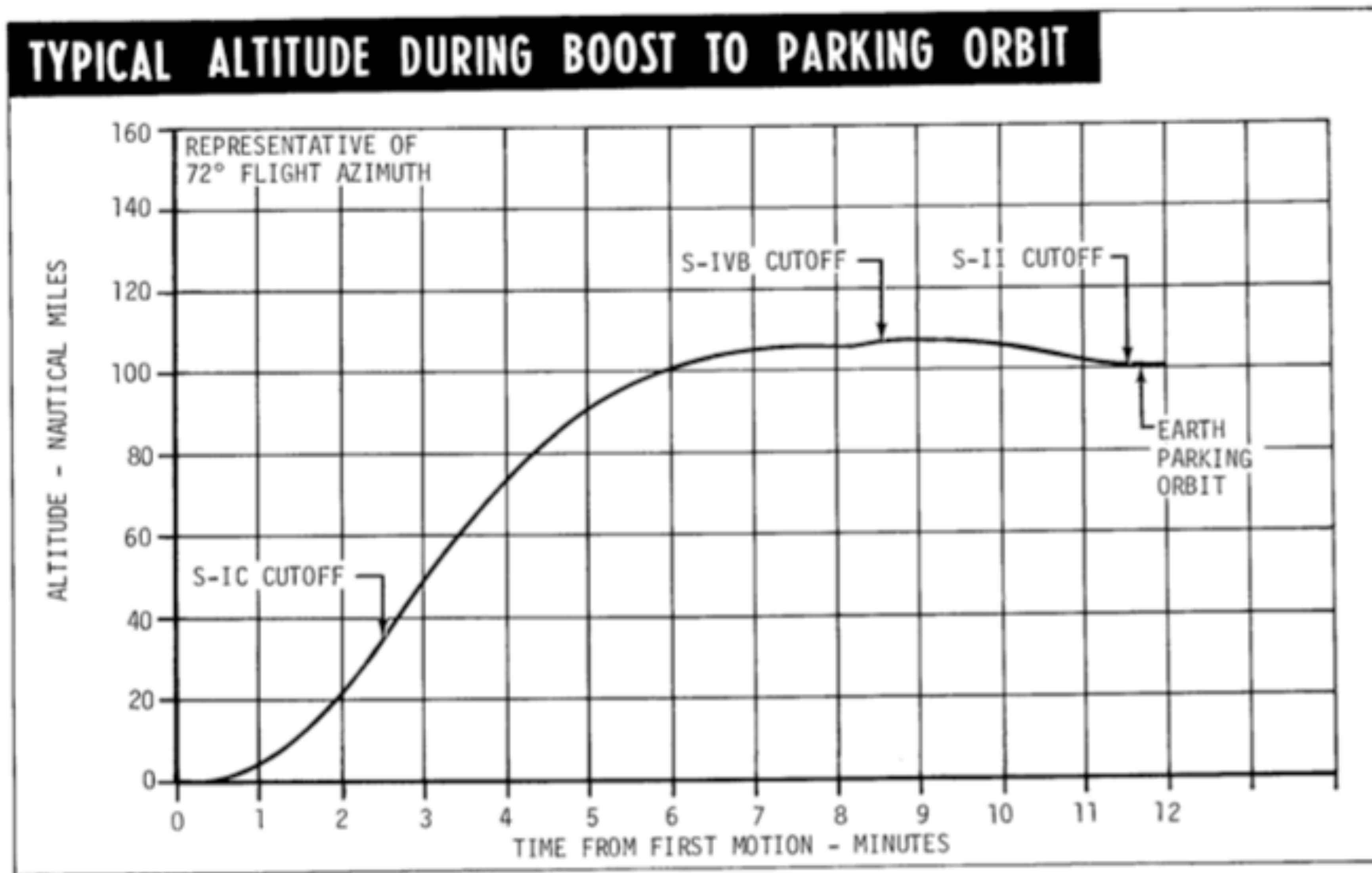
# Velocity as a Function of Time



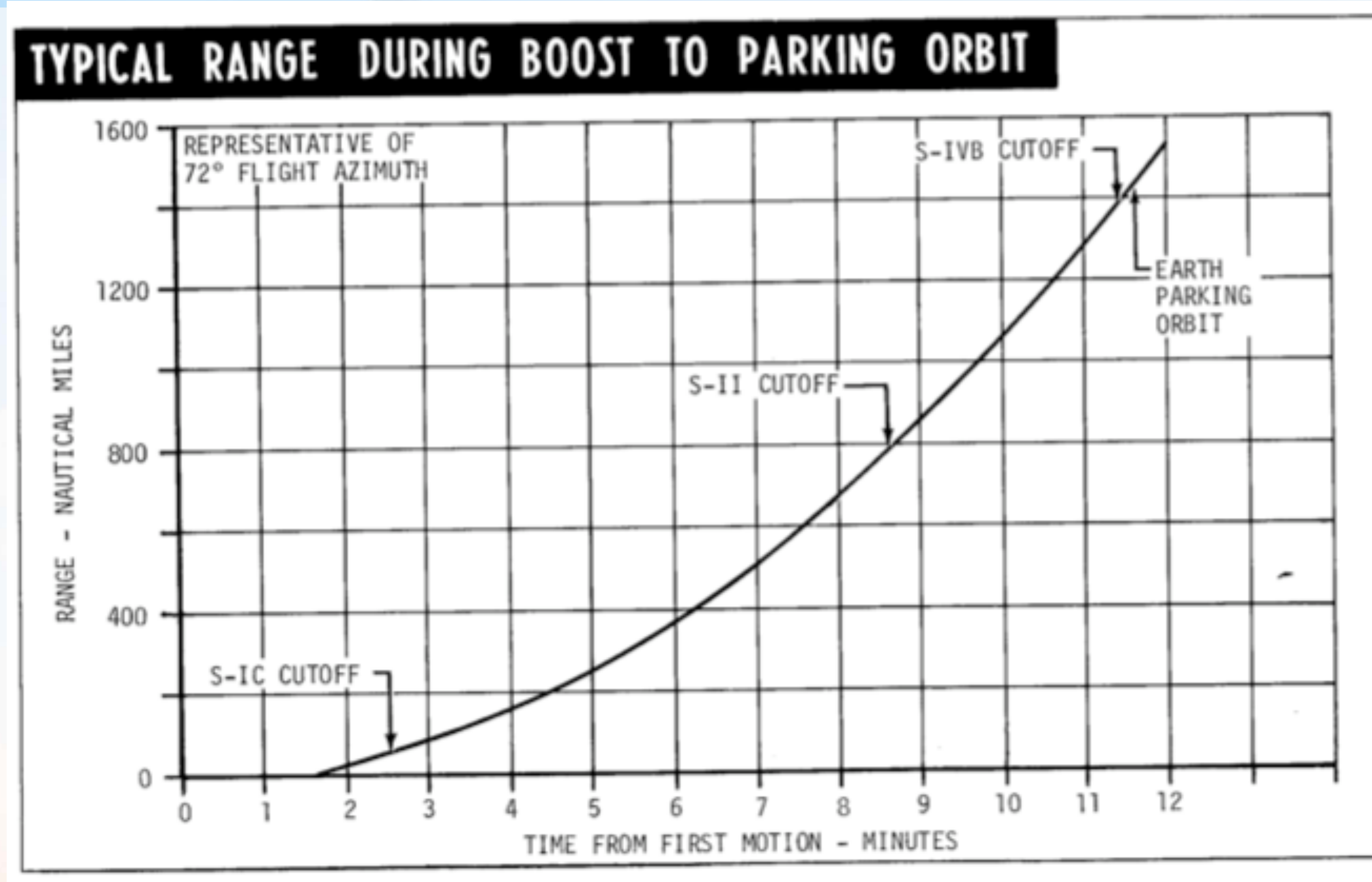
# Acceleration as a Function of Time



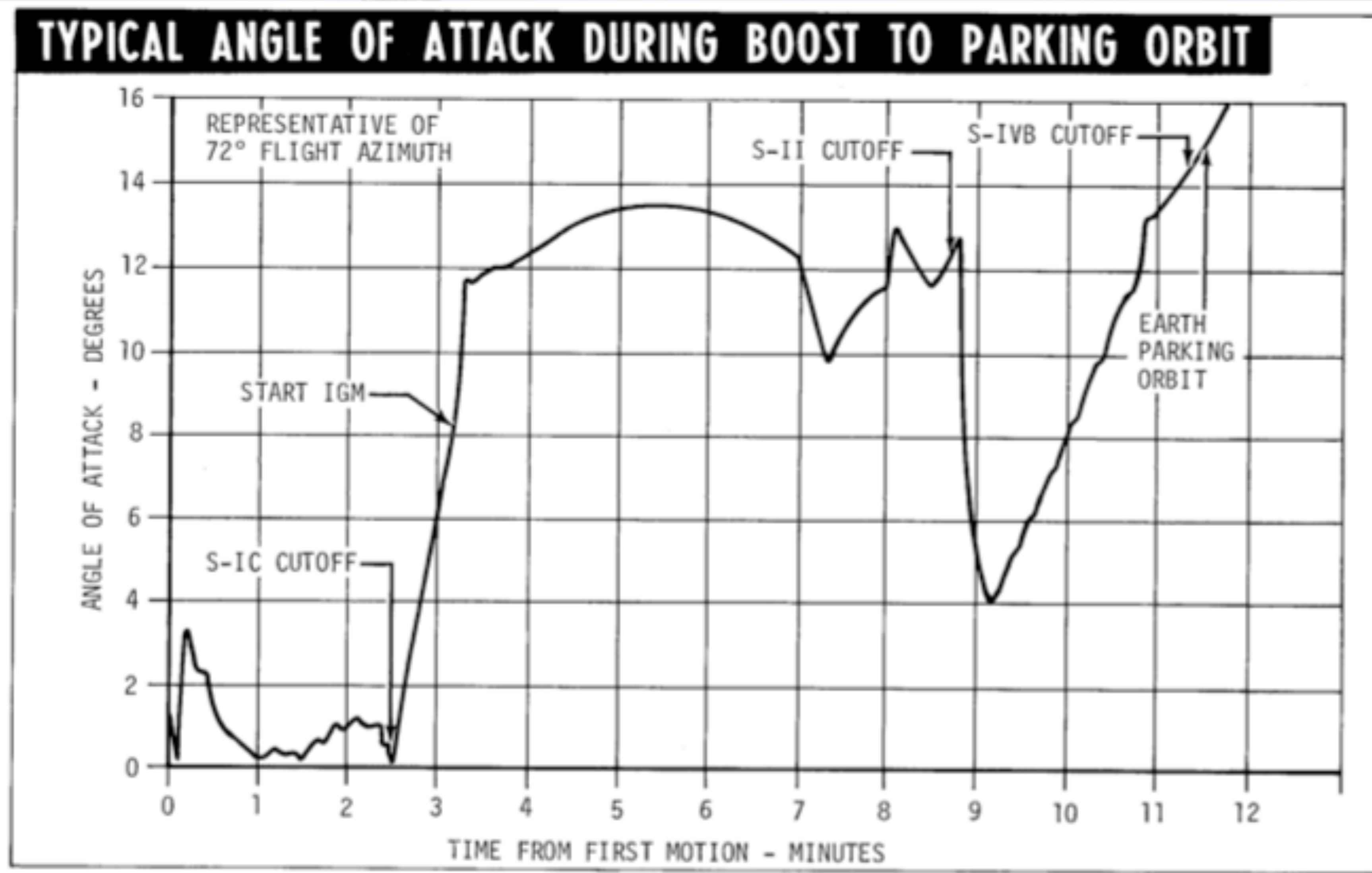
# Altitude vs. Time



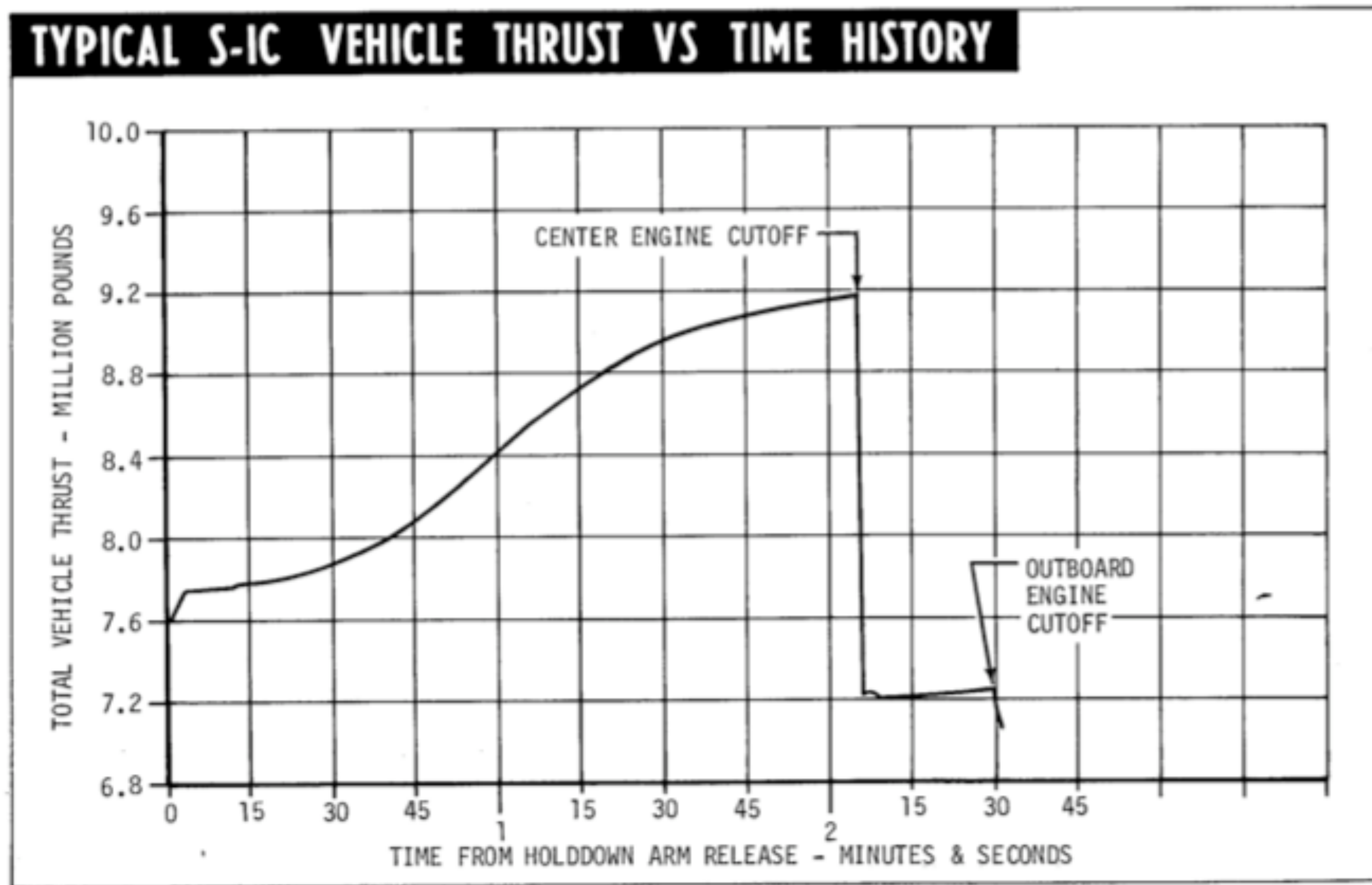
# Down-Range Distance vs. Time



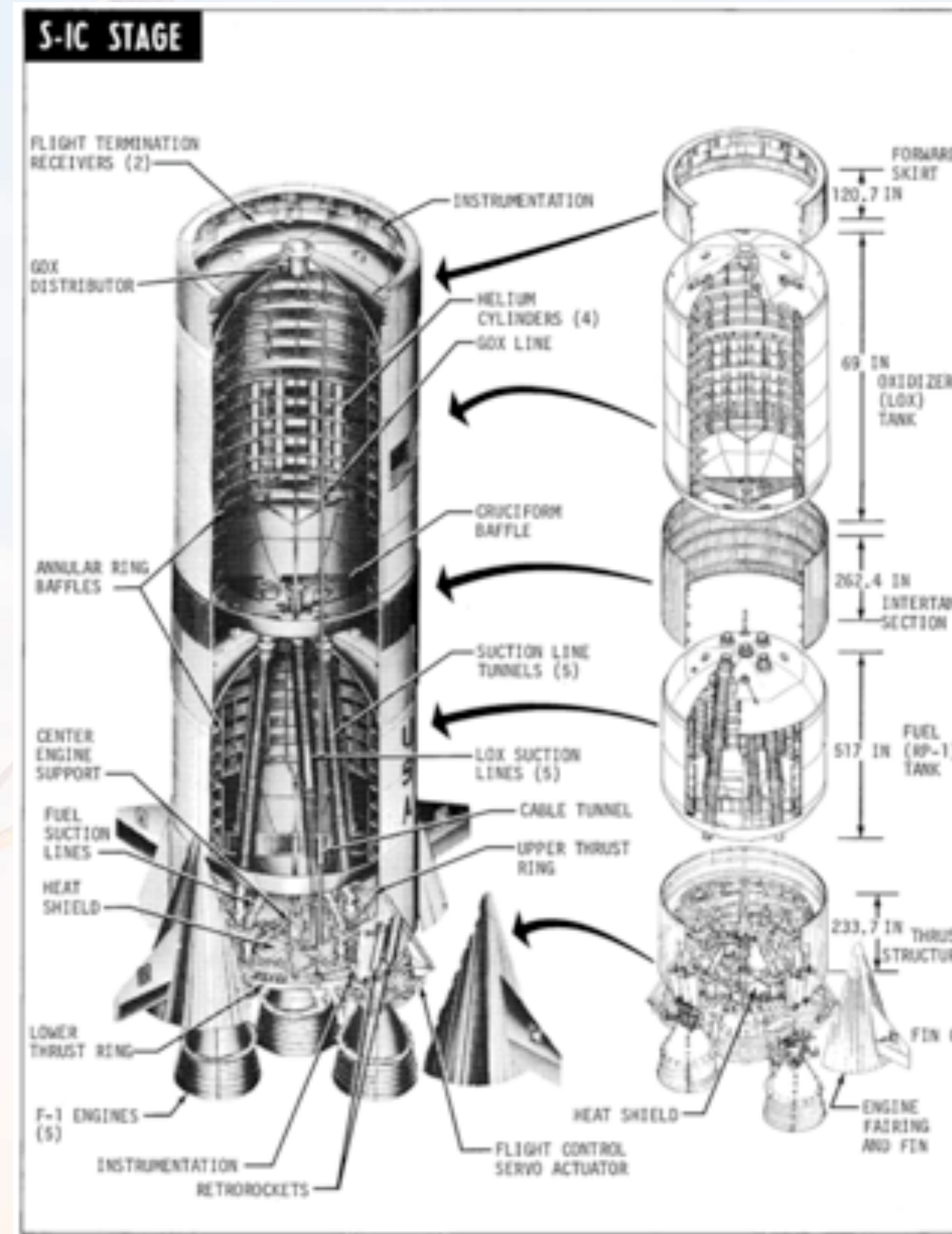
# Angle of Attack in Trajectory



# First Stage Thrust vs. Time

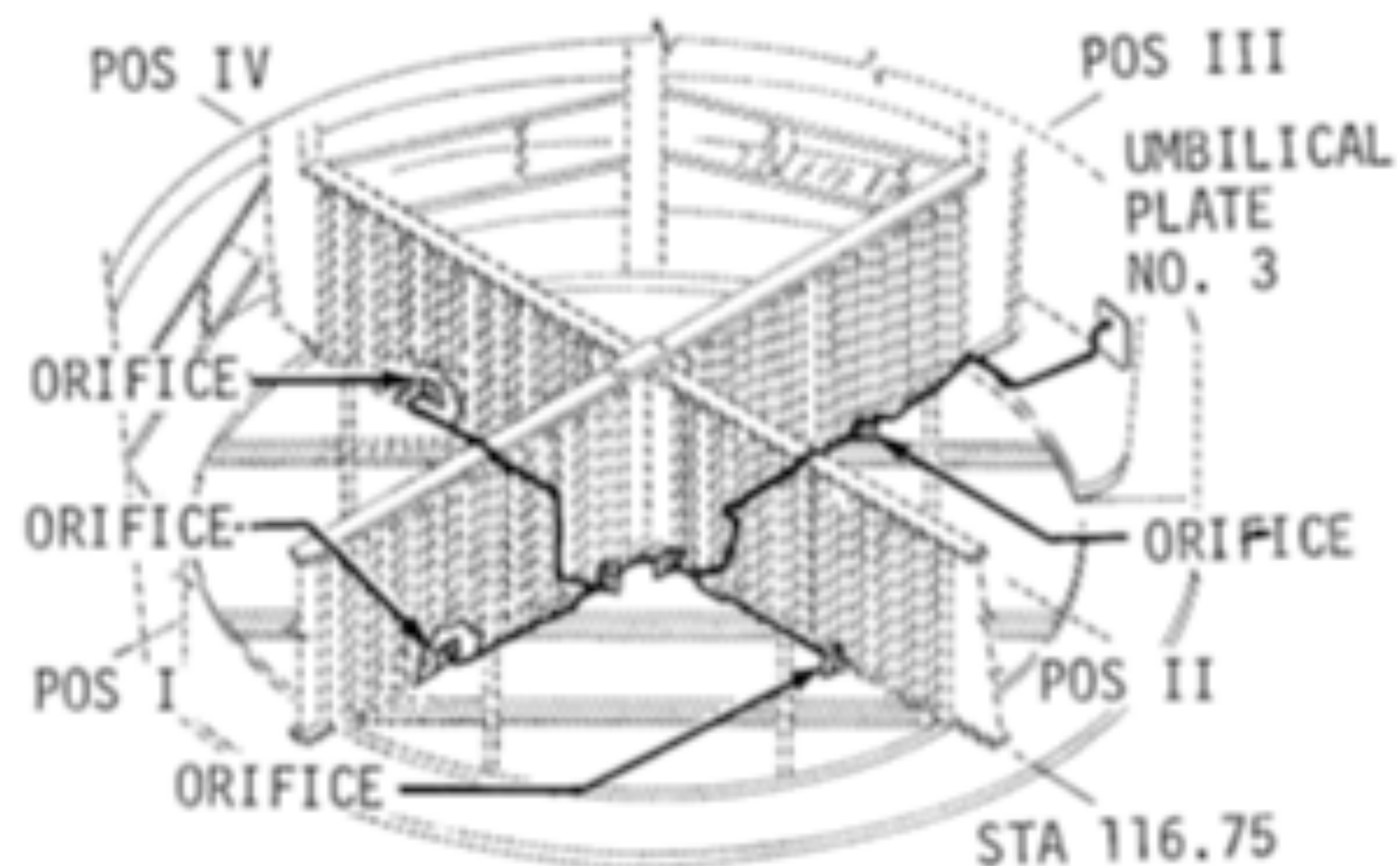


# S-IC First Stage Internal Configuration



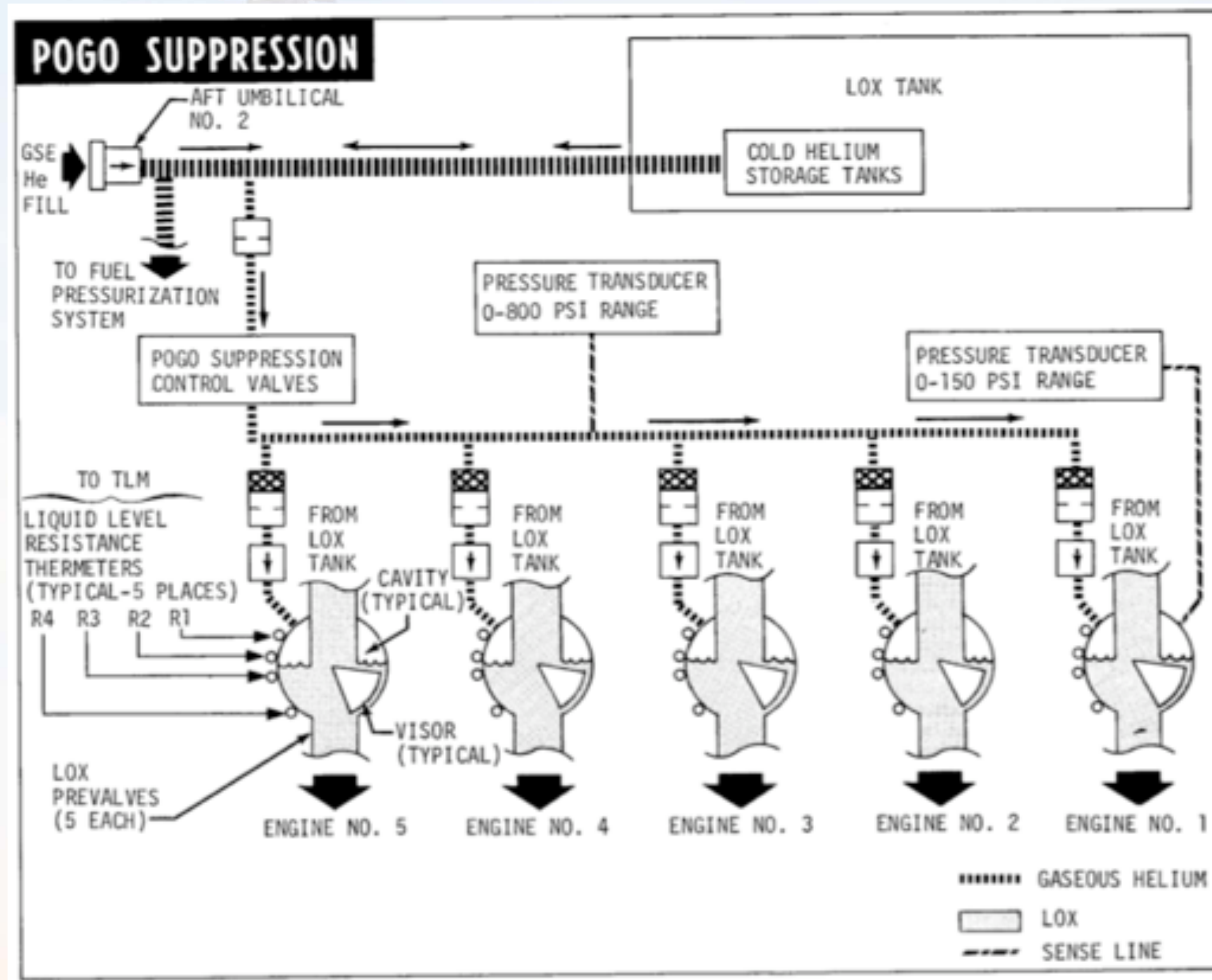
# Hydrogen Leak Sensors

## HAZARDOUS GAS DETECTION - THRUST STRUCTURE

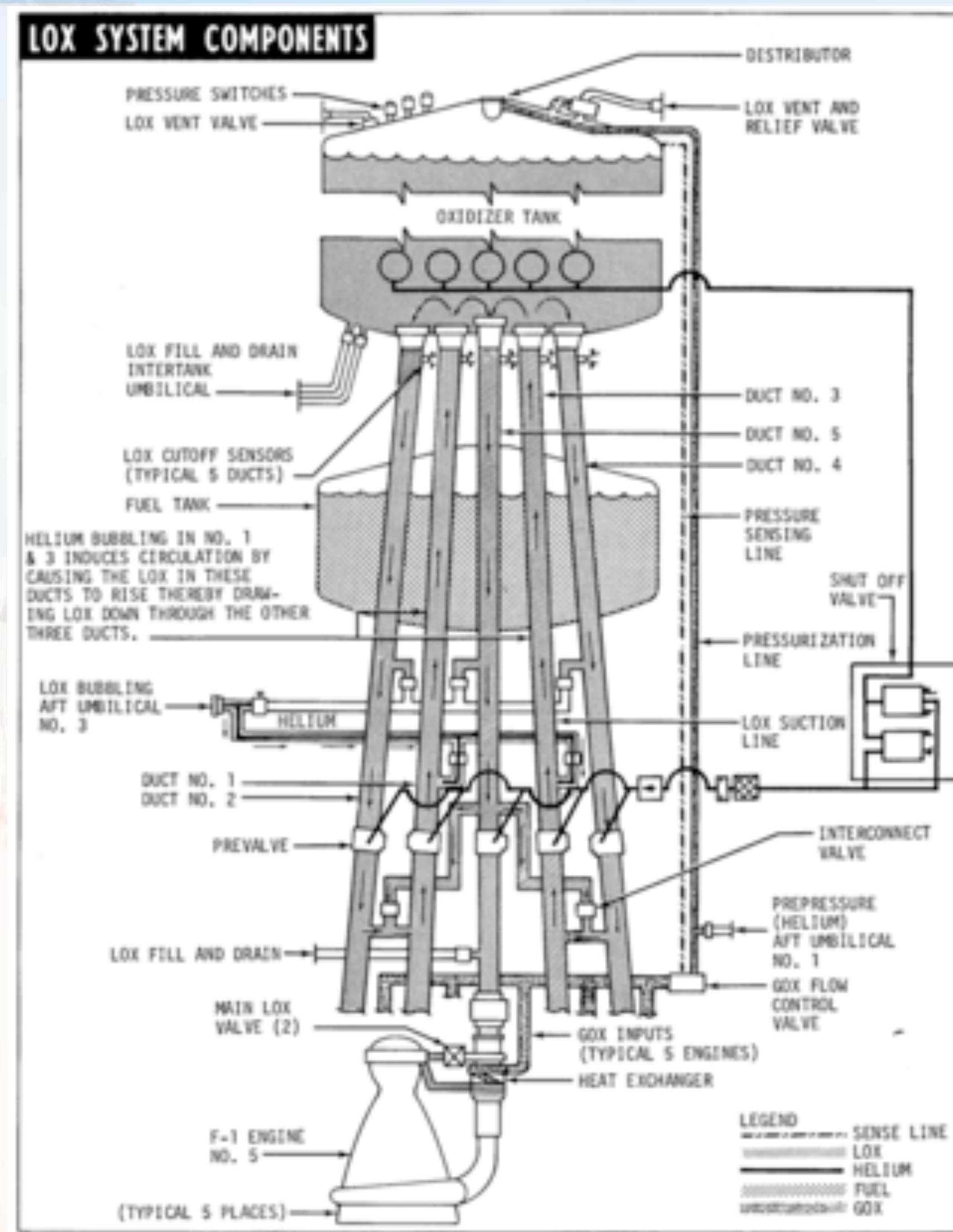




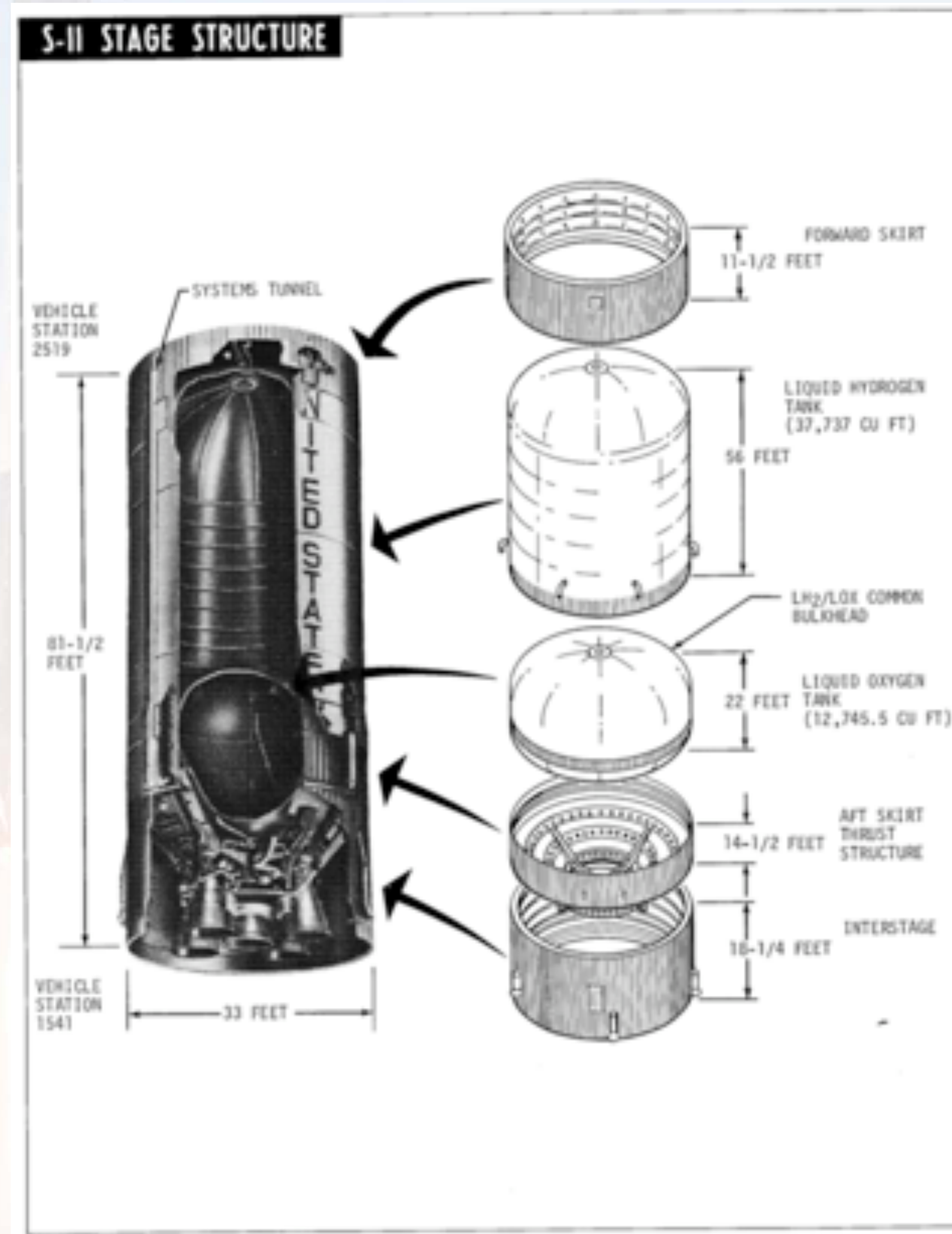
# Pogo Suppression System



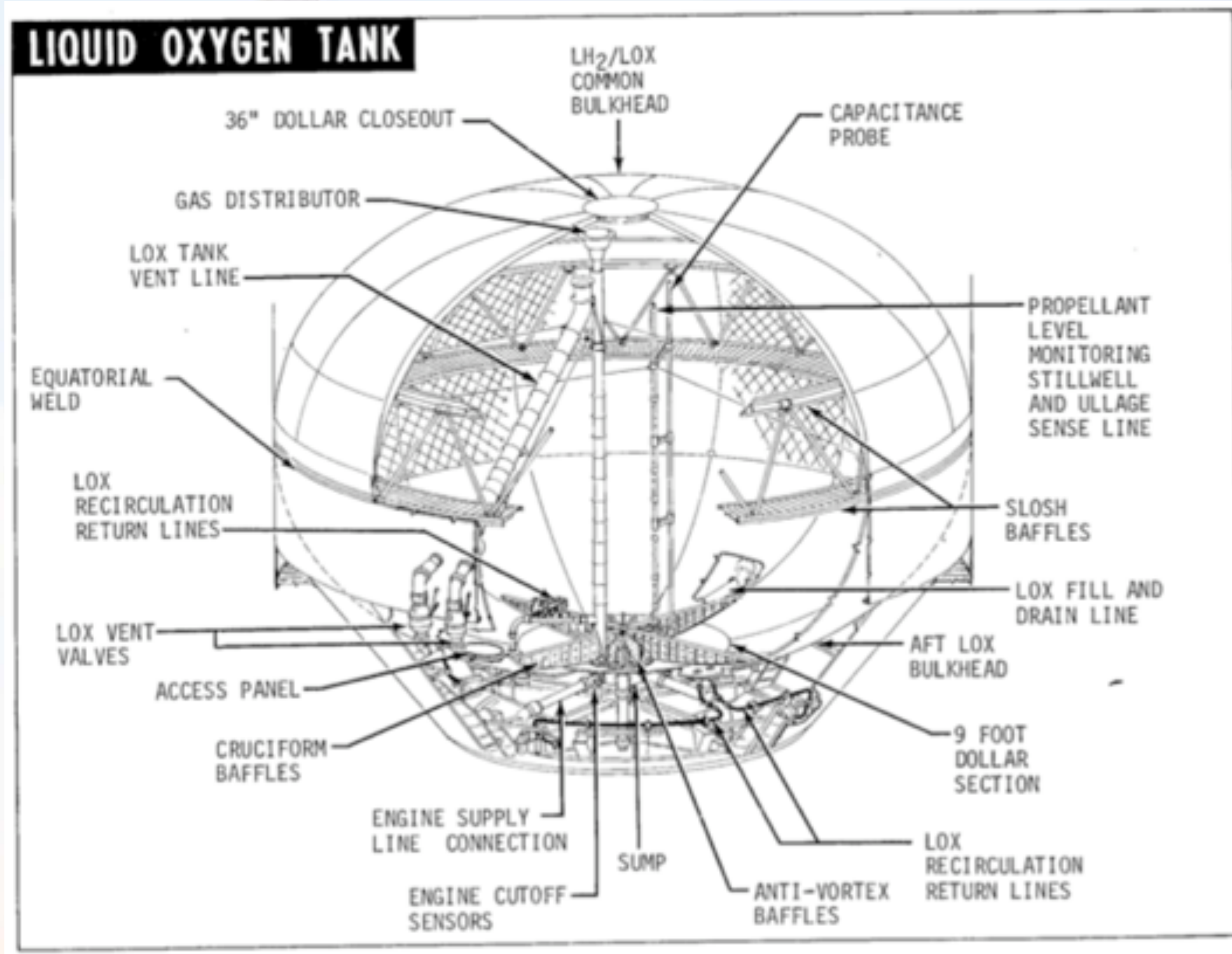
# S-IC LOX Feed System



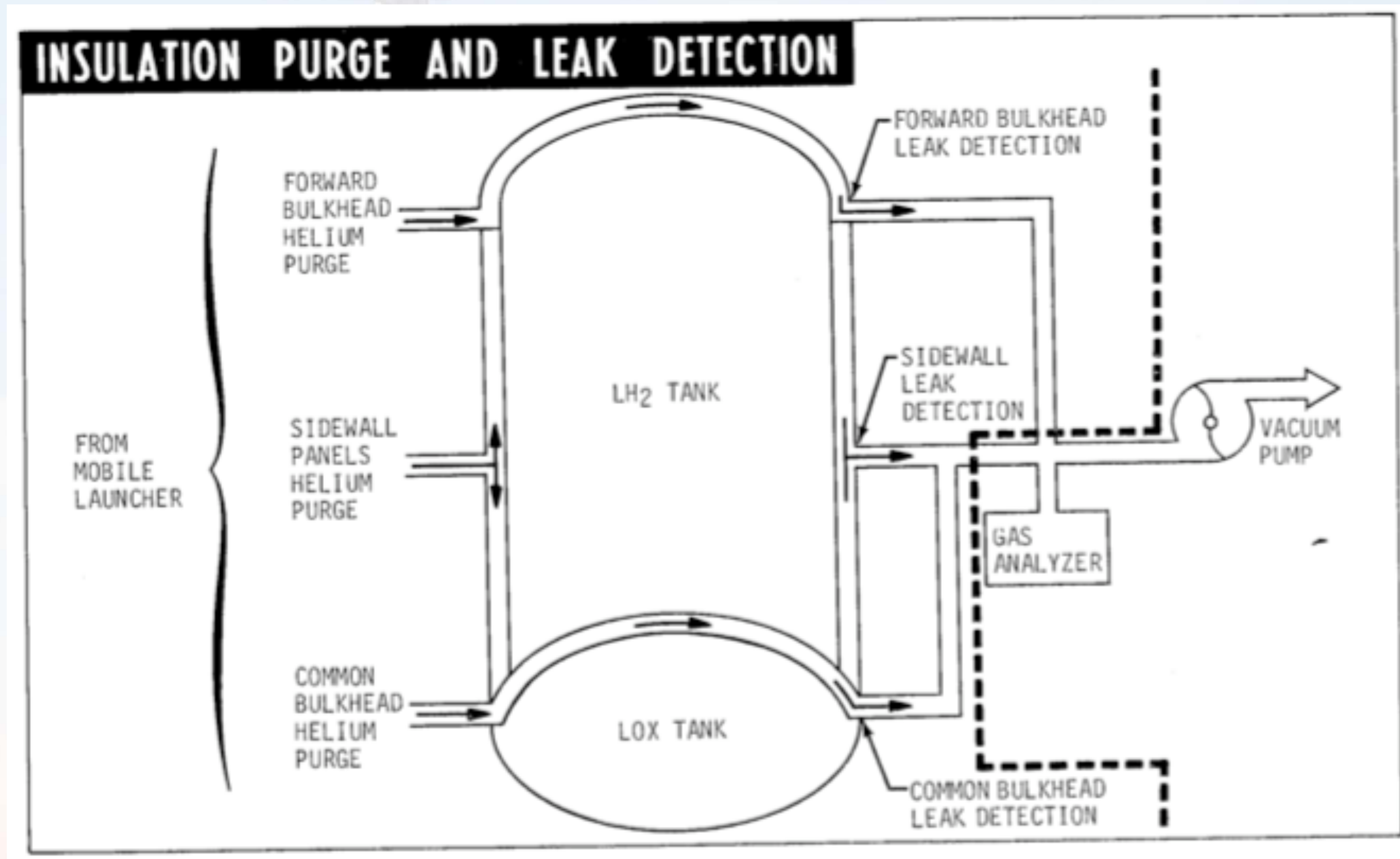
# S-II Stage Structure



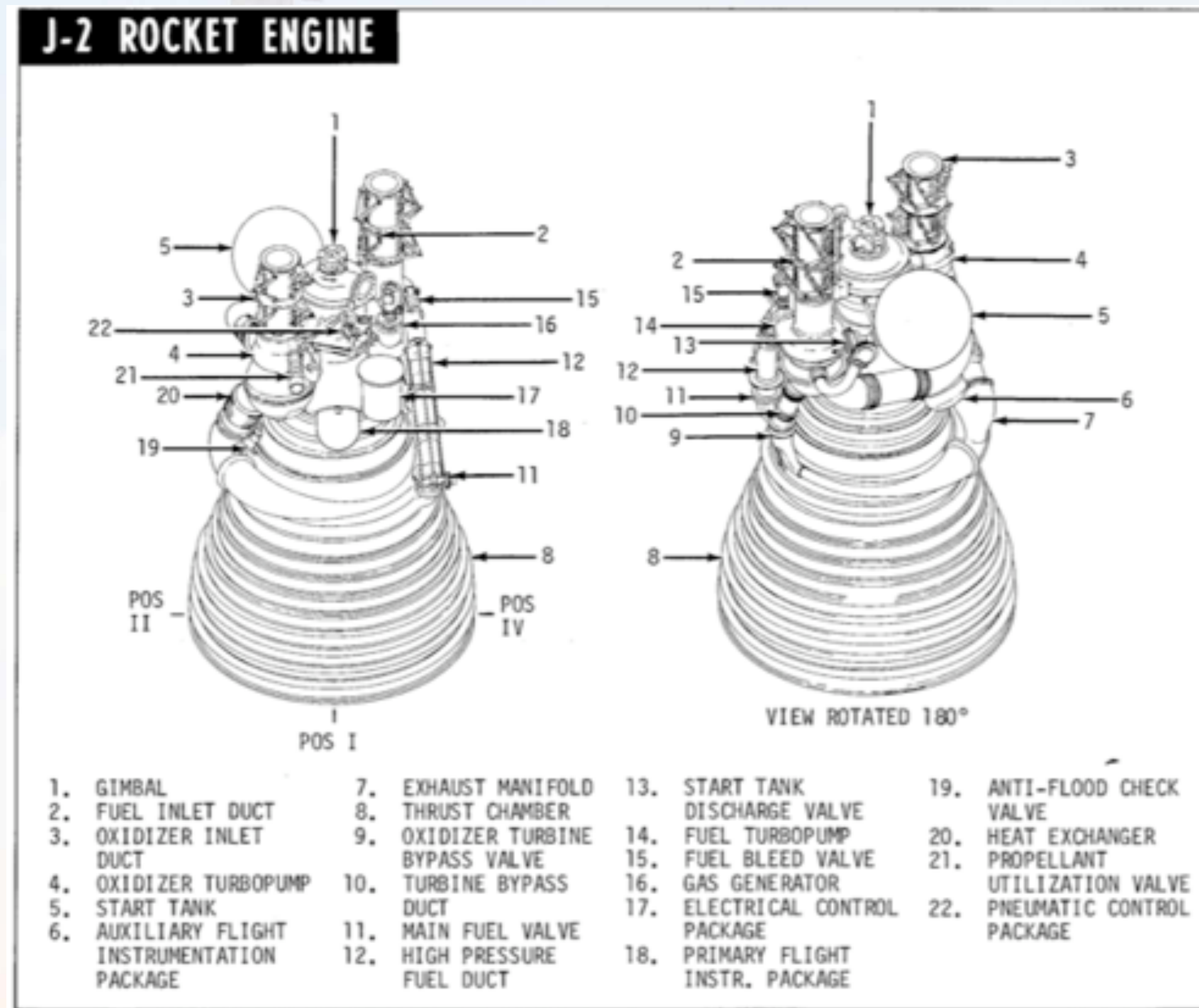
# S-II LOX Tank Configuration



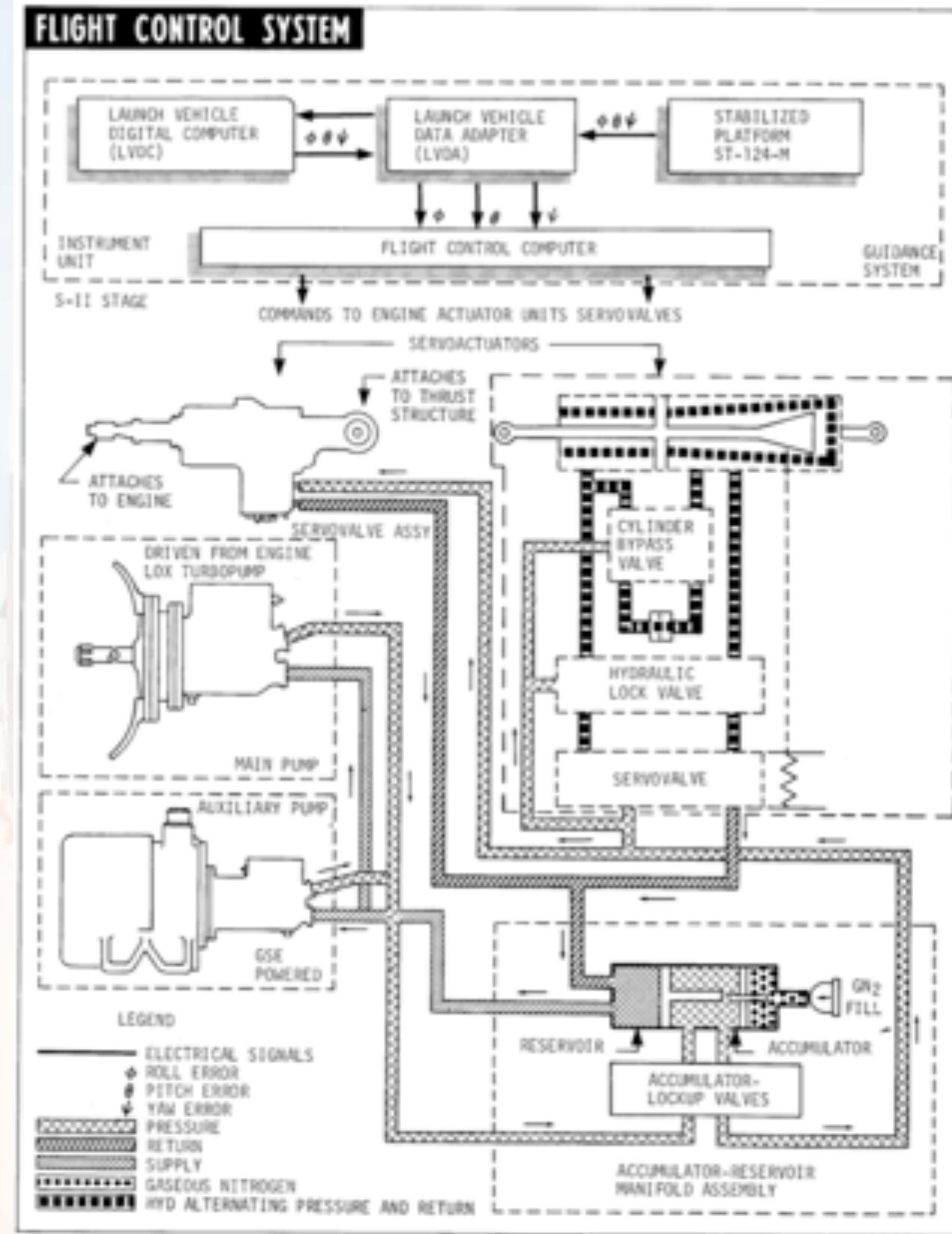
# S-II Tank Purge and Leak Detection



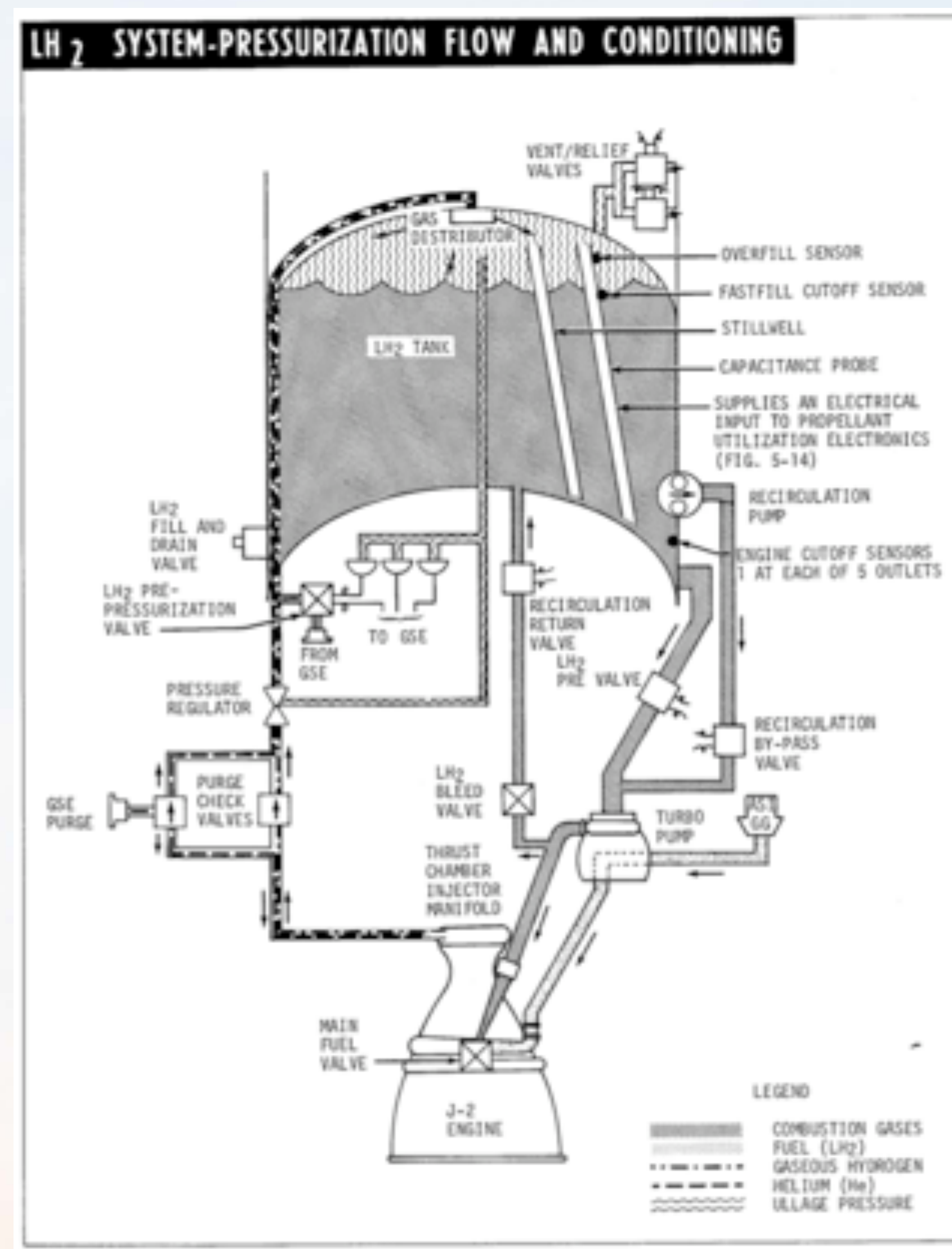
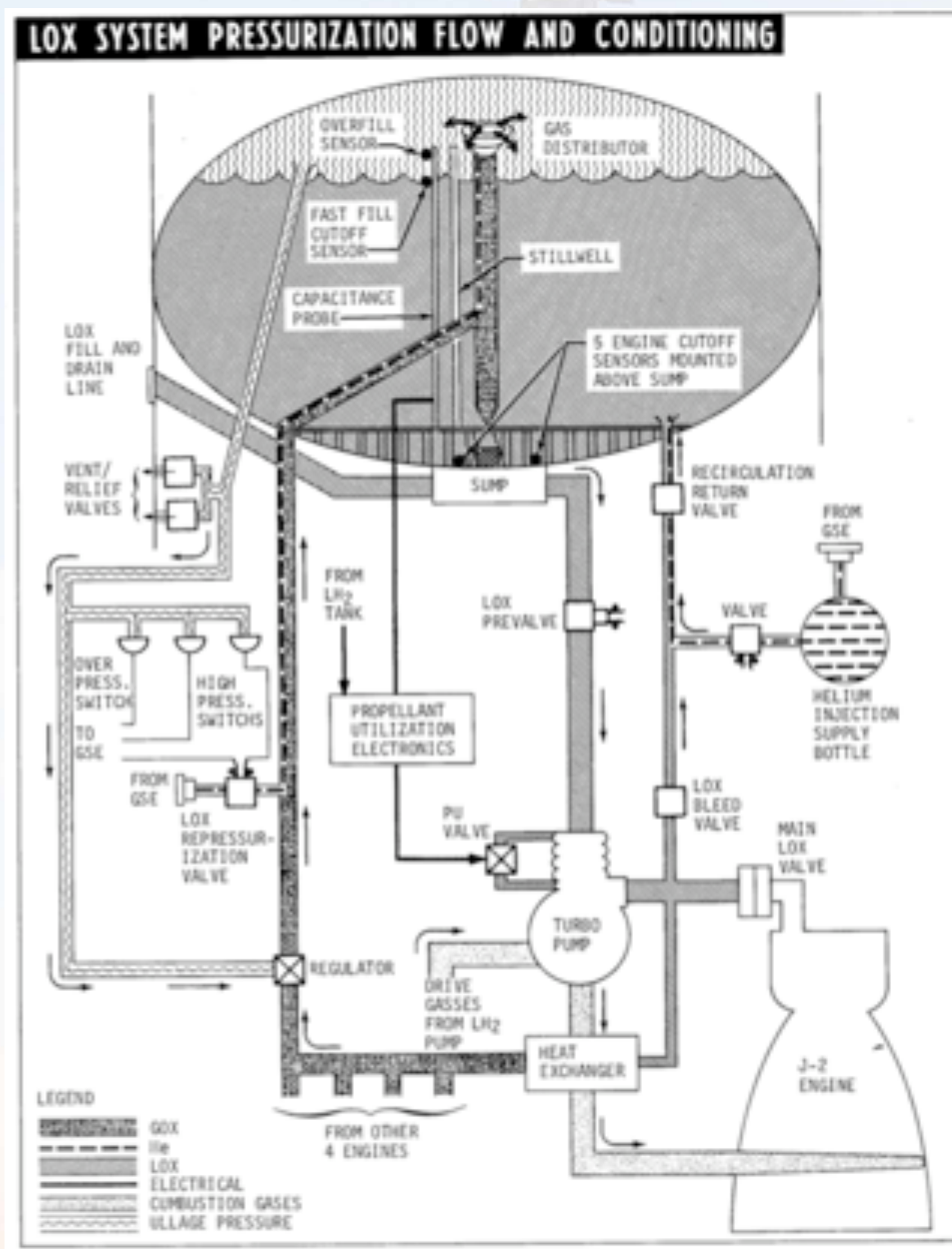
# J-2 Rocket Engine (S-II Stage)



# S-II Flight Control System Block Diagram

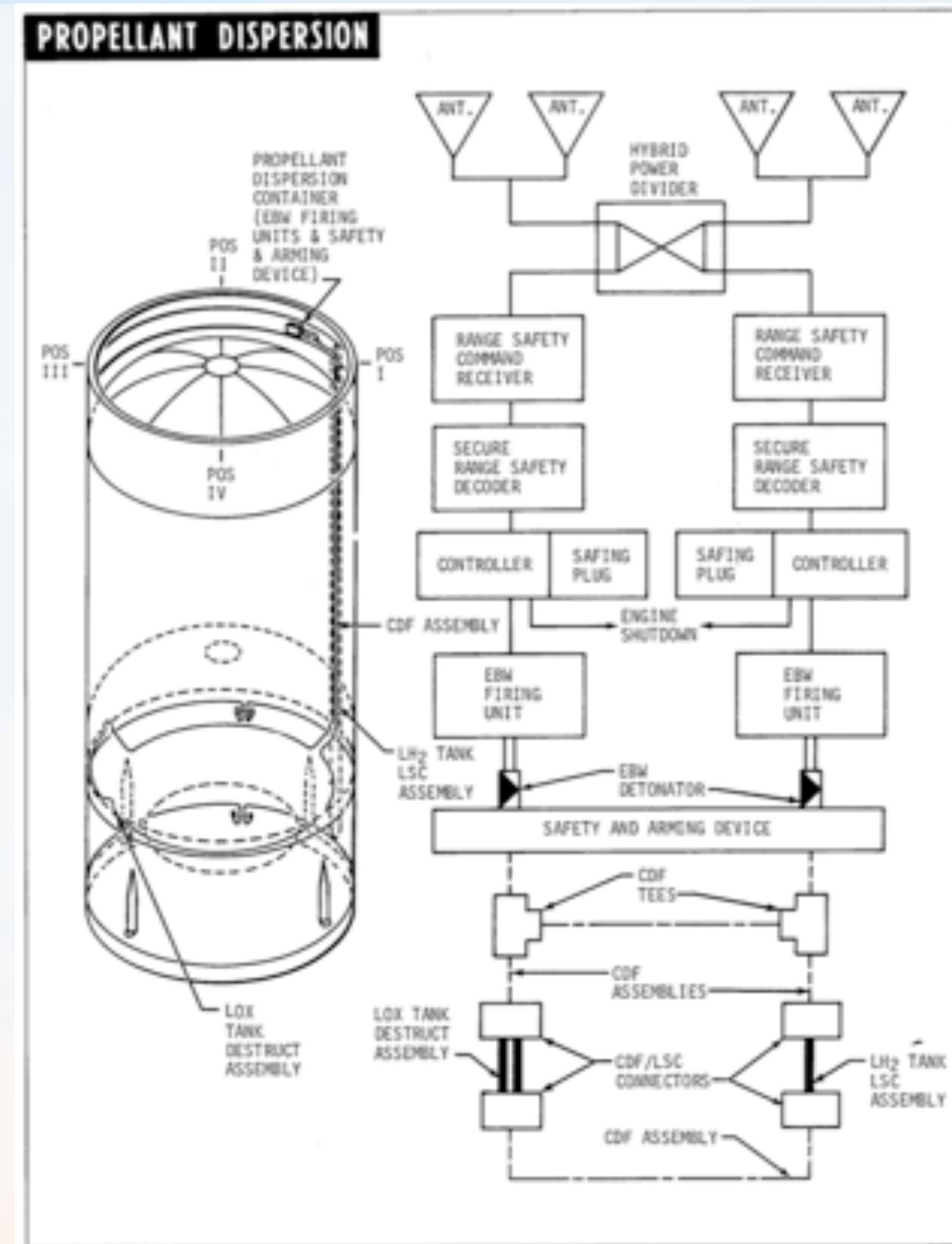
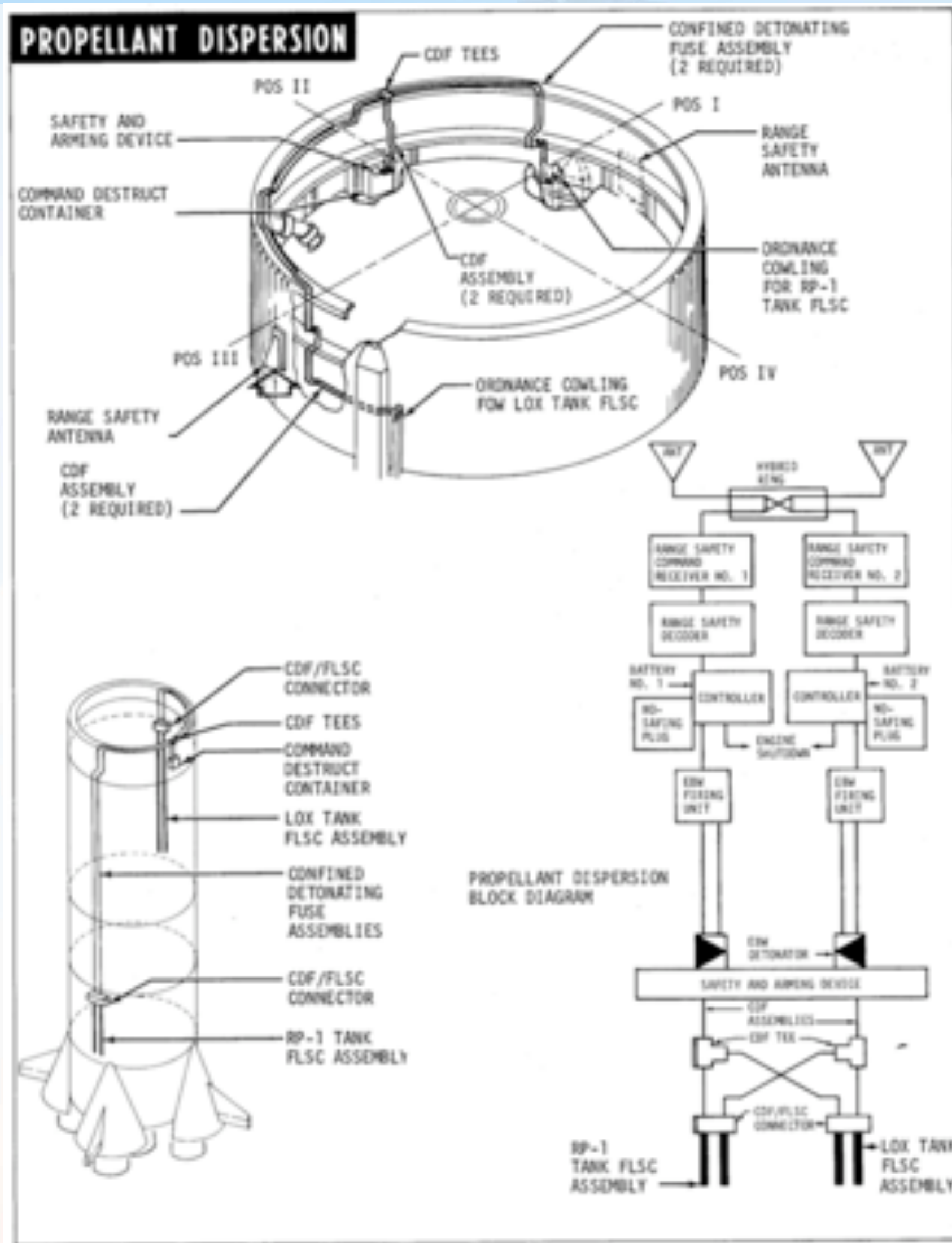


# S-II Propellant Pressurization Systems

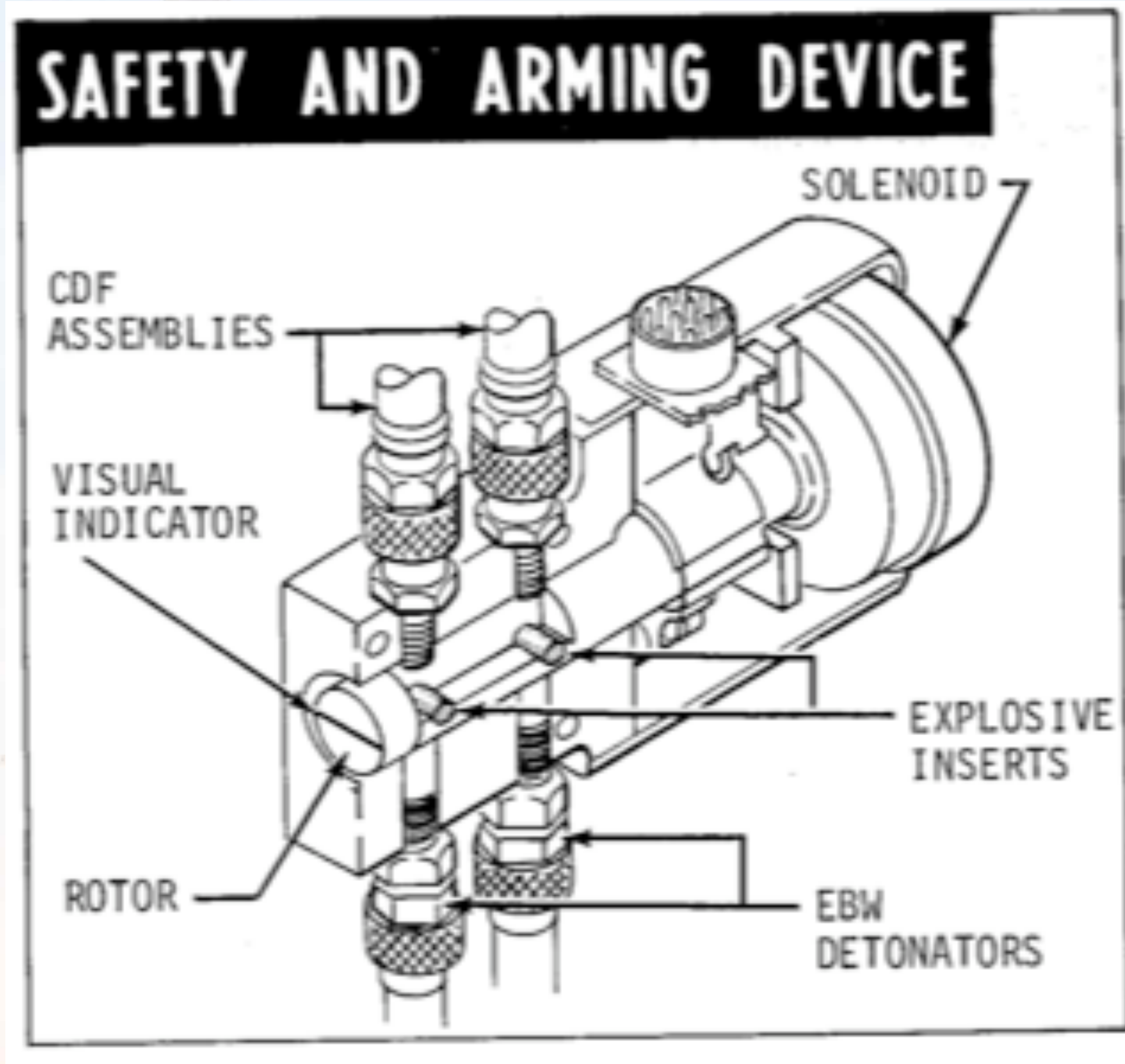




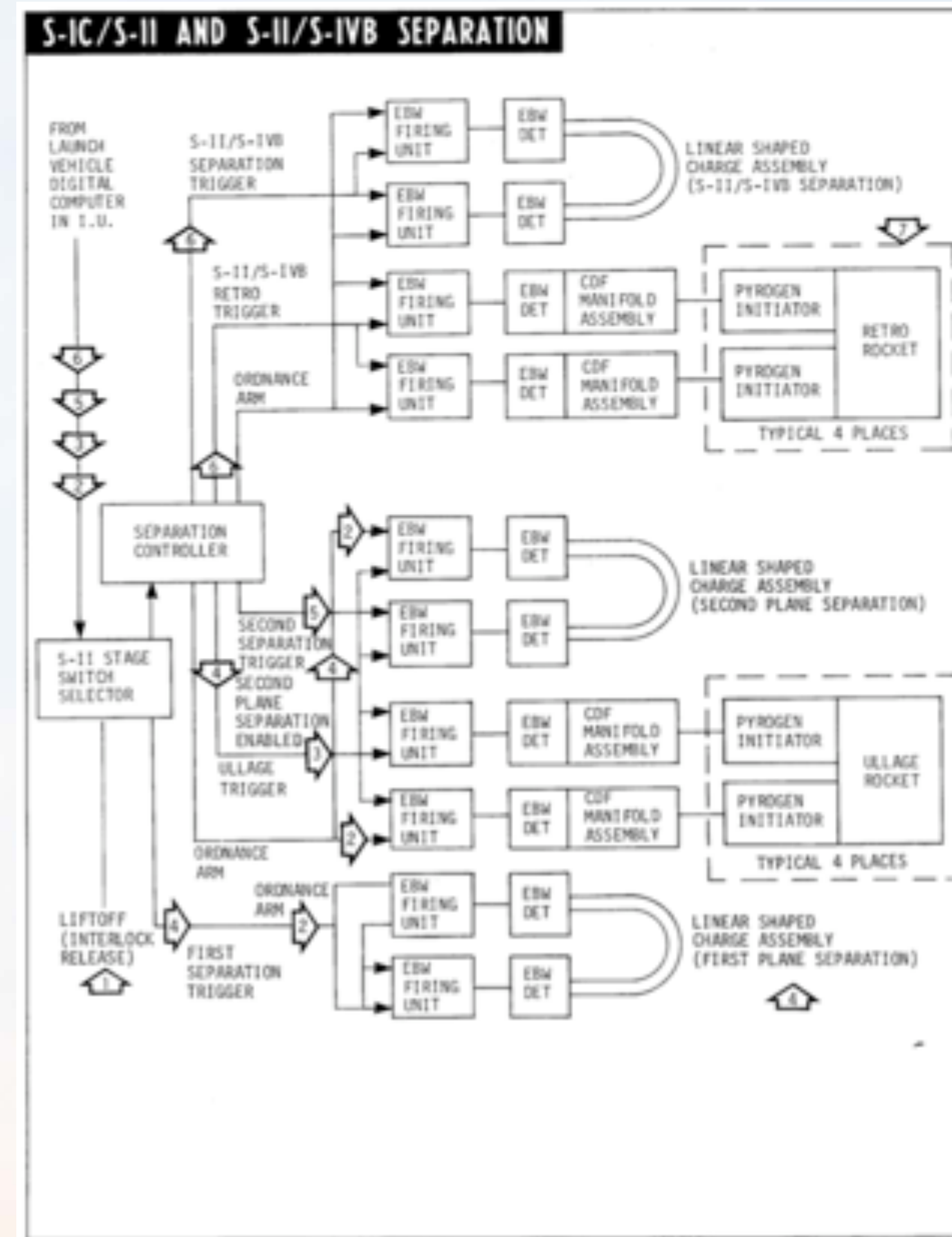
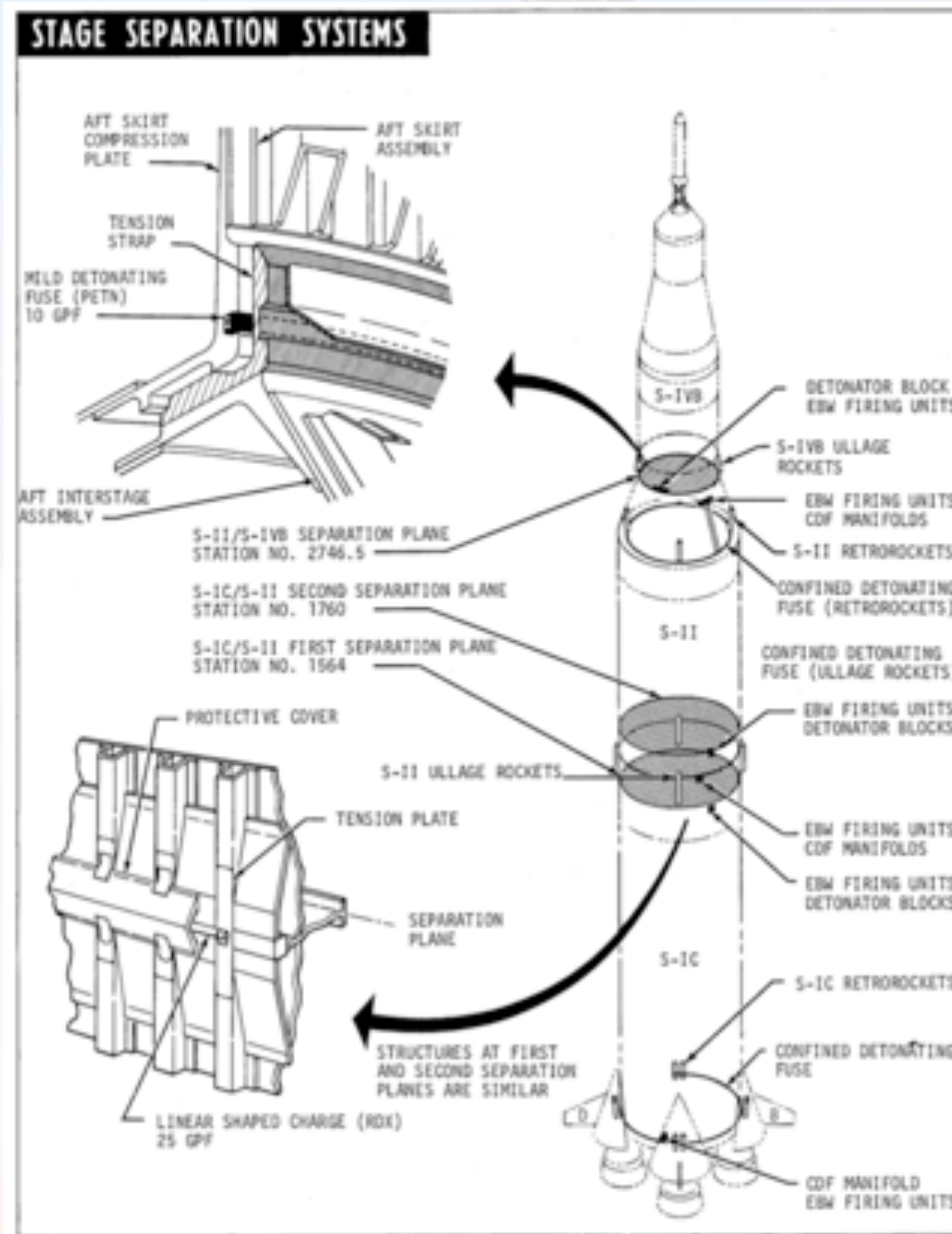
# Range Safety System (S-IC/S-II)



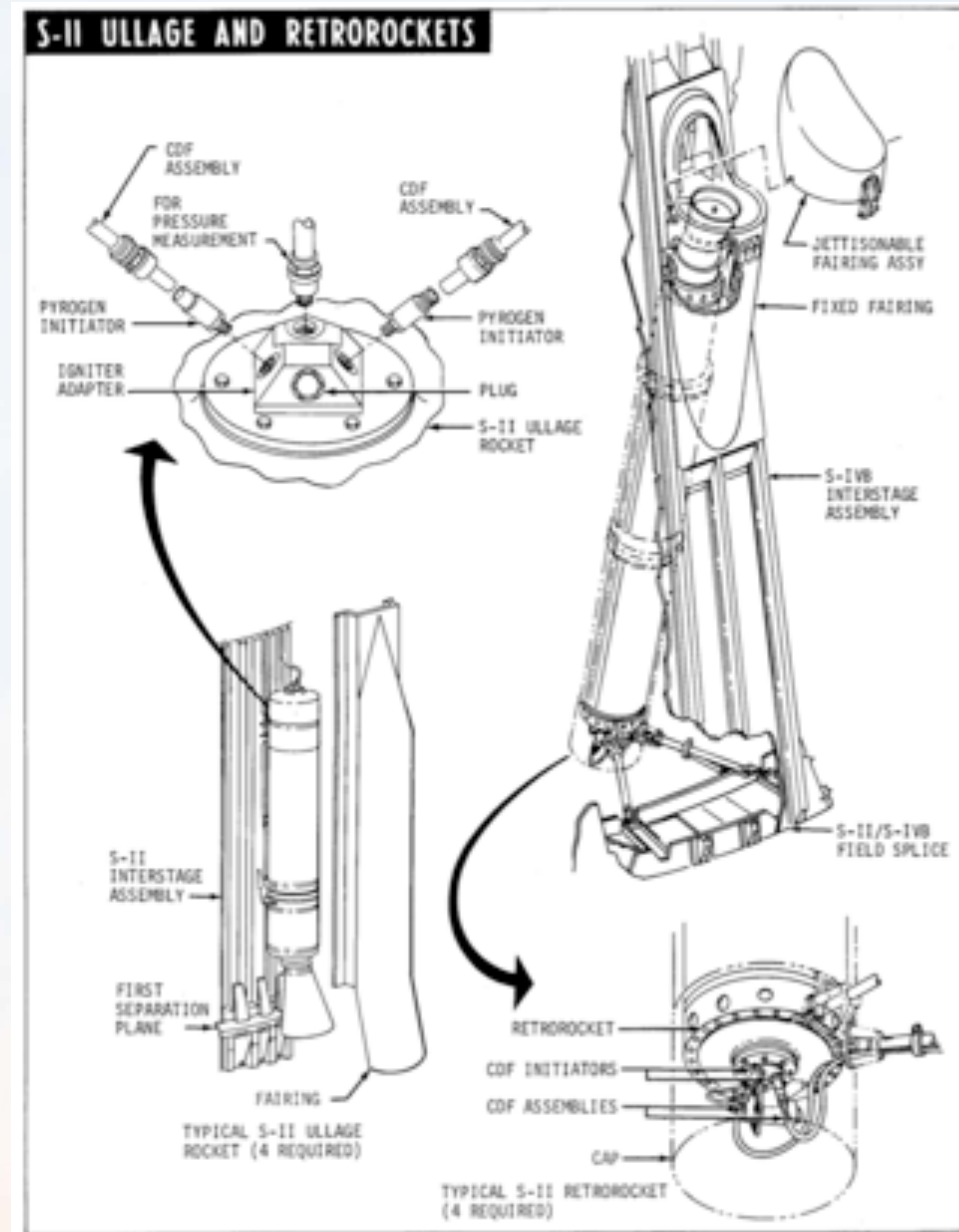
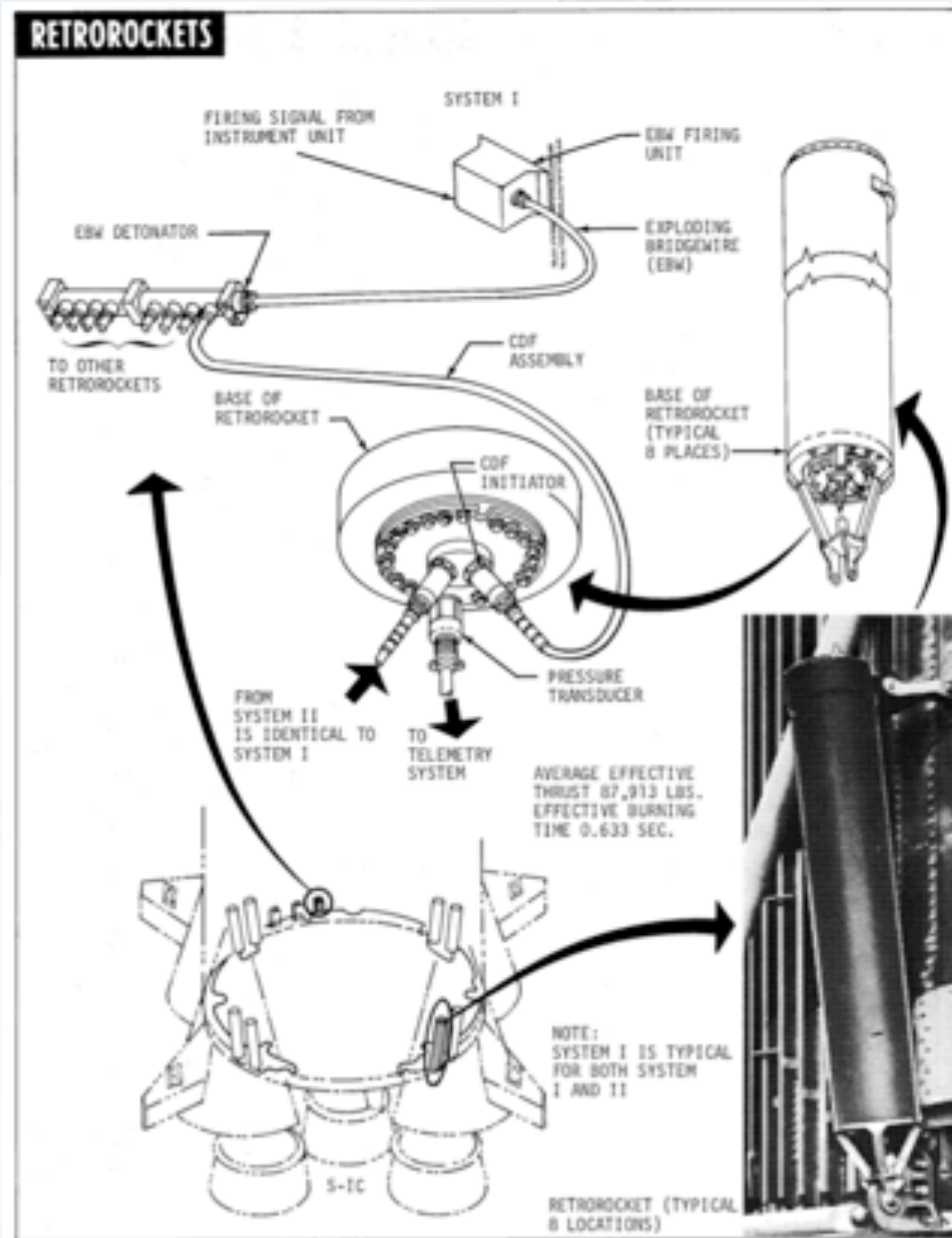
# Safe and Arm Switch



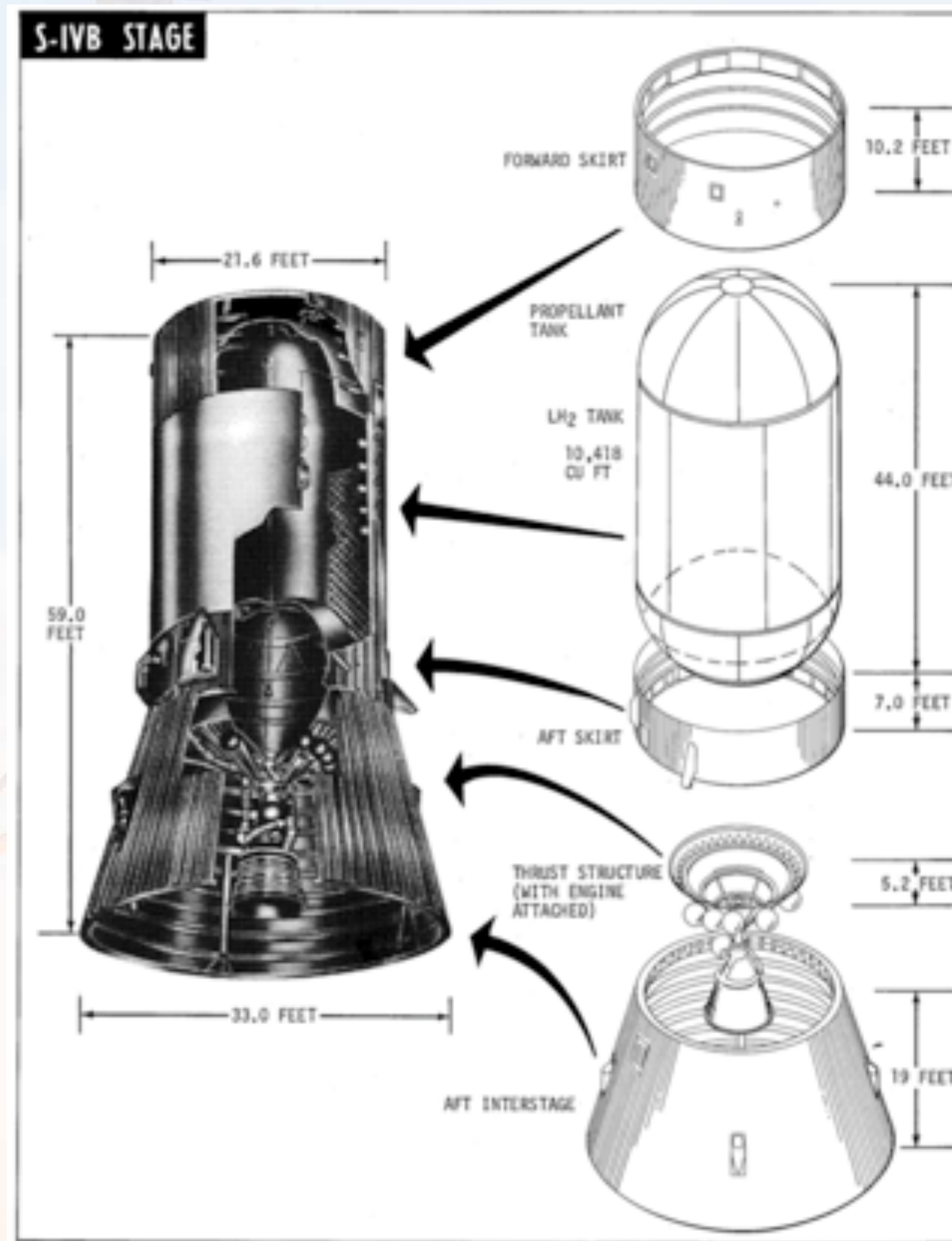
# Stage Separation



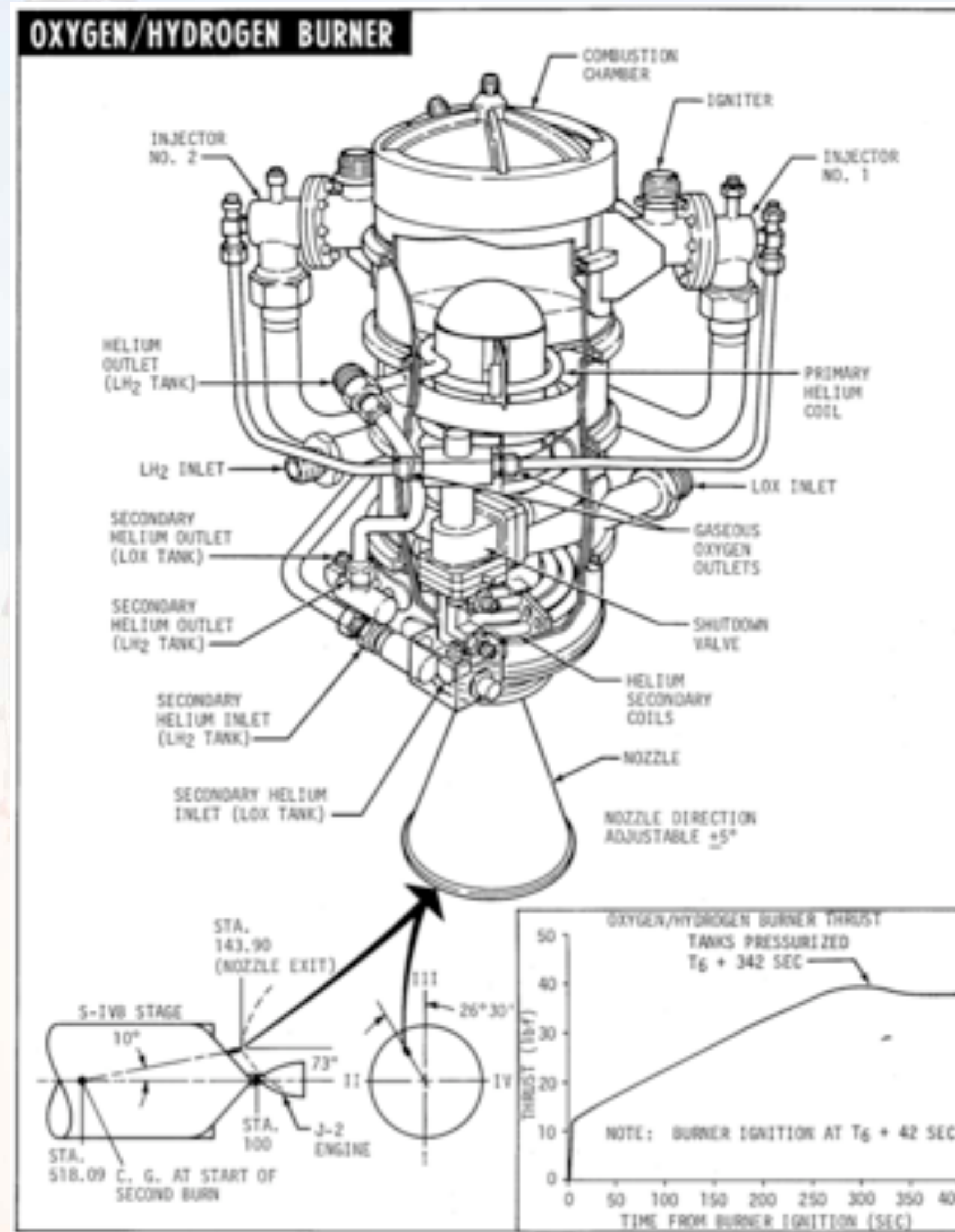
# Retro and Ullage Rockets (Stage Separation)



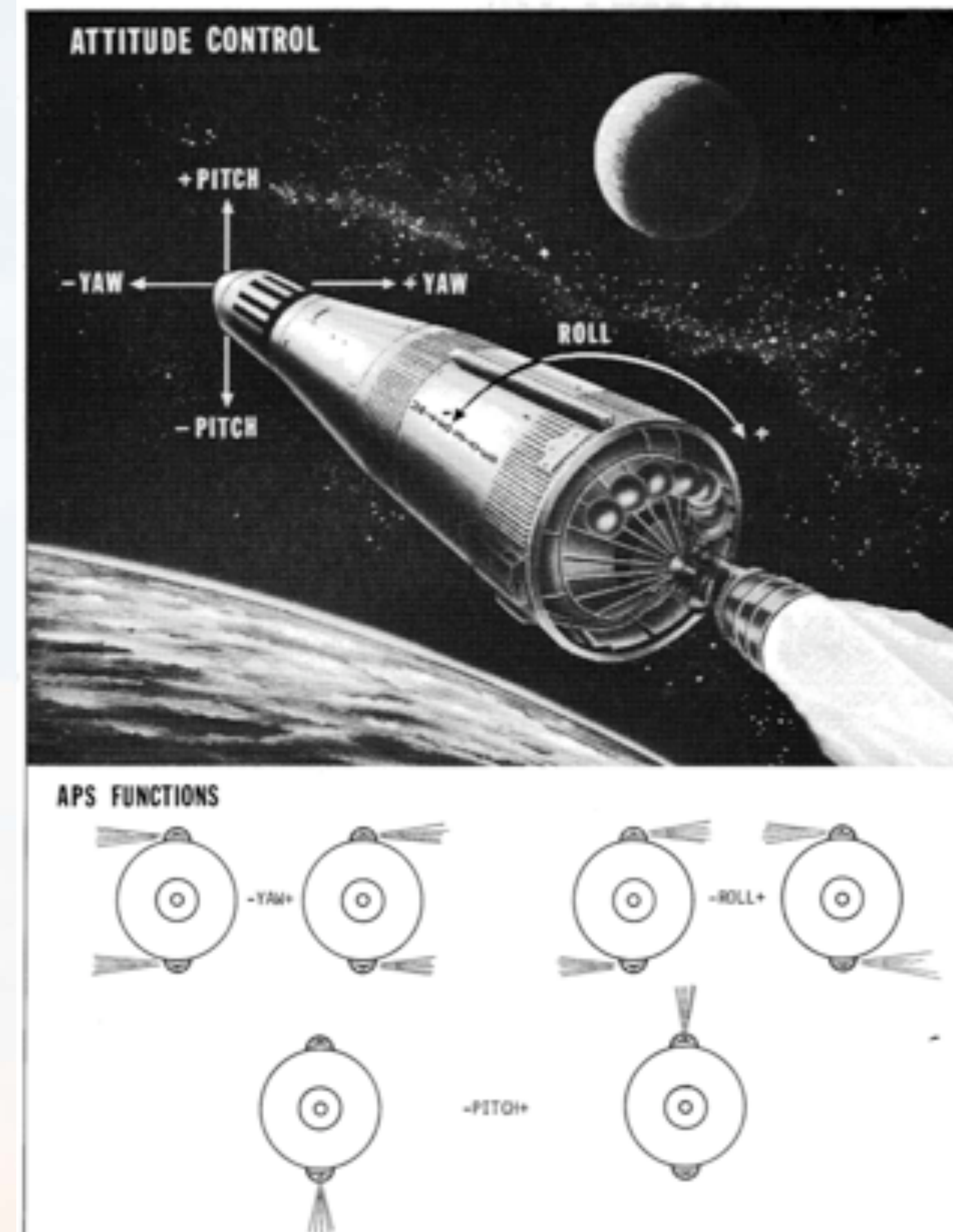
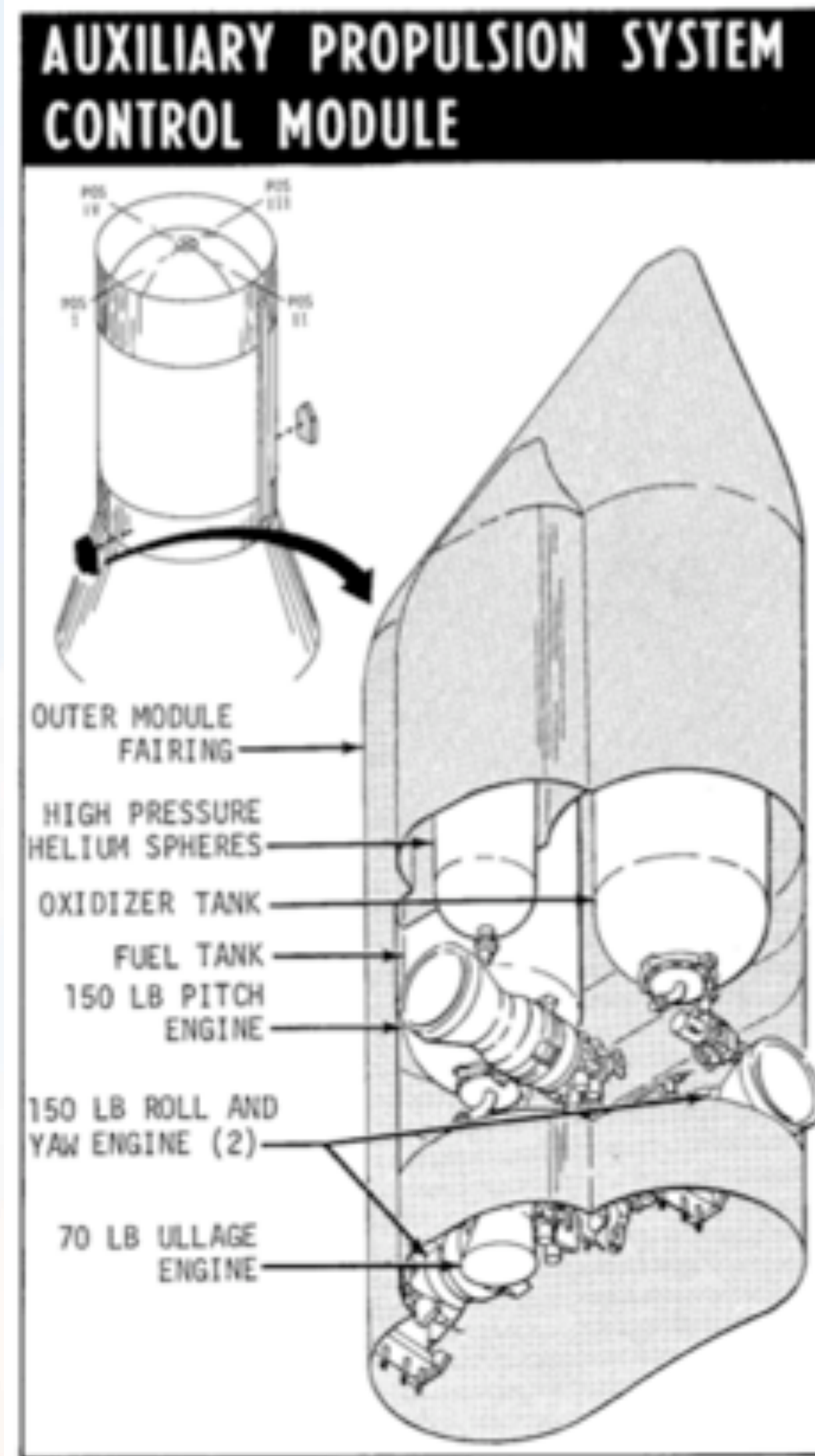
# S-IVB Configuration



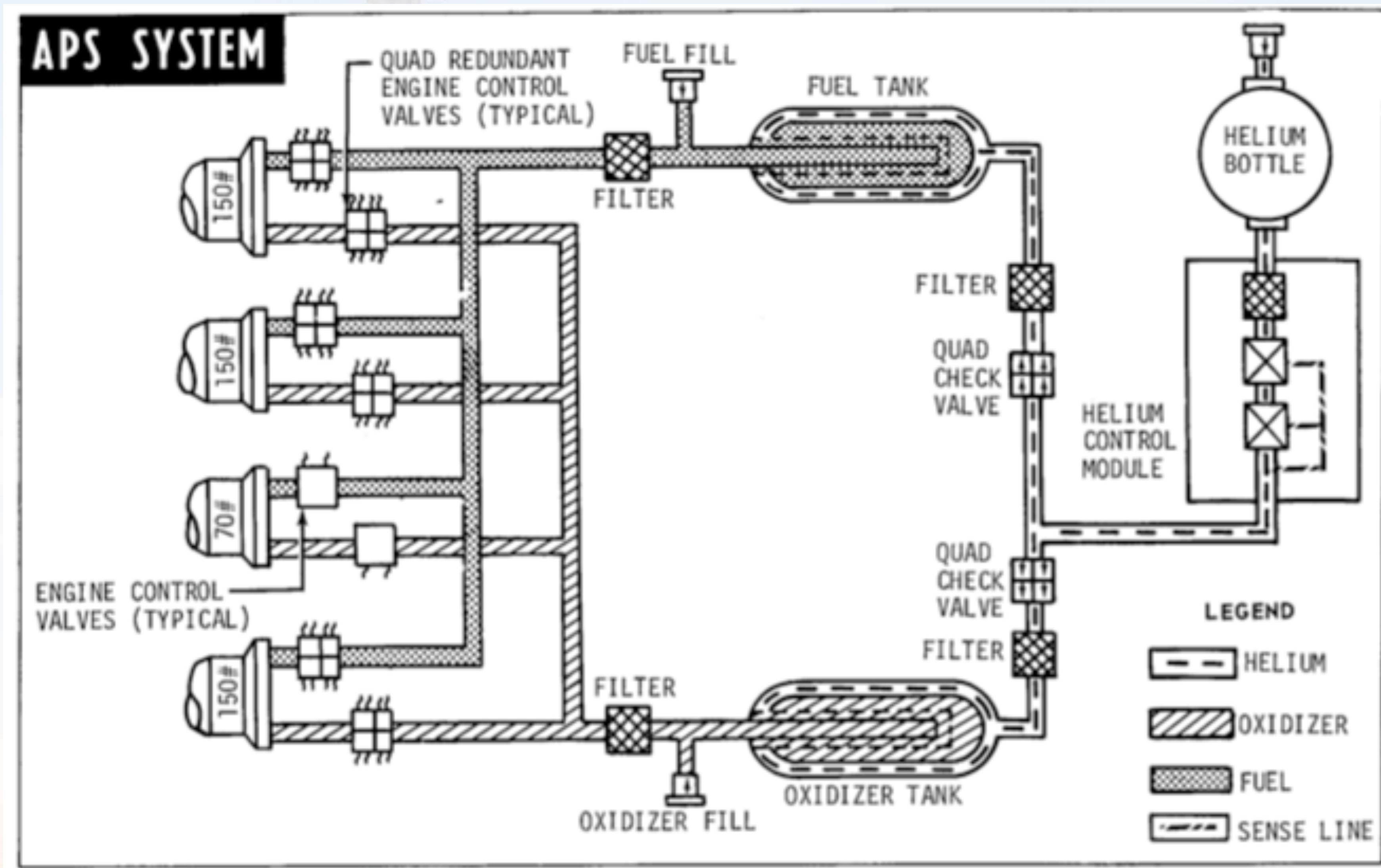
# O<sub>2</sub>/H<sub>2</sub> Burner (GHe Heater)



# S-IVB Auxiliary Propulsion System



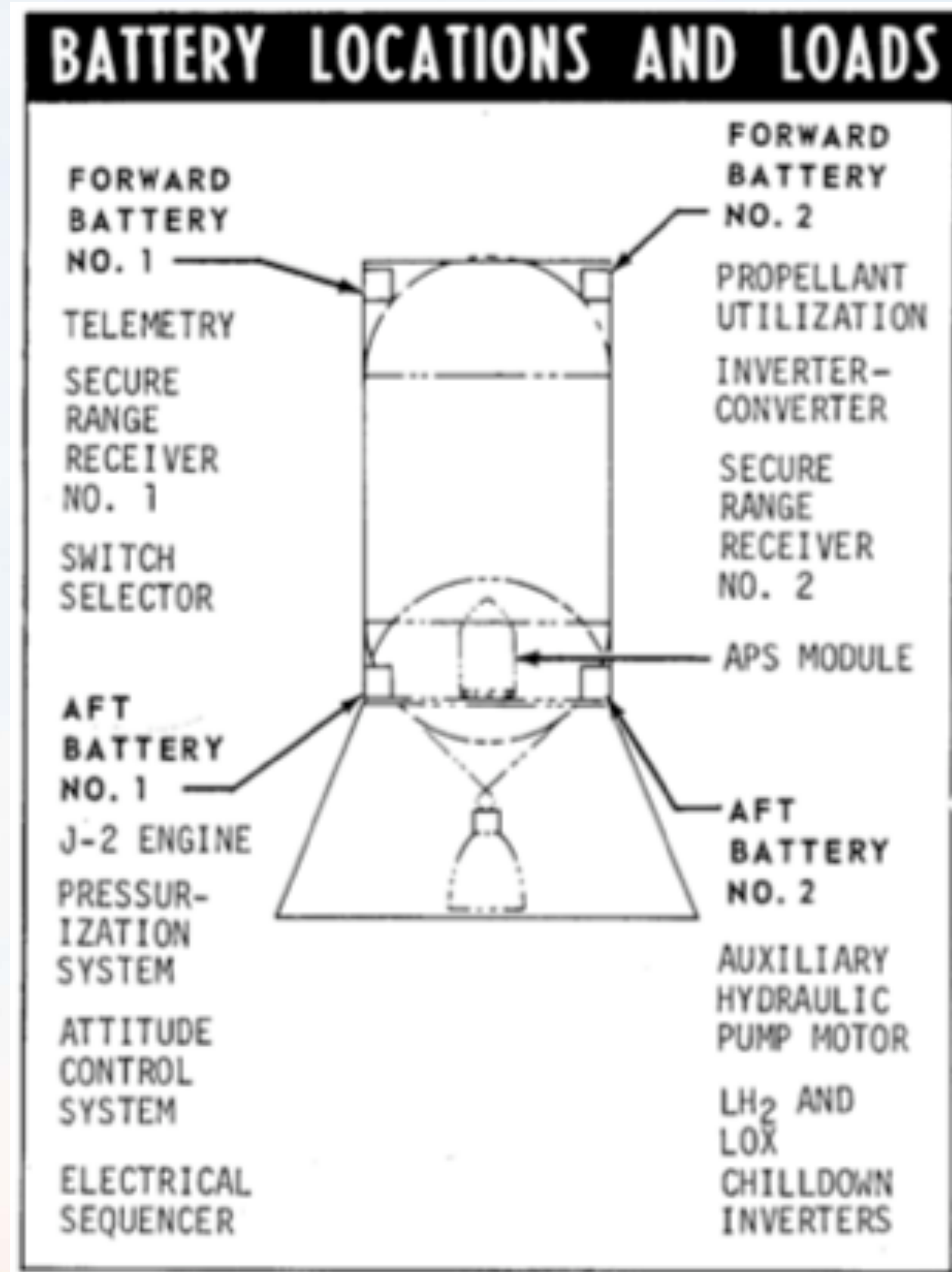
# APS Plumbing and Control



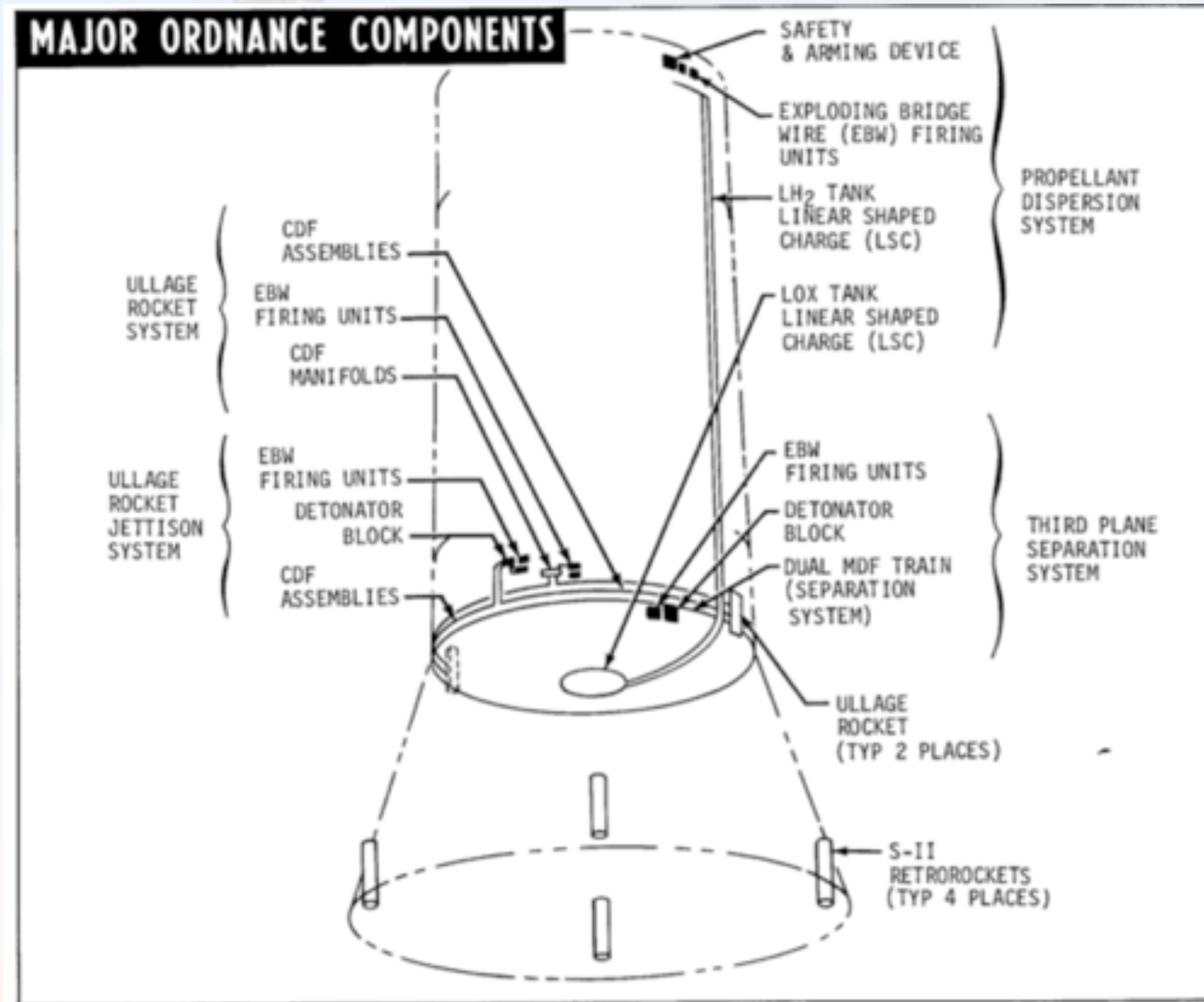


# S-IVB Battery System

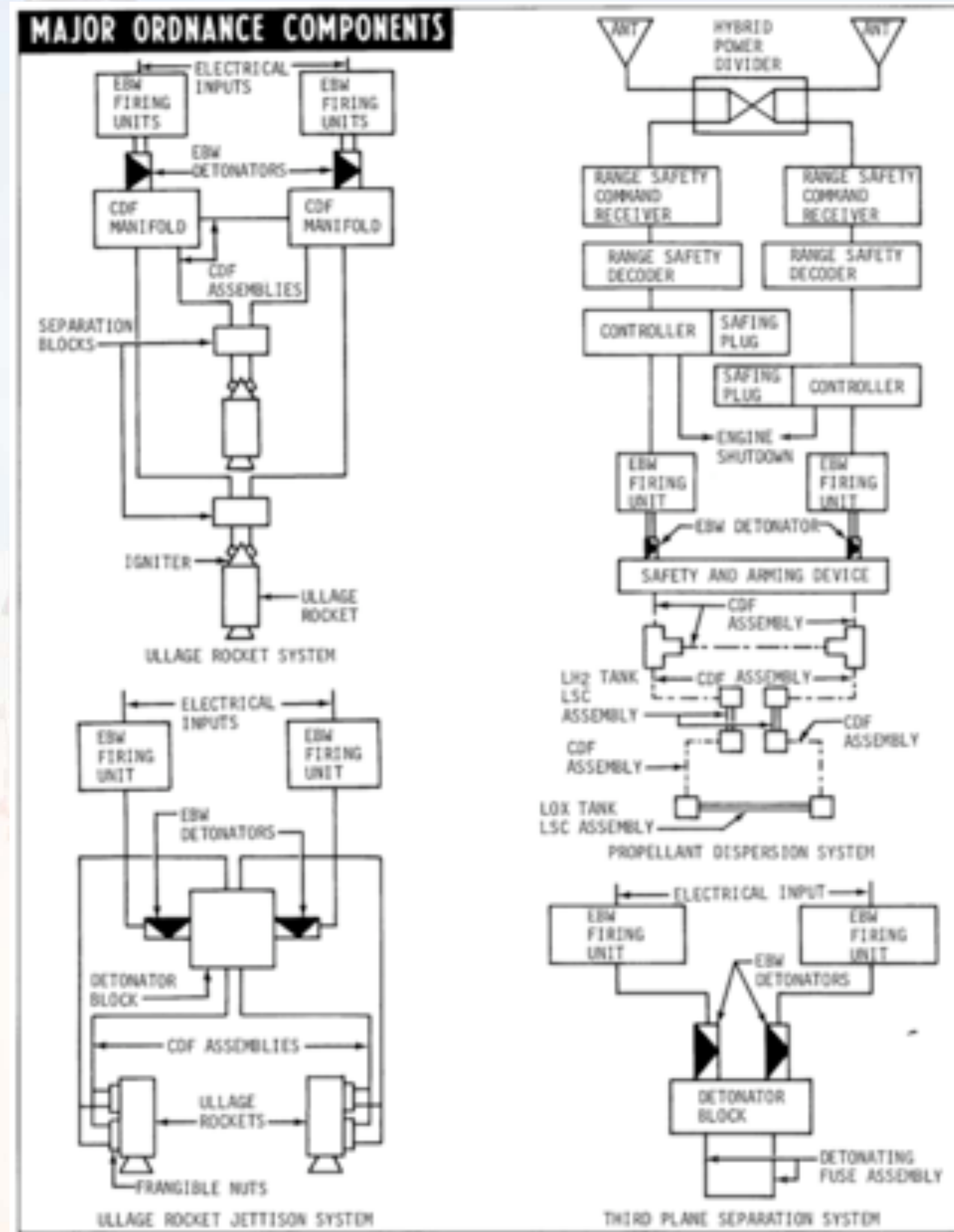
S-IVB BATTERY CHARACTERISTICS				
TYPE	Dry charge			
MATERIAL	Zinc/silver-oxide			
ELECTROLYTE	Potassium hydroxide (KOH) in pure water			
CELLS	20, with taps for selecting 18 or 19 to reduce output voltage as required			
NOMINAL VOLTAGE OUTPUT	1.5 vdc per cell 28 (+2) vdc per 18 to 20 cell group Aft Battery No. 2 is made up of two regular 28 (+2) vdc batteries and has an output of 56 (+4) vdc			
CURRENT RATING	FORWARD NO. 1	FORWARD NO. 2	AFT NO. 1	AFT NO. 2
	179 AH	12.2 AH	179 AH	49.6 AH
Gross Weight (Design target weight)	90 lbs	Two units: 20 lbs ea.	90 lbs	75 lbs



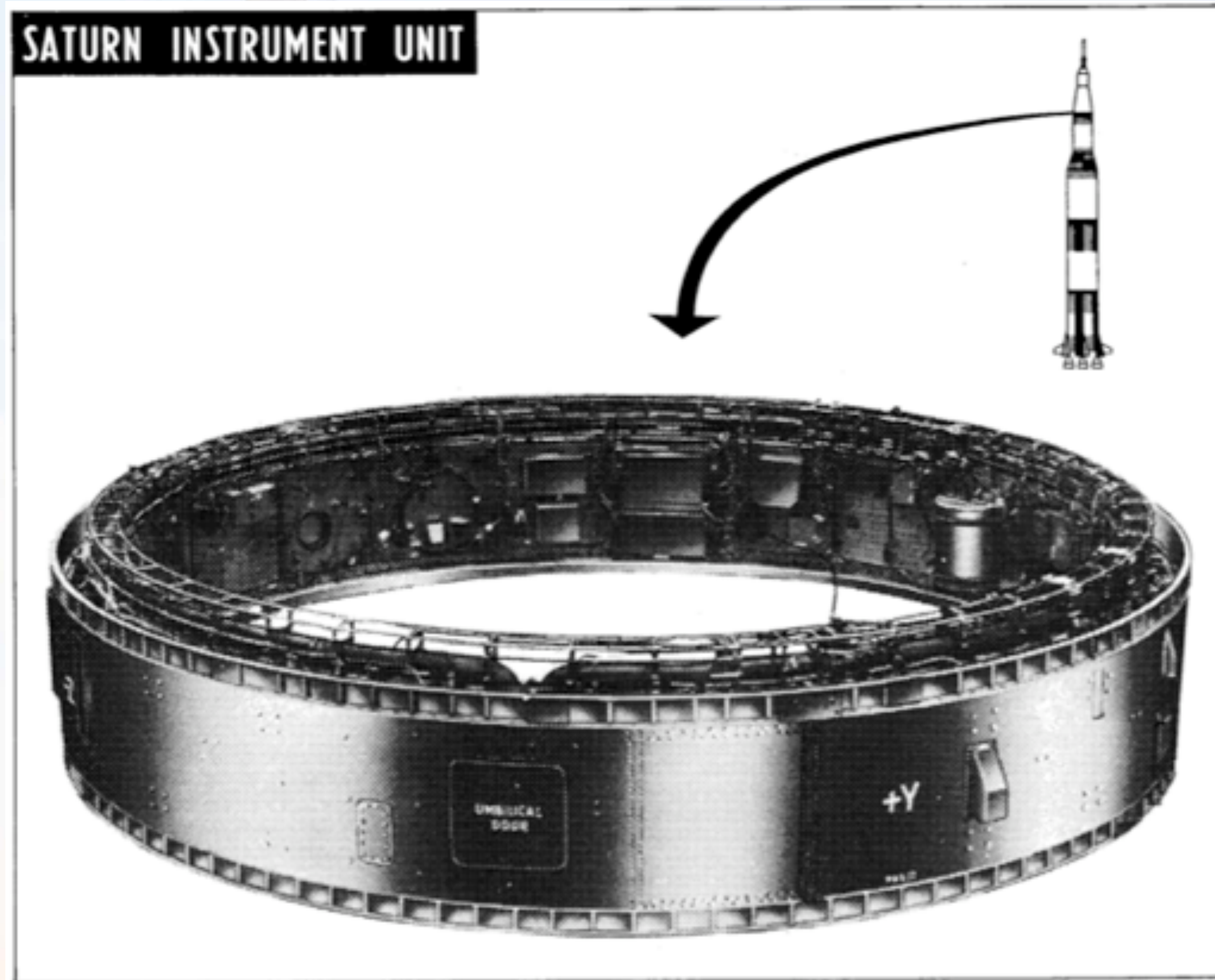
# S-IVB Pyrotechnics



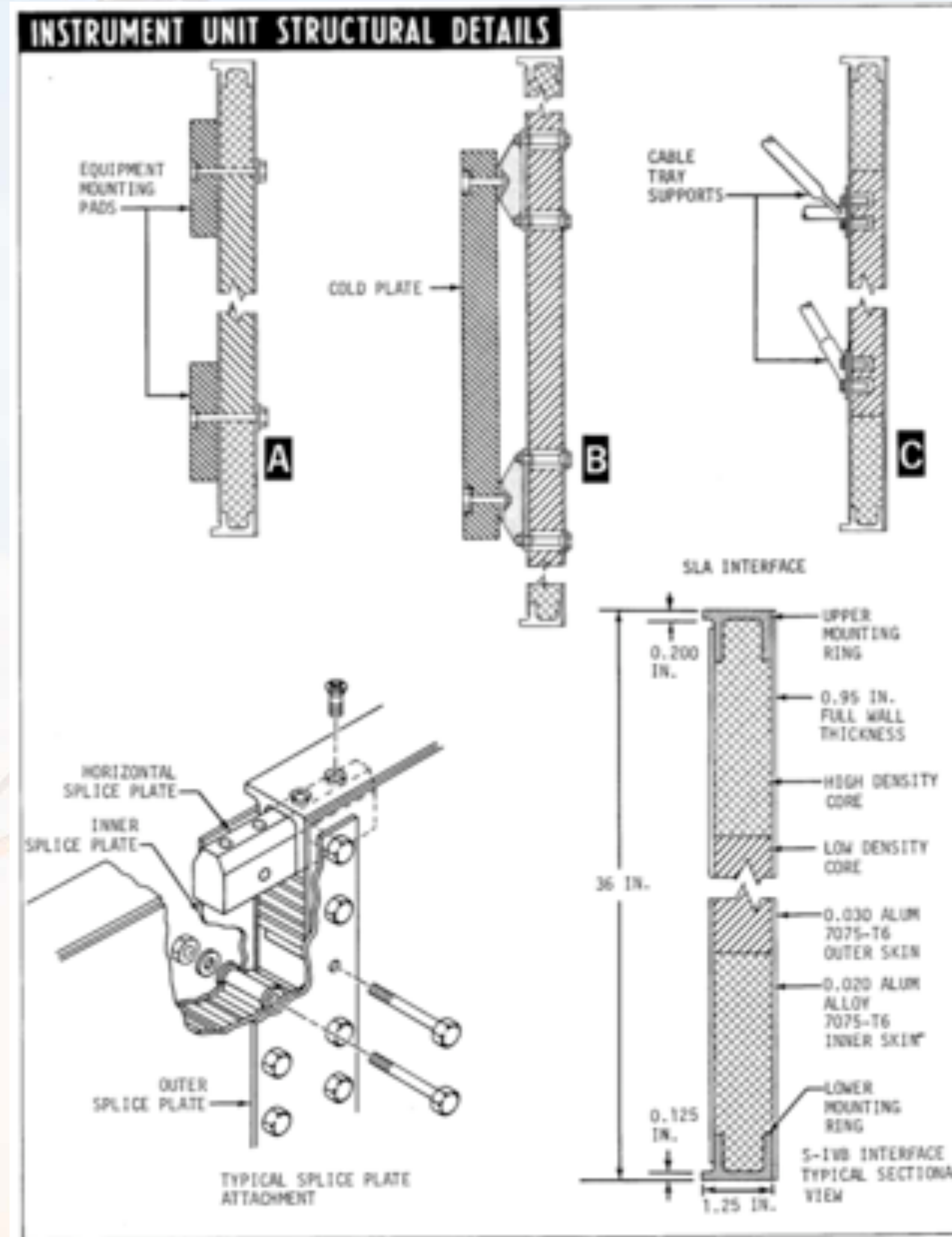
# S-IVB Ordinance Control



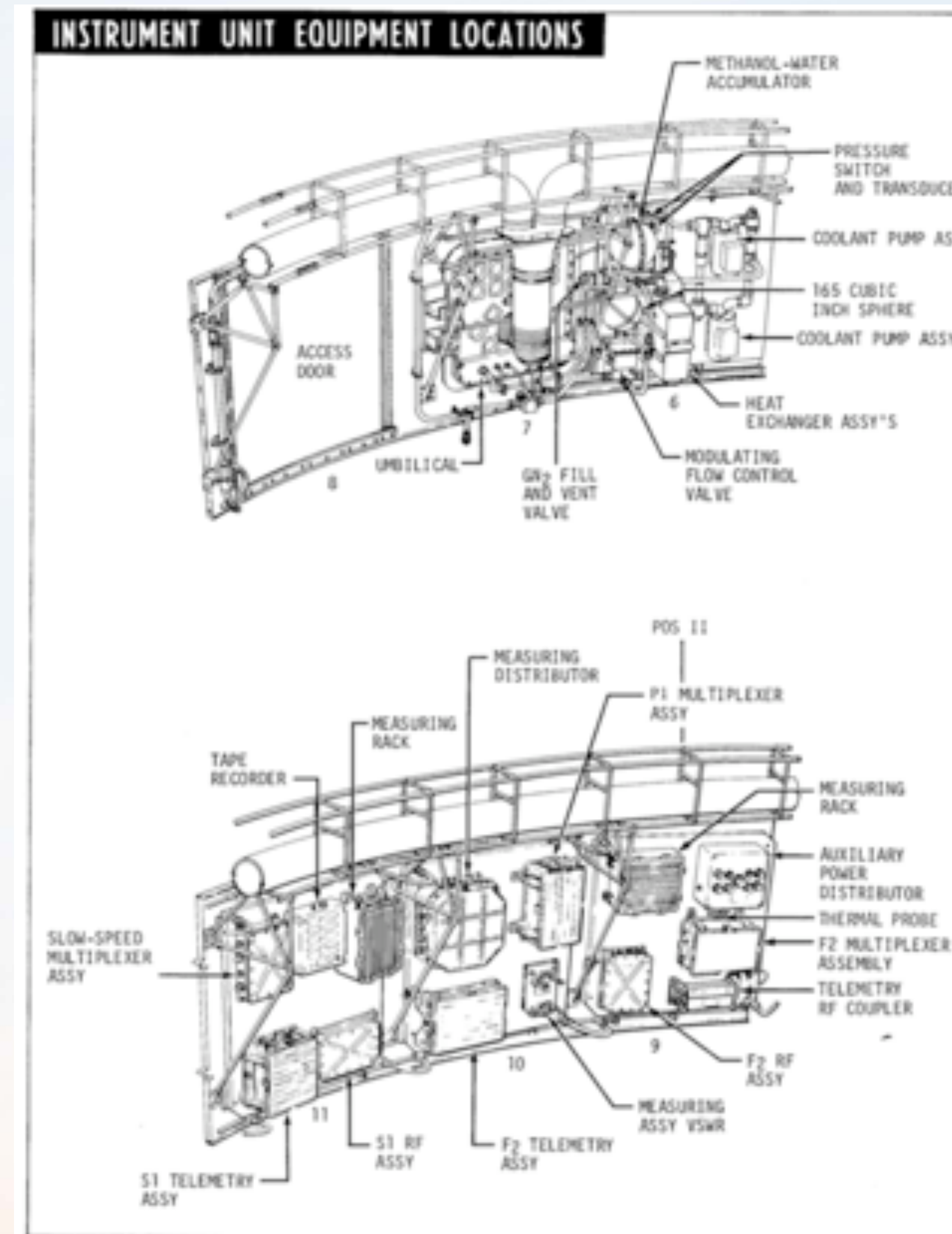
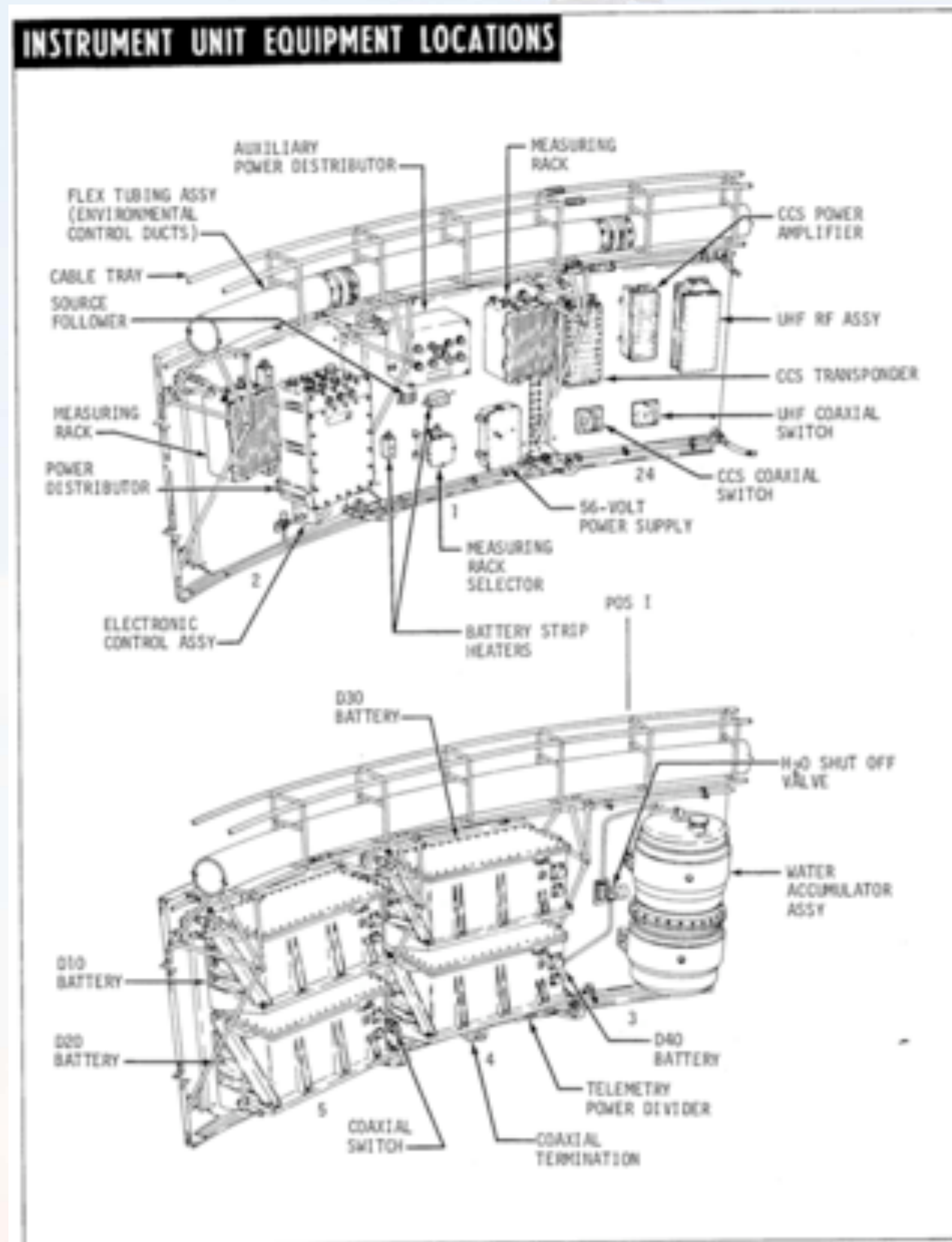
# Saturn Instrument Unit



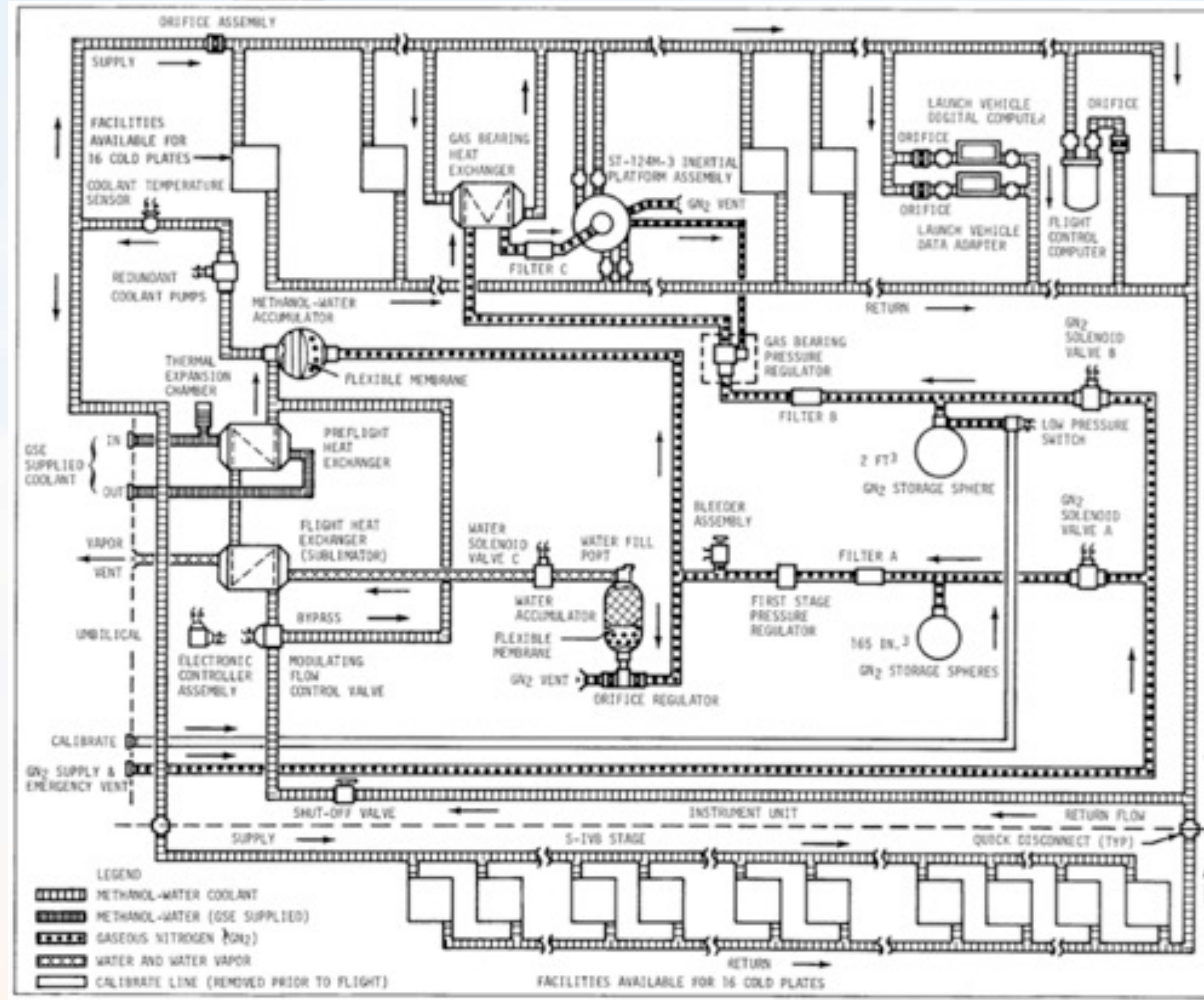
# IU Structural Details



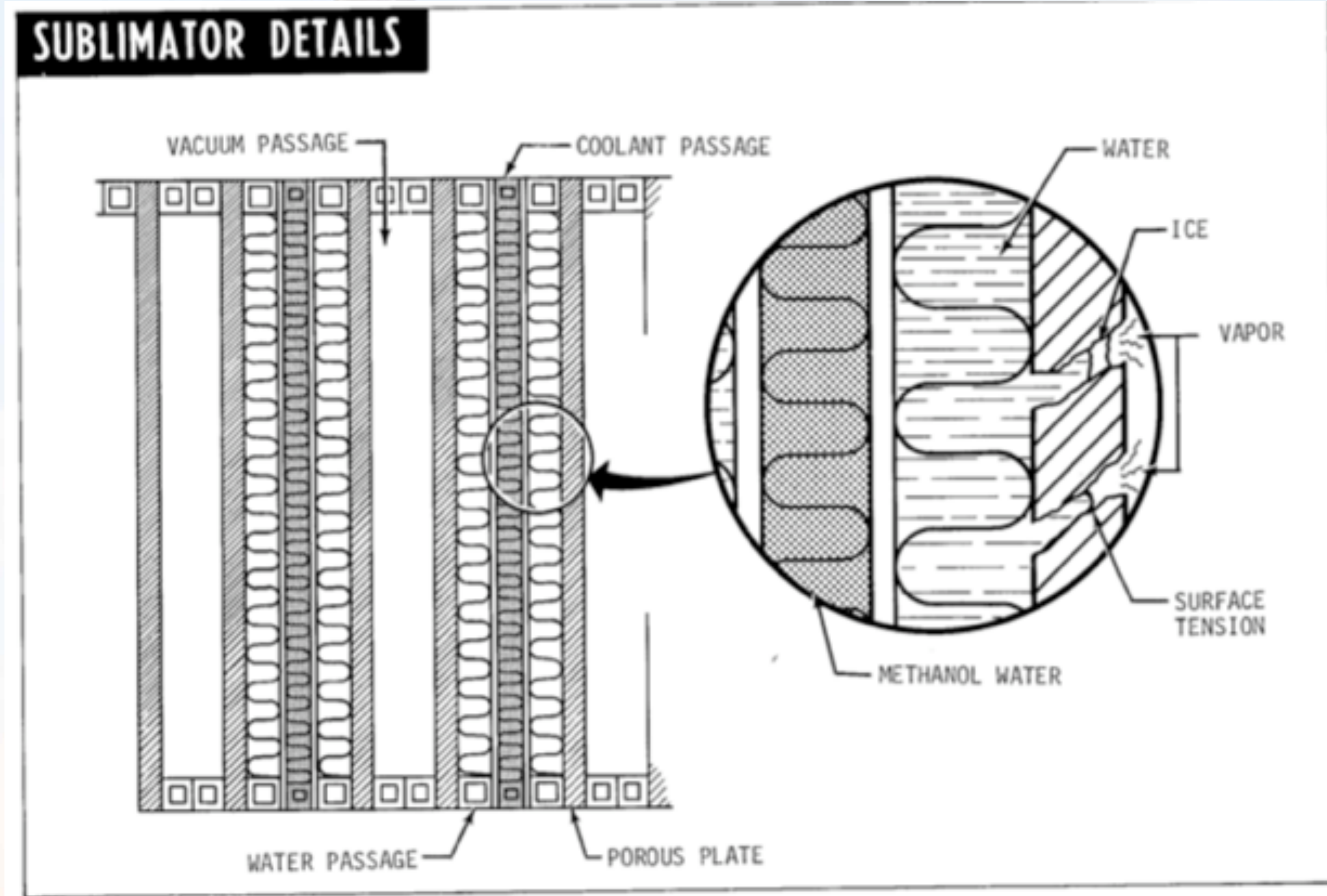
# IU Equipment Locations



# IU Thermal Conditioning System

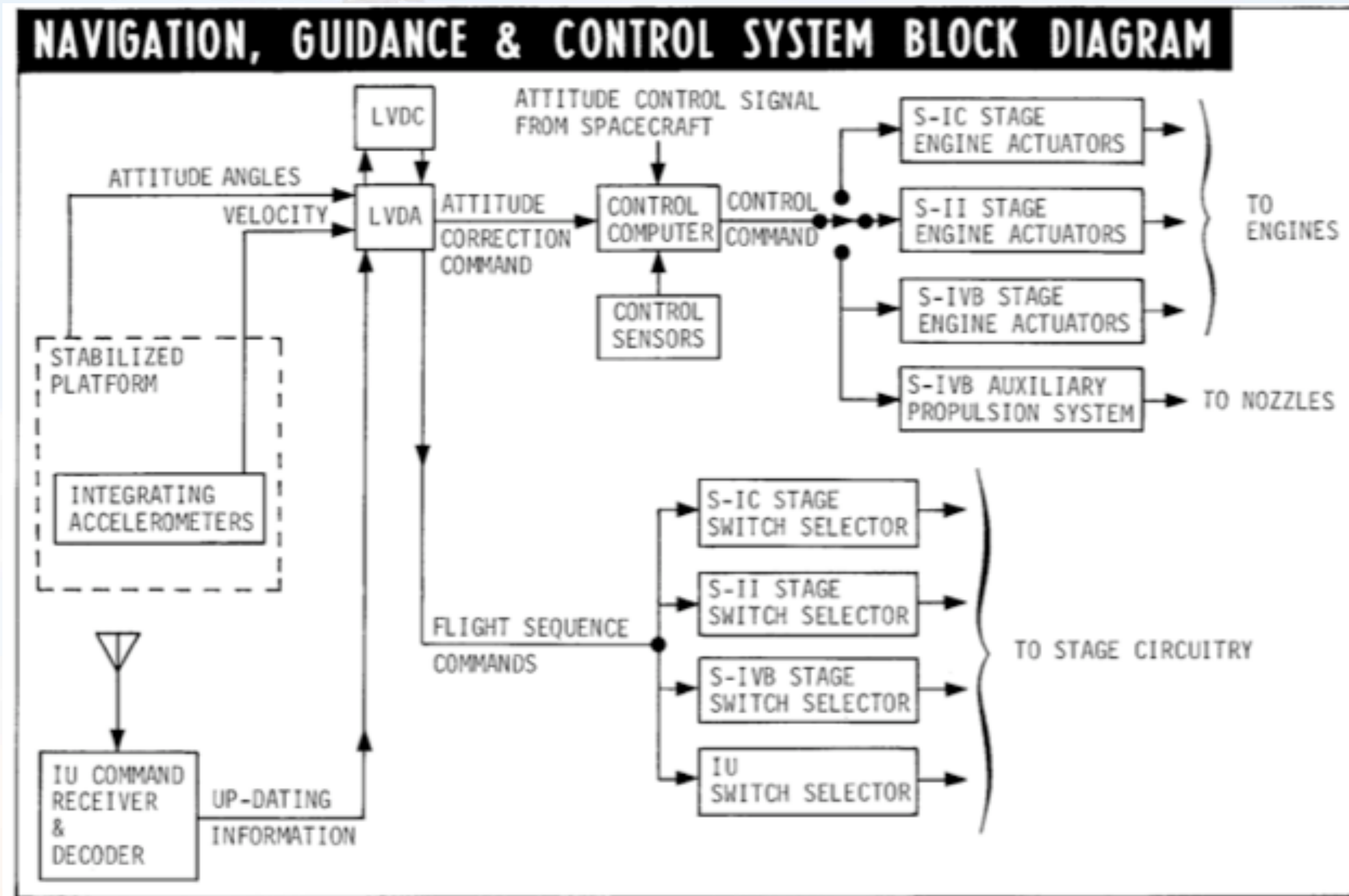


# IU Thermal Conditioning Sublimator

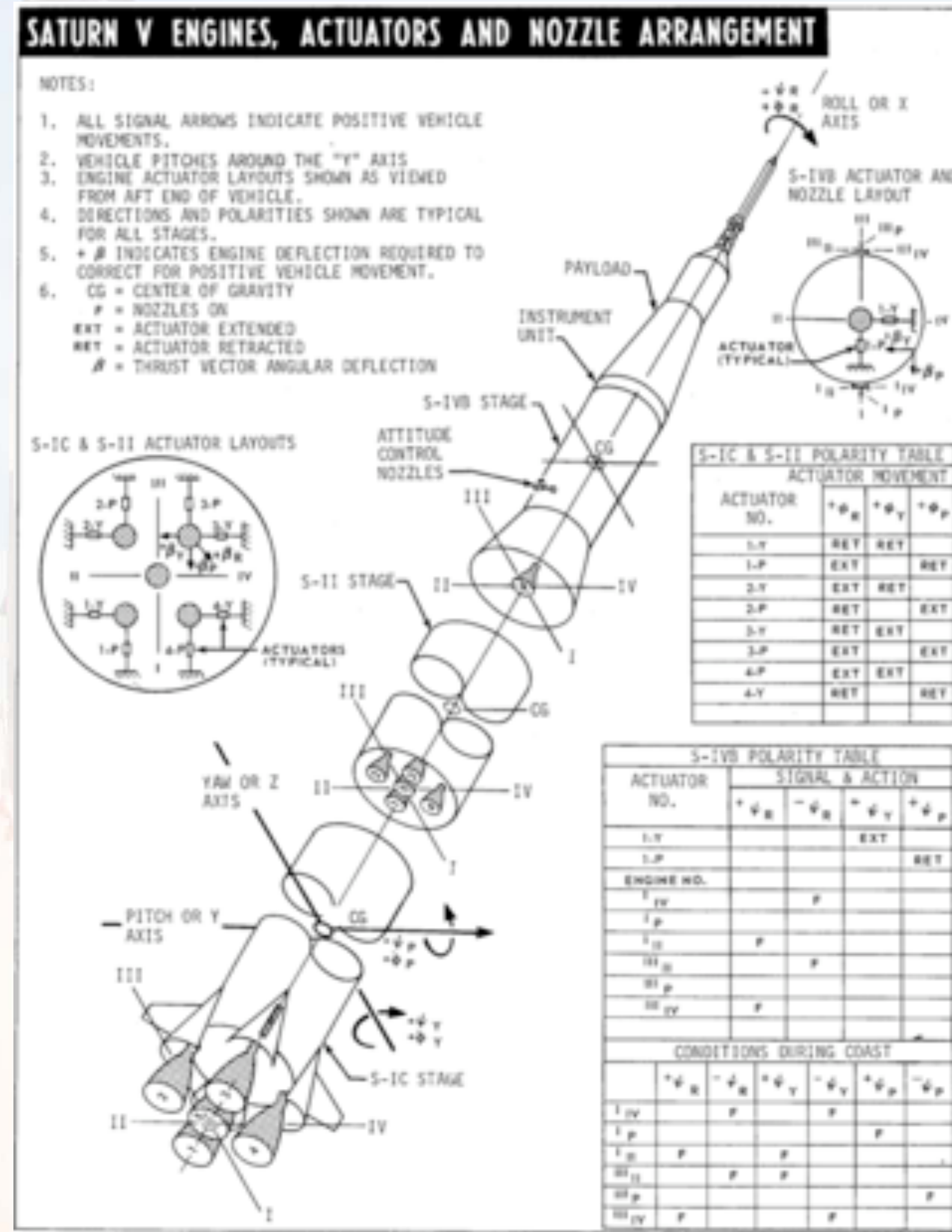




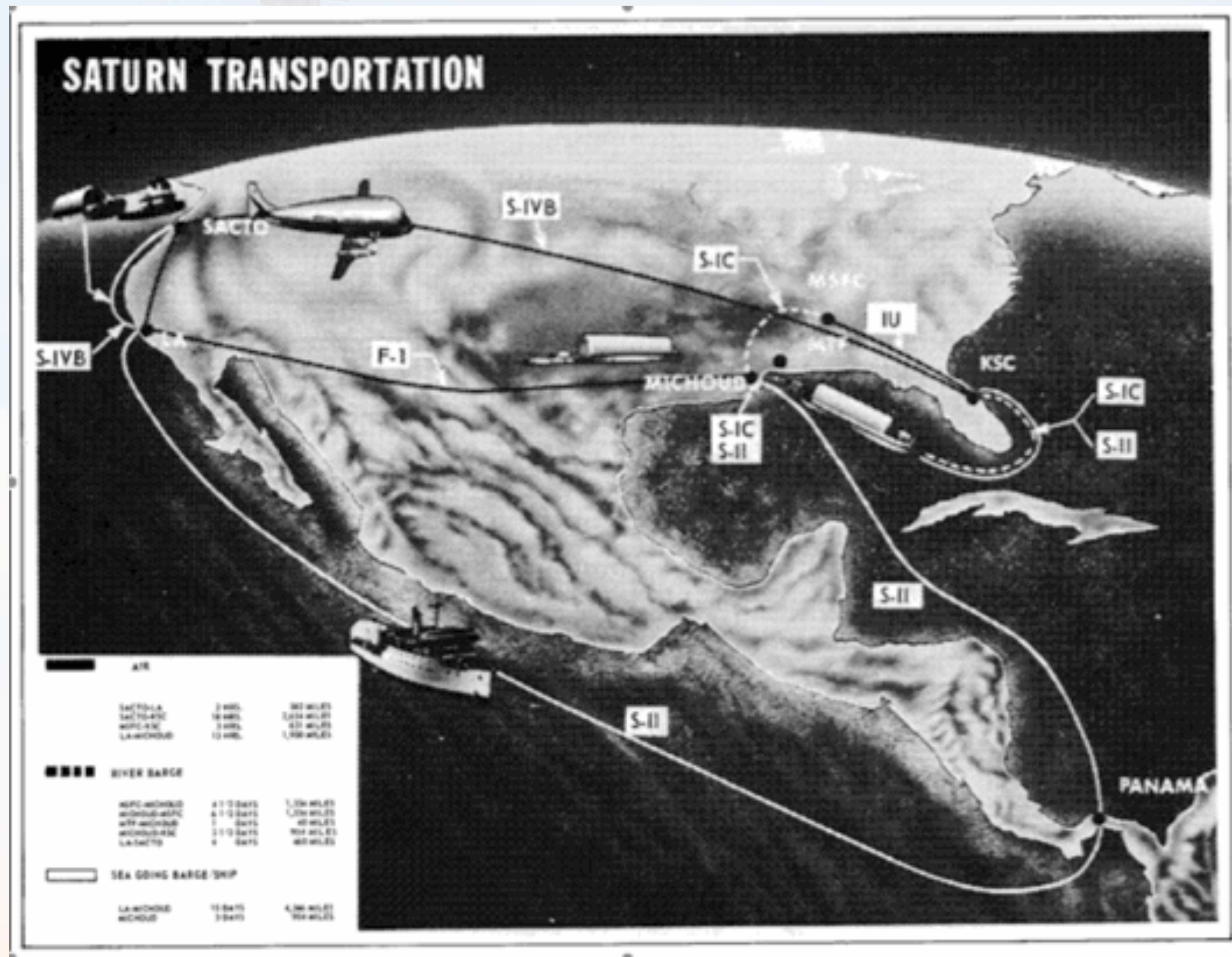
# GN&C System Block Diagram



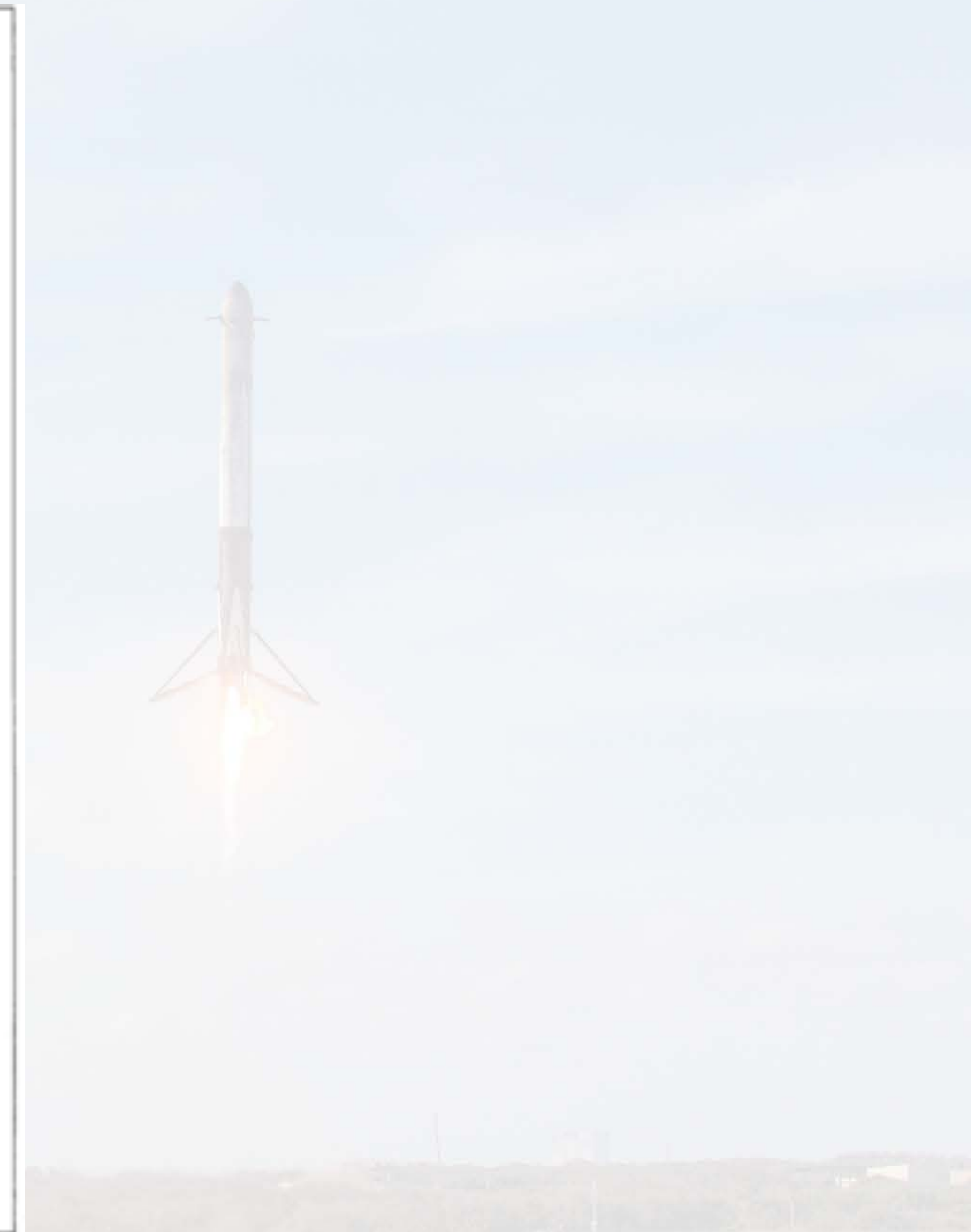
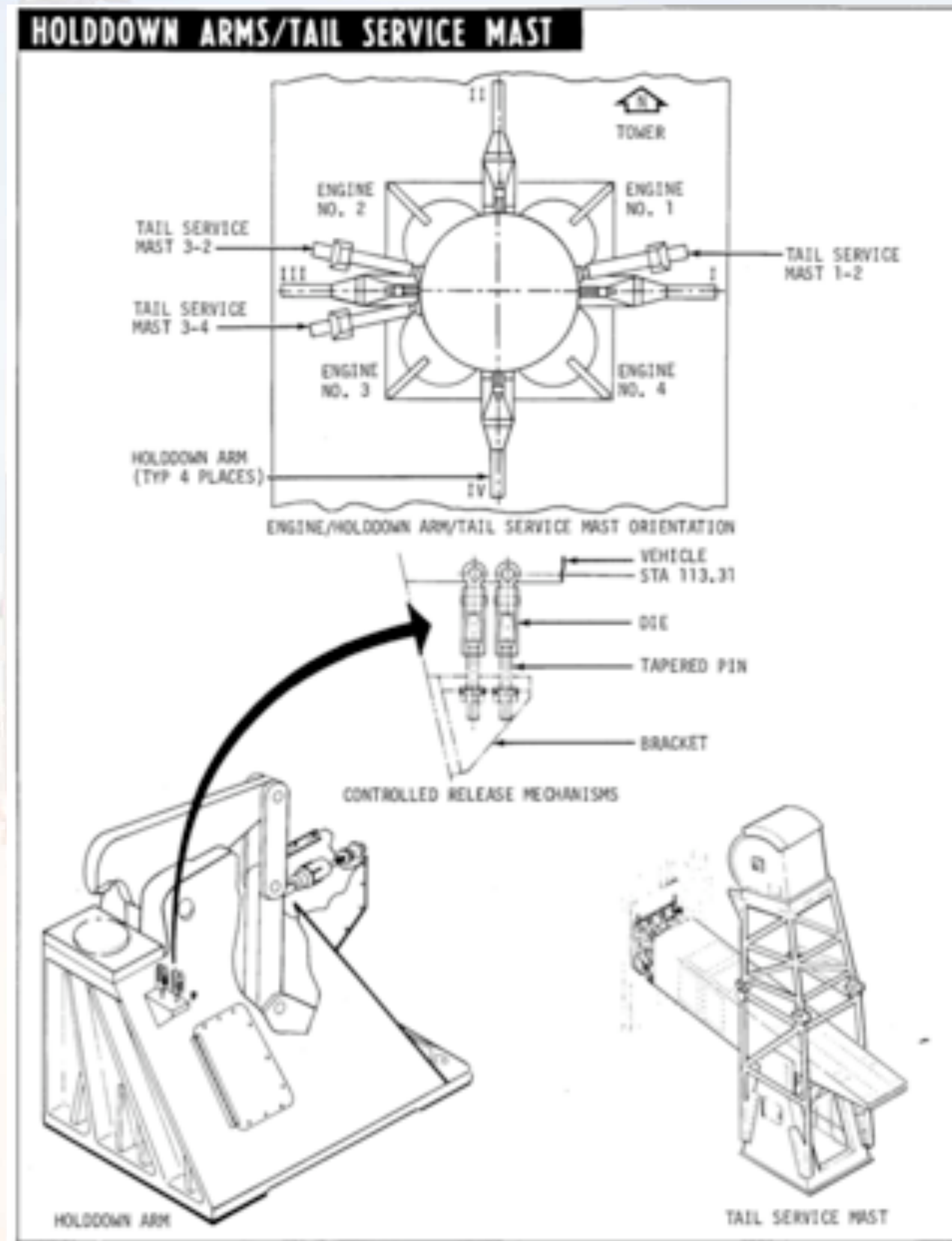
# Vehicle Control Actuators



# Ground Handling of Components



# Launch Pad Interfaces



# Emergency Pad Egress

