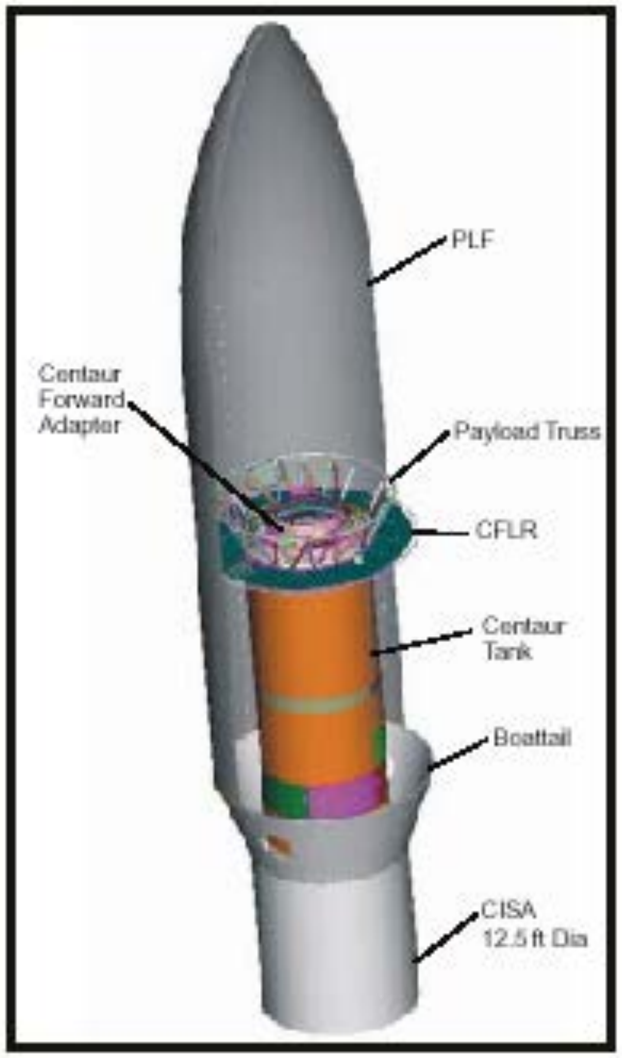
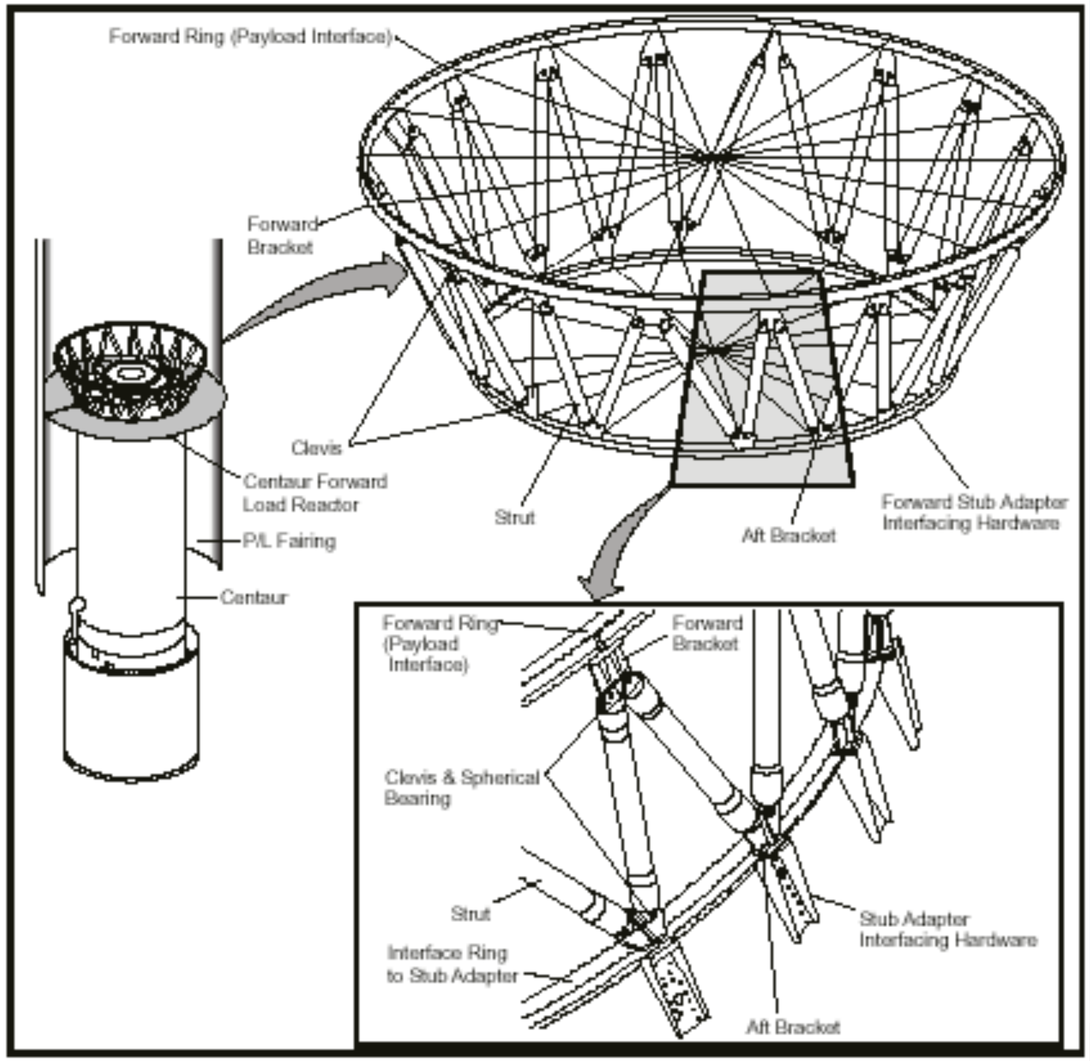
Vehicle Structures and Mechanisms

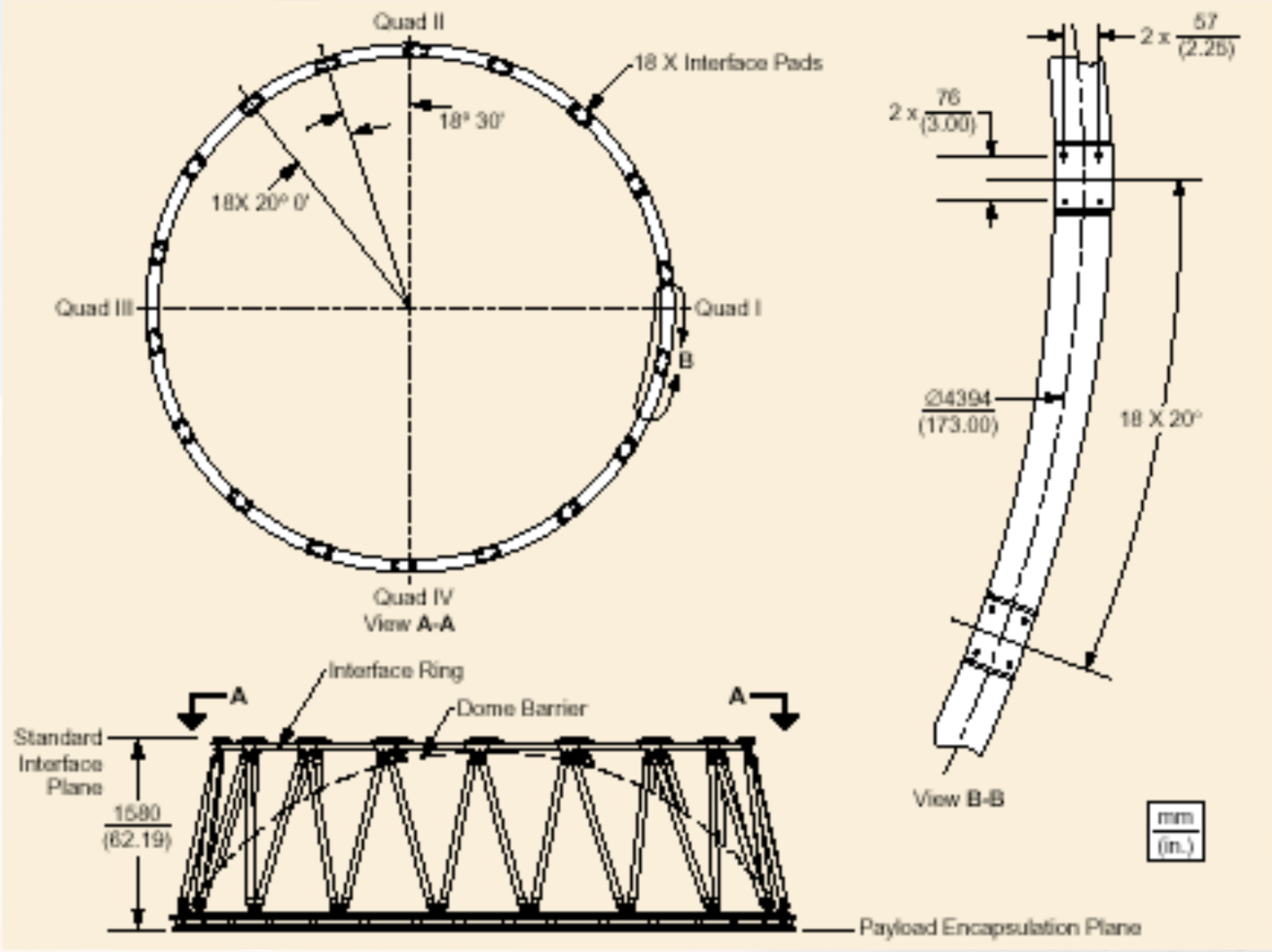
- Payload interfaces to launch vehicles
- Examples of structural design approaches from past space vehicle structural designs
- Examples of current structural concepts for Constellation vehicles and other human lunar programs
- Mechanisms and pyrotechnics

Atlas V Payload Fairing Configuration

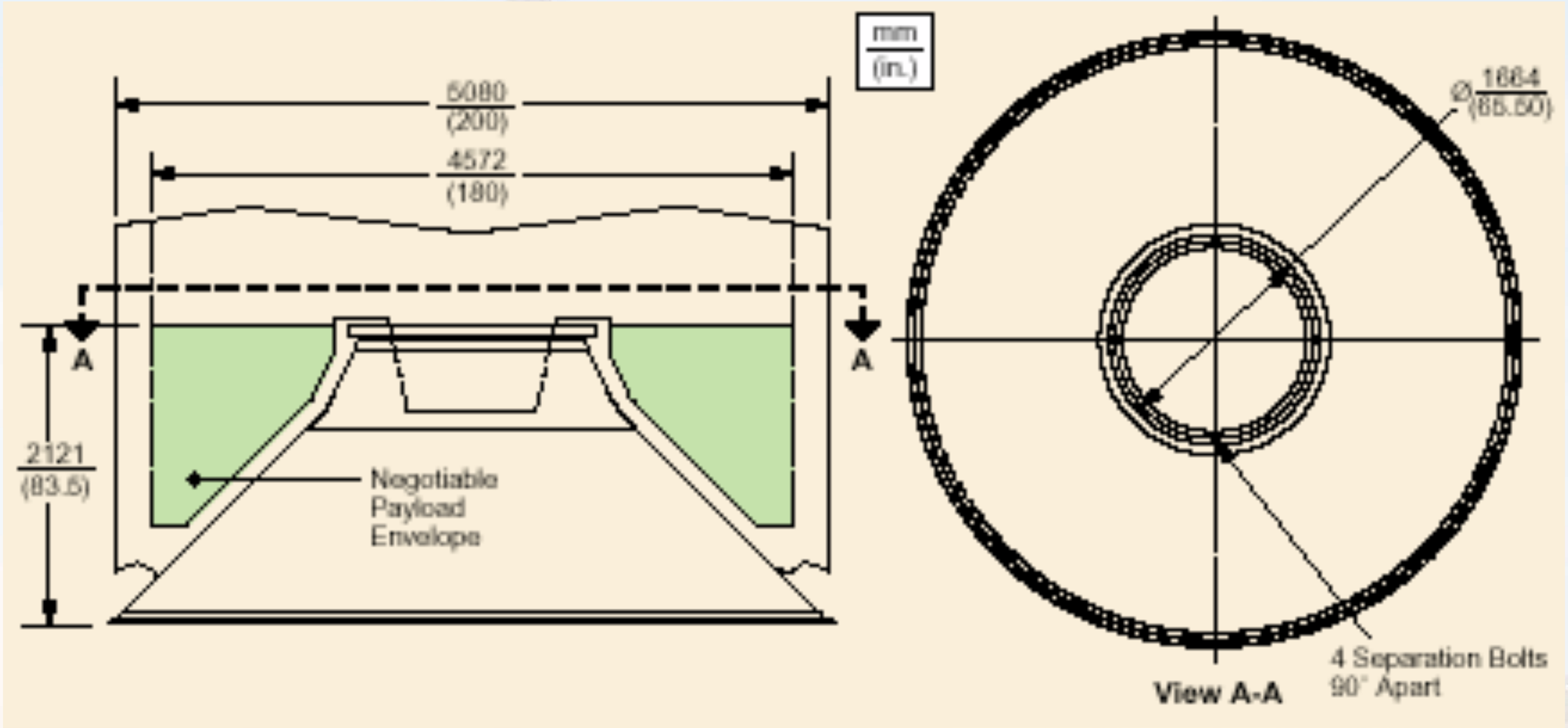




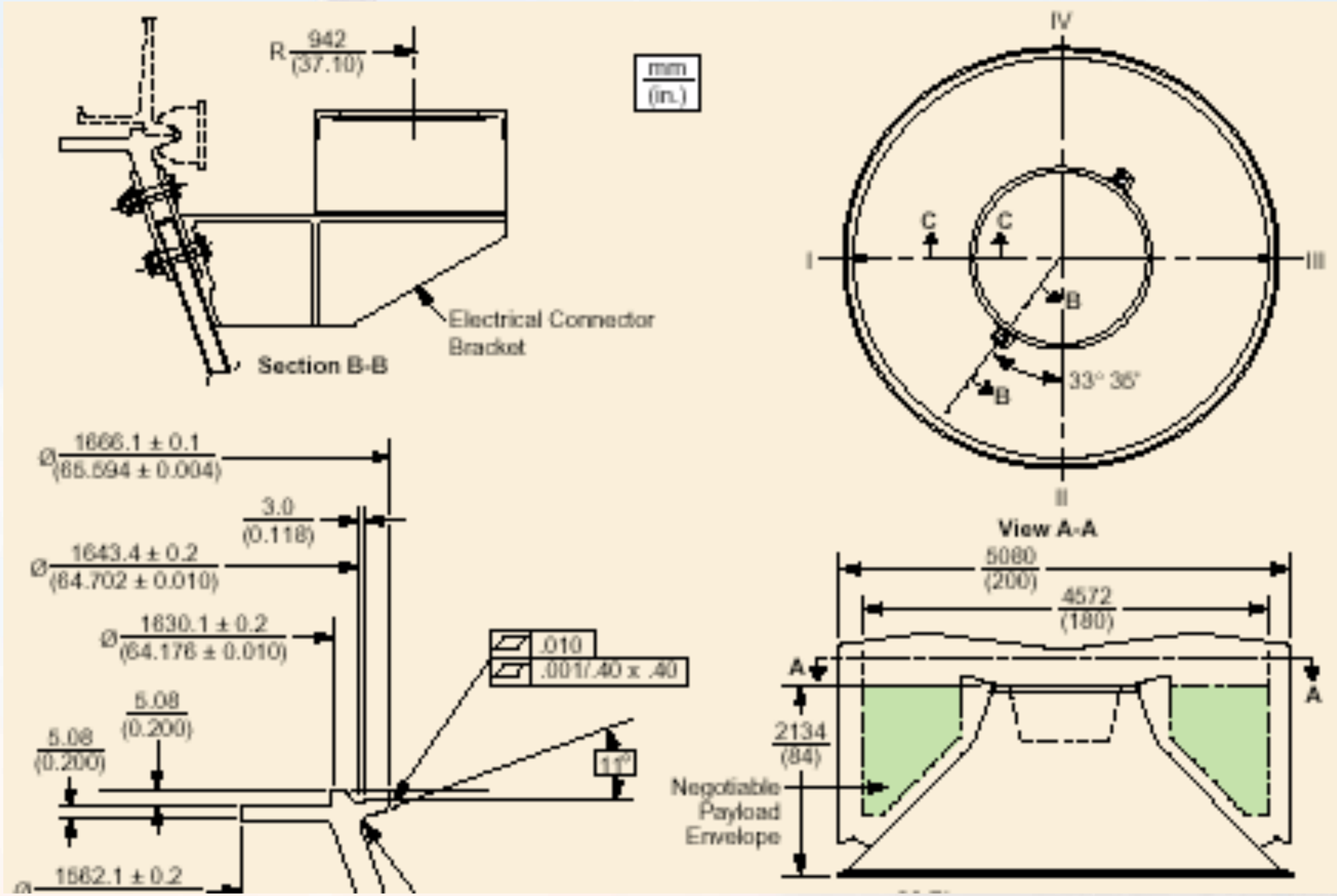
Delta IV Bolted Payload Attach Fitting



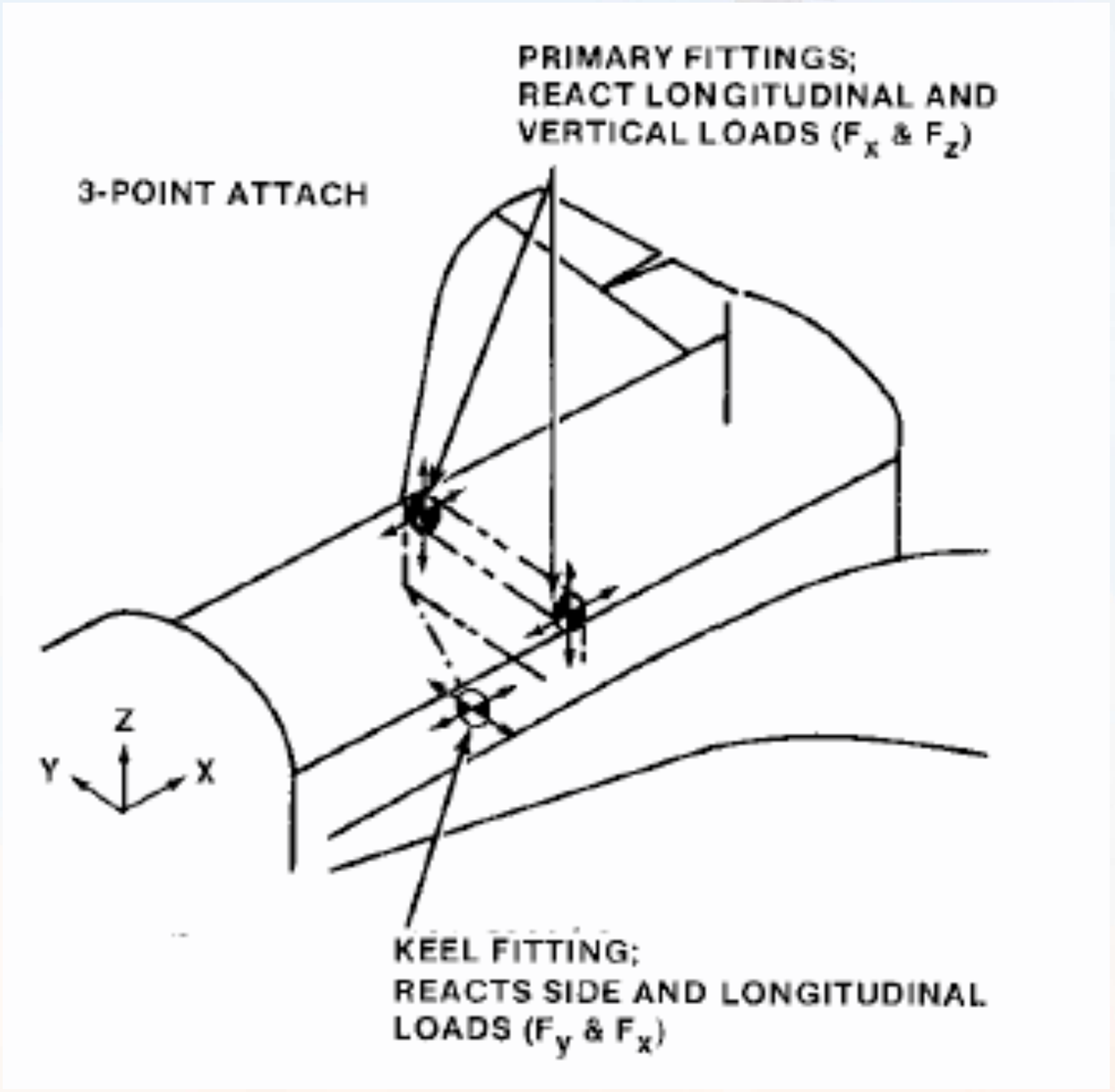
Delta IV Pyro Payload Attach Fitting

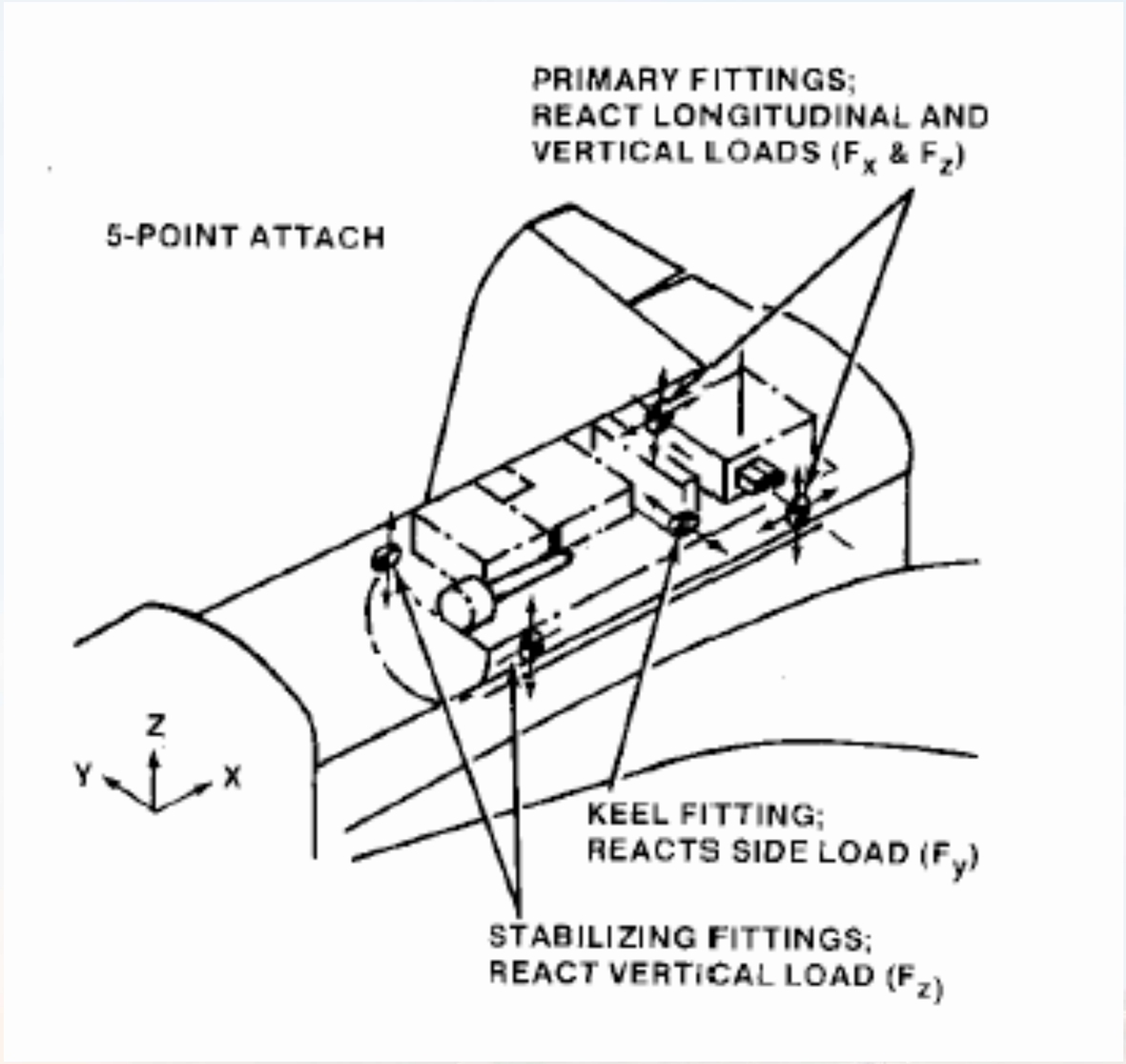


Delta IV Marmon Band PAF

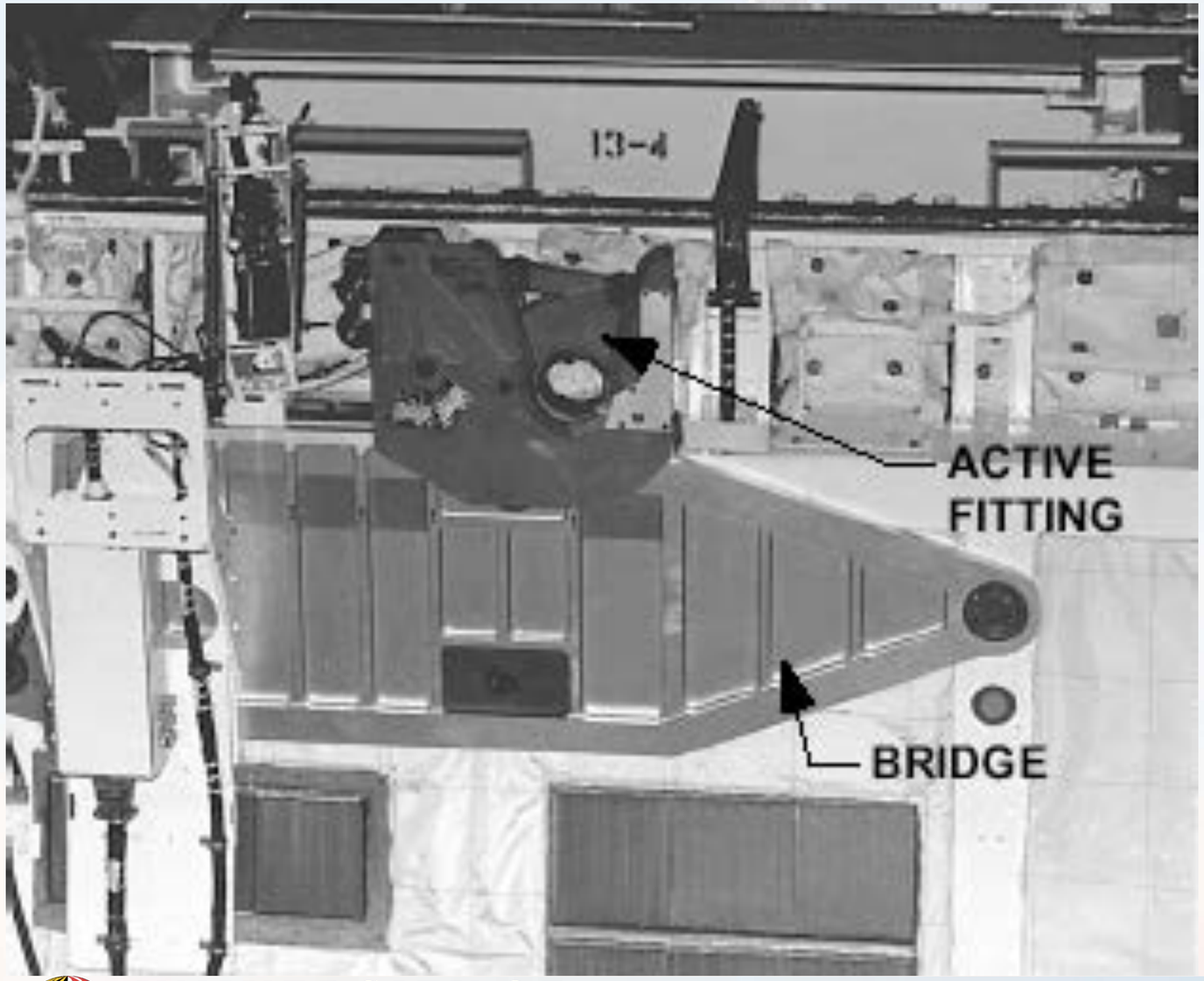


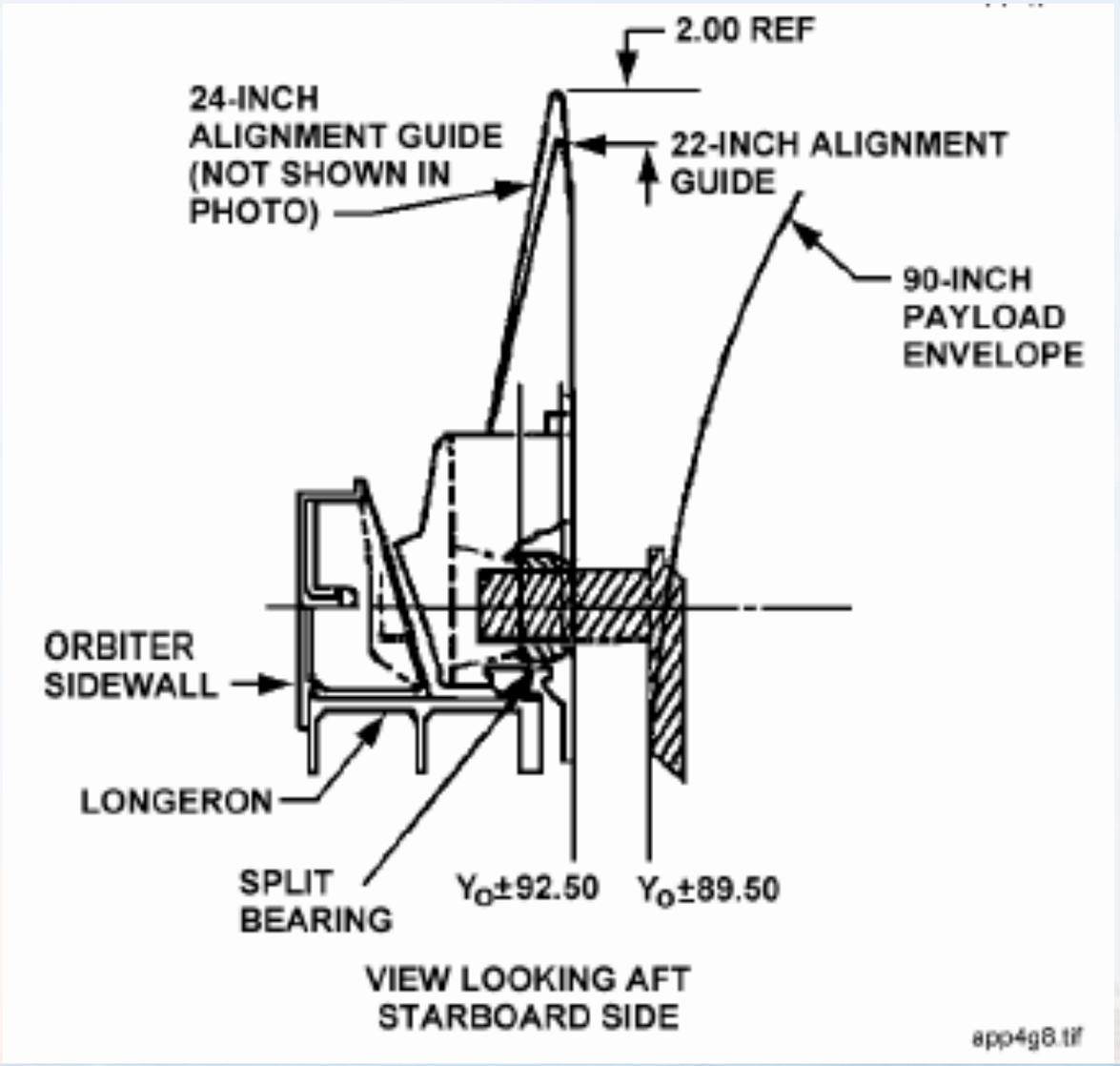
Shuttle Payload Restraint Configurations



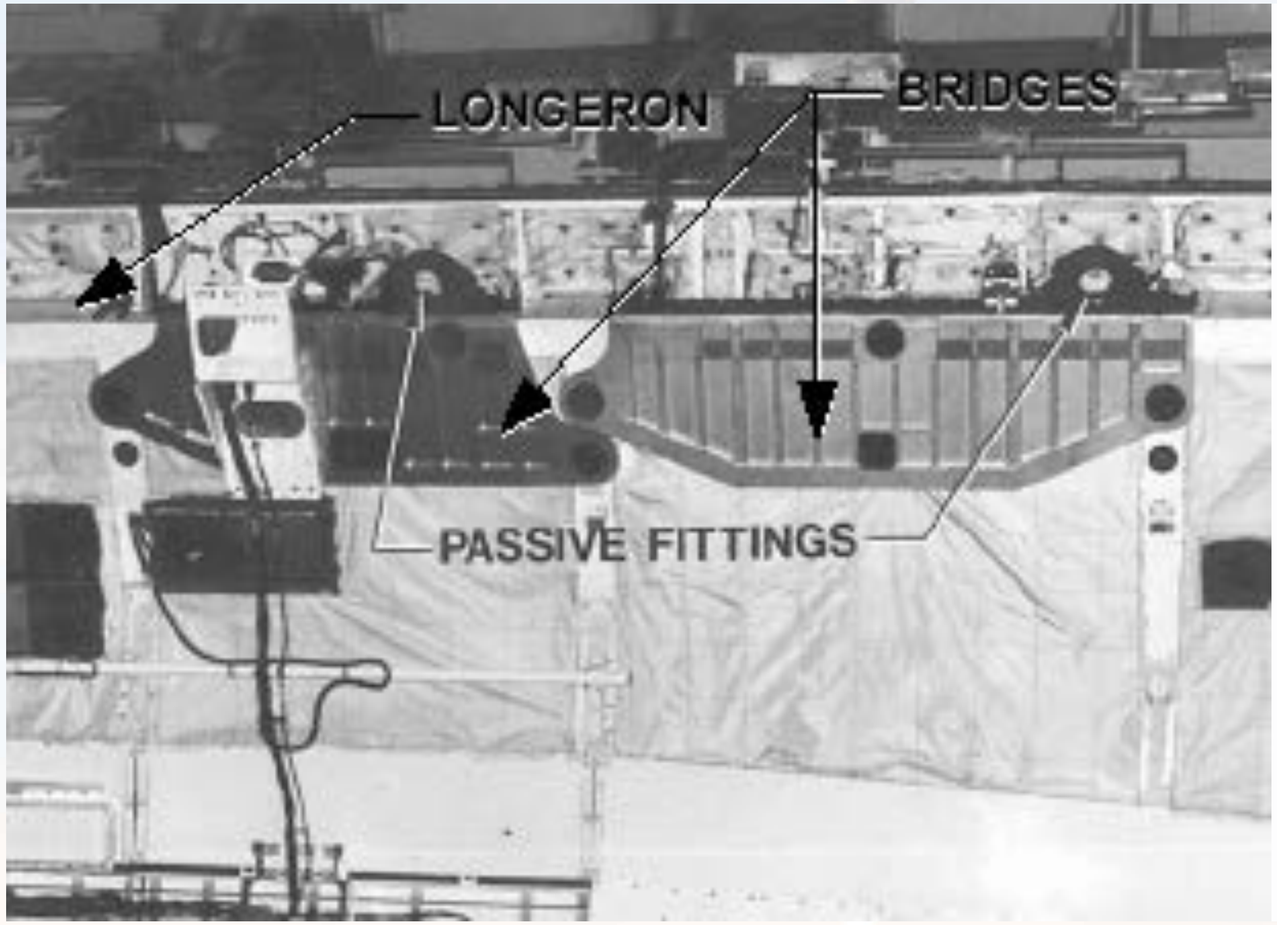


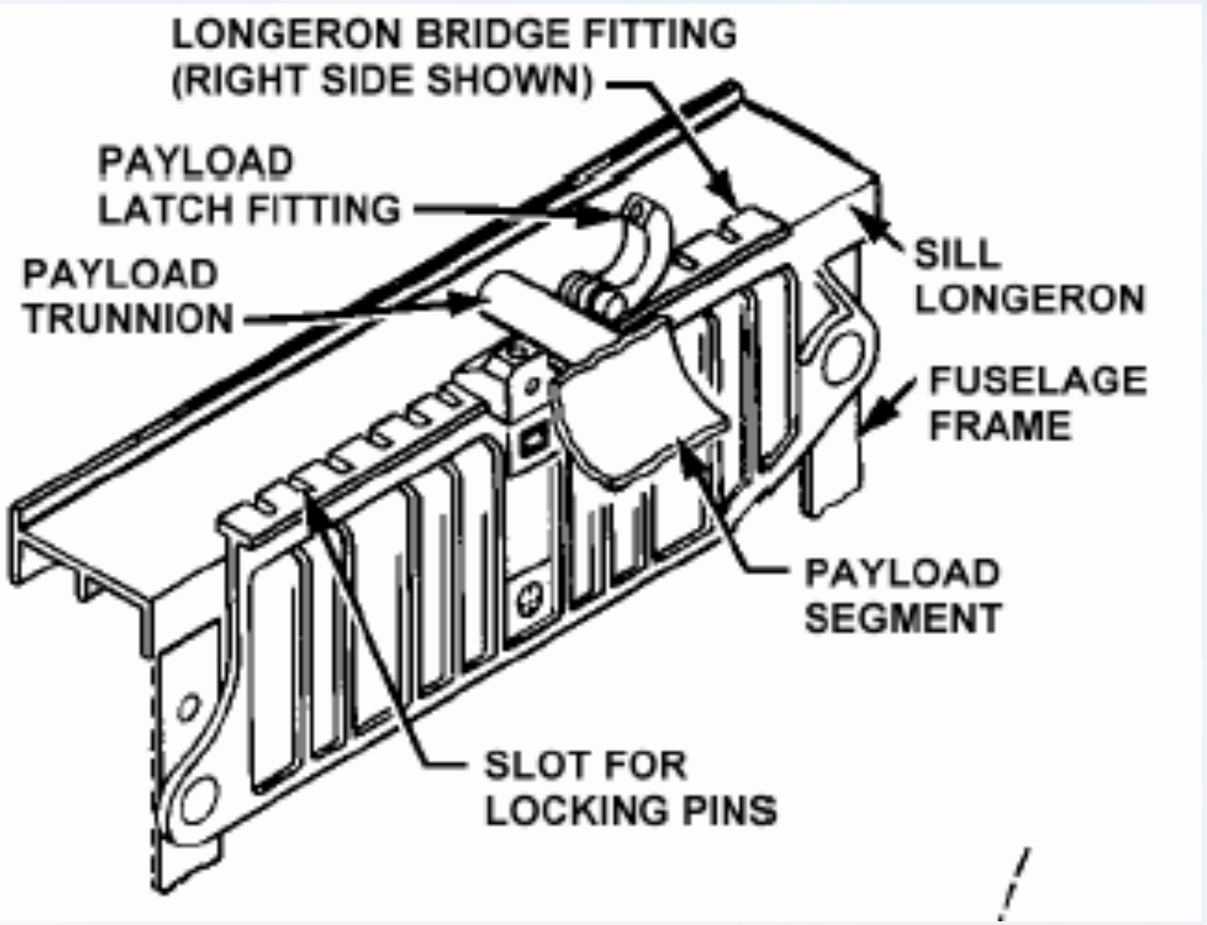
Orbiter Active Latches



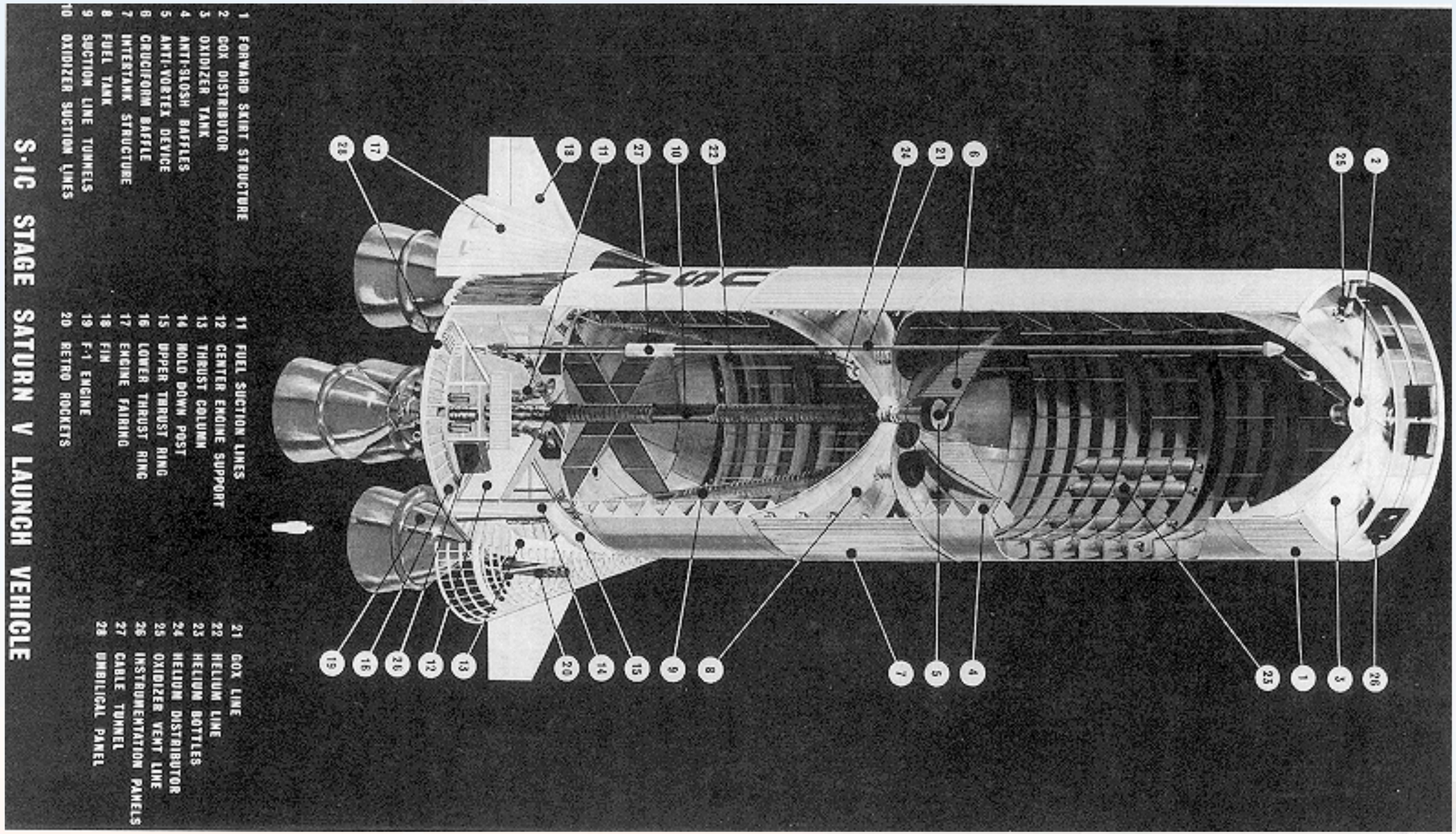


Orbiter Passive Latches





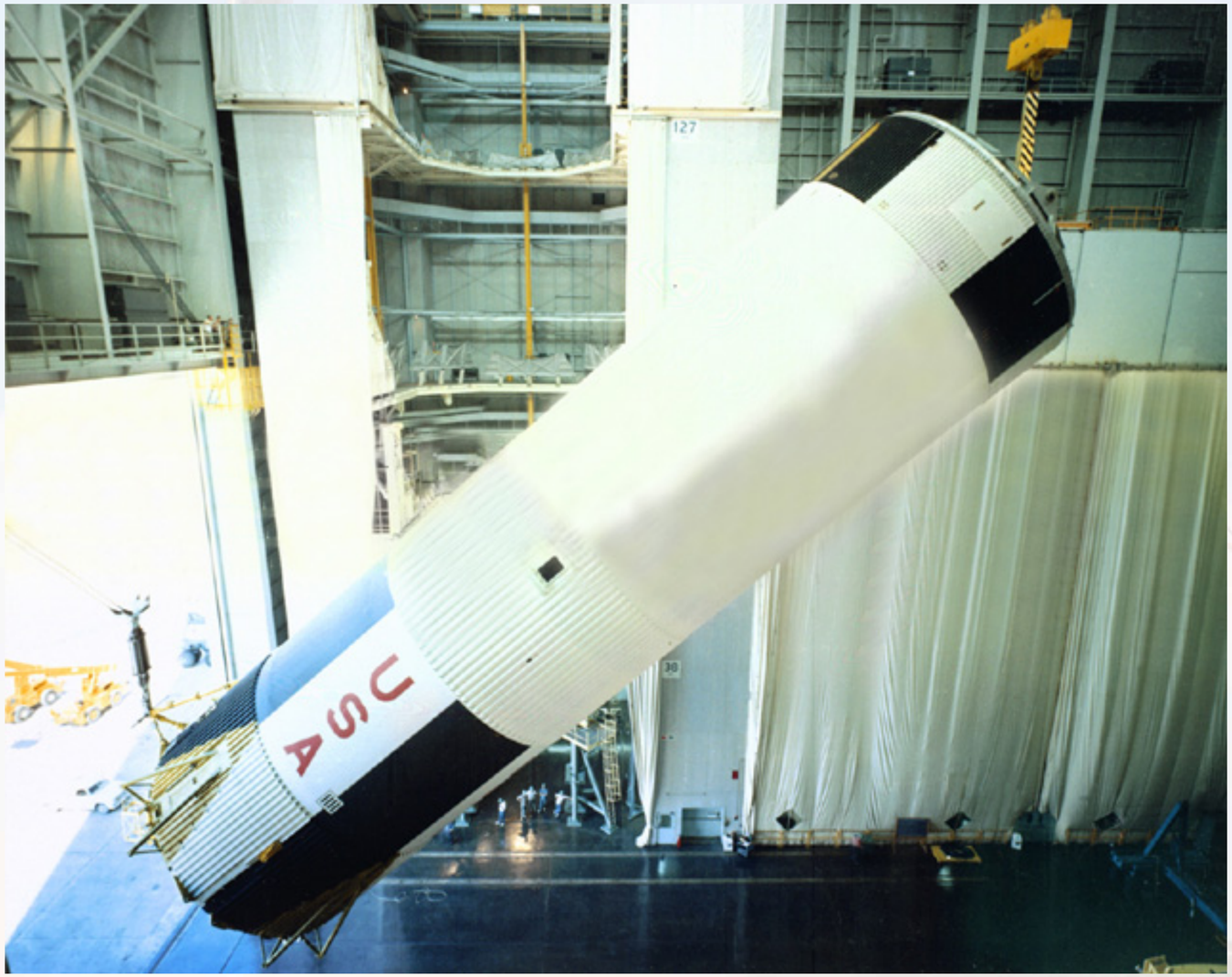
Saturn V First Stage (S-IC) Cutaway



Saturn V S-IC Intertank Fairing

Saturn V S-IC Intertank Assembly

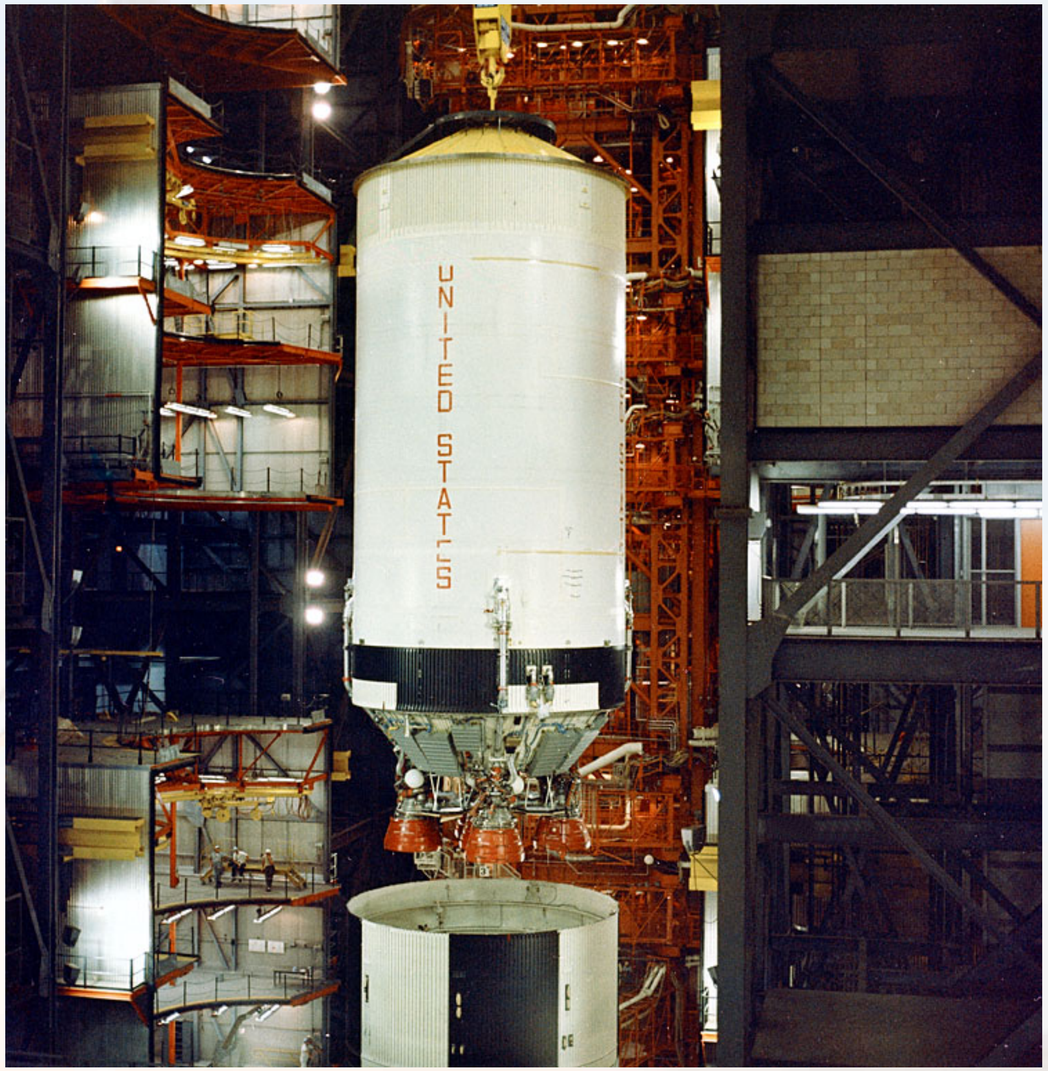
Saturn V S-IC Ground Handling



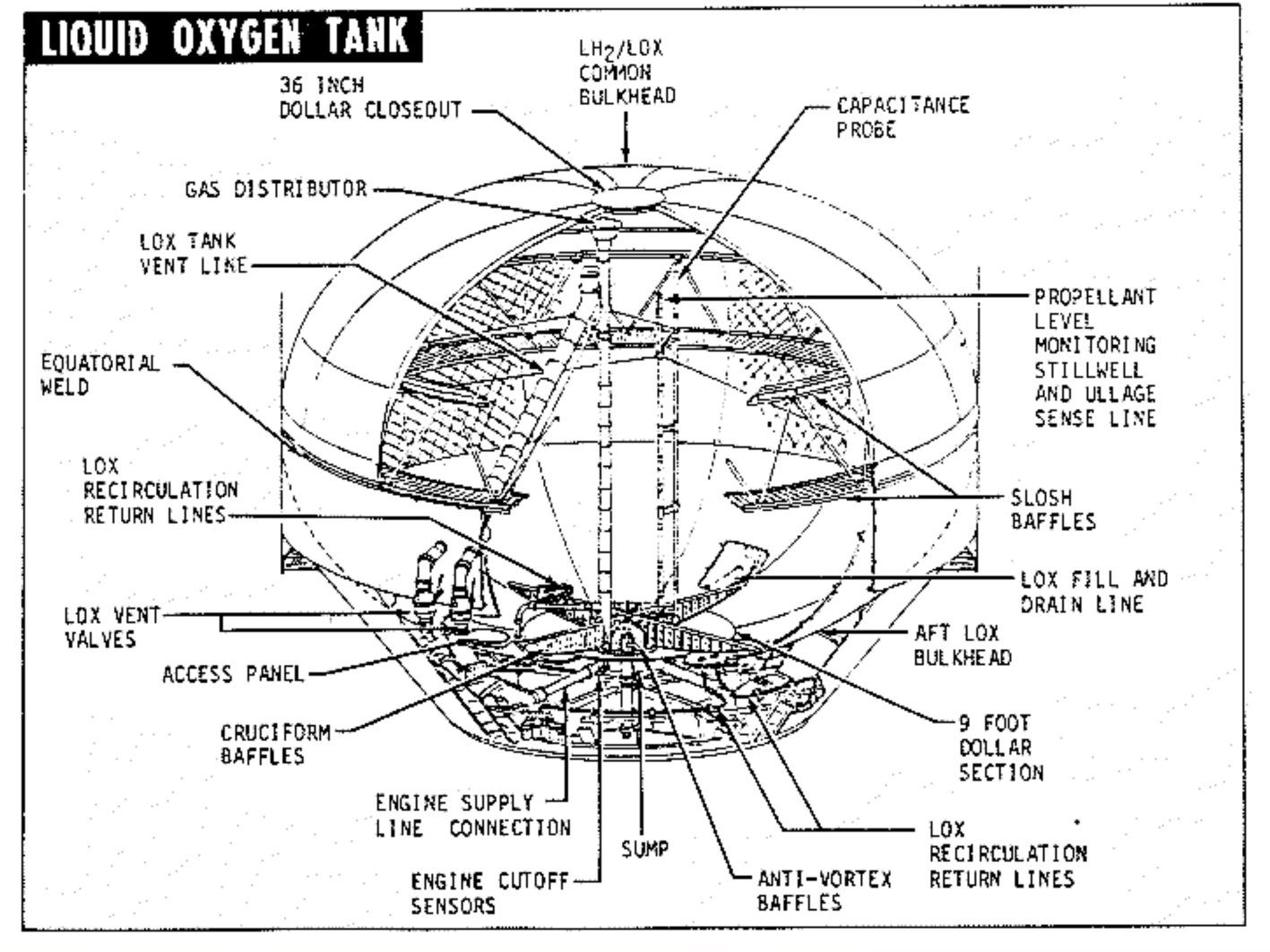
N-1 Ground Handling

Buran Ground Handling

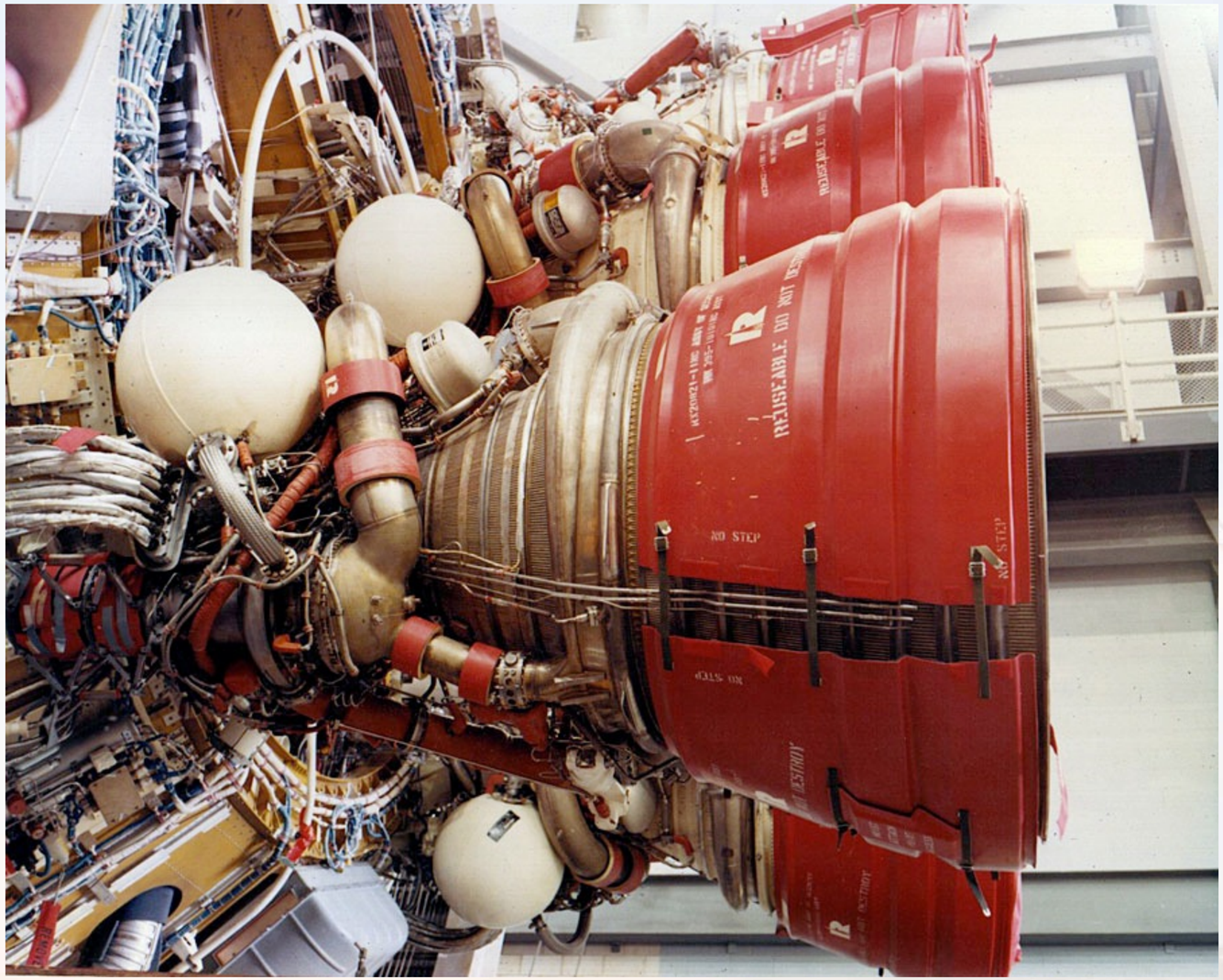
Saturn V S-II Stage Stacking



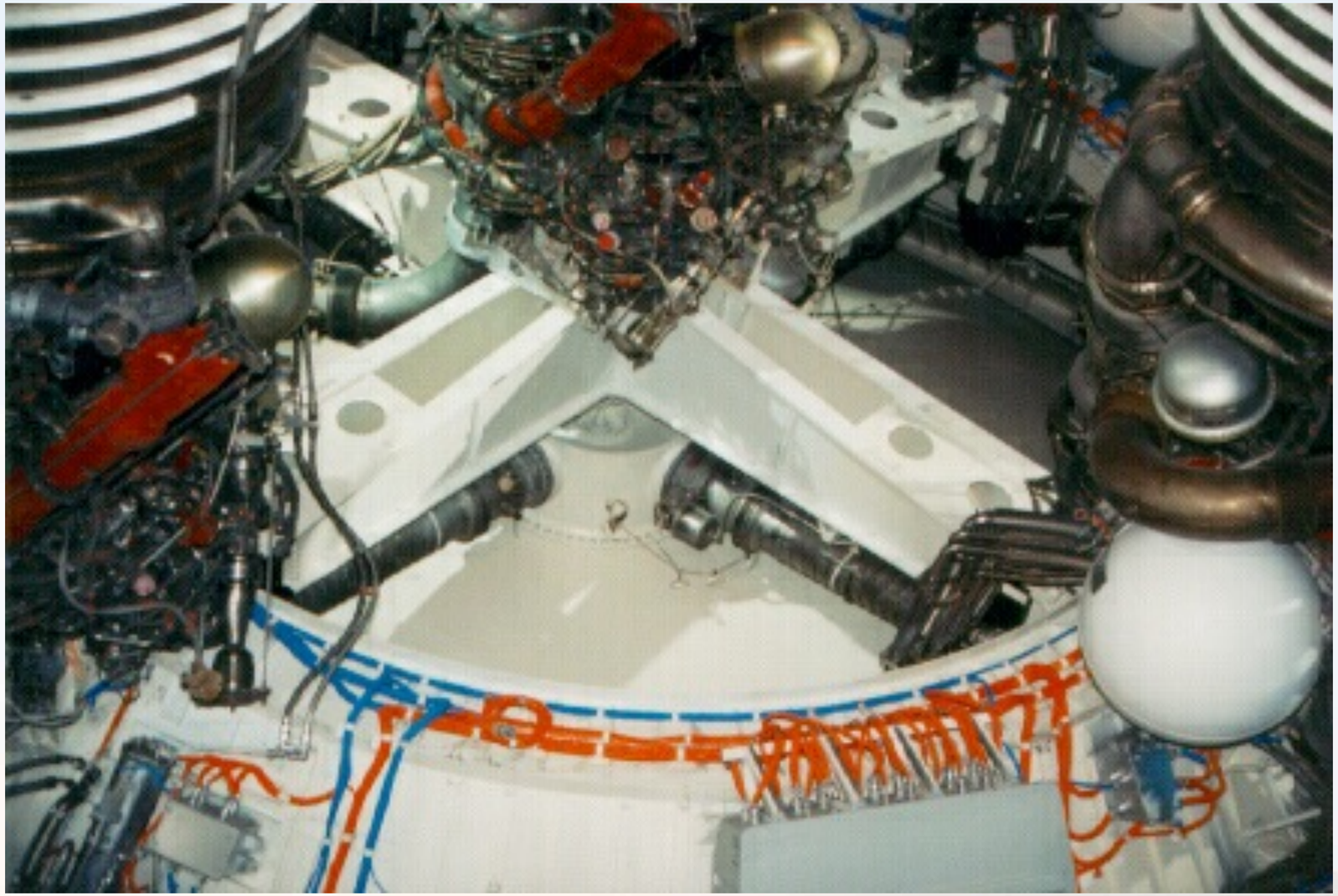
Saturn V S-II LOX Tank Cutaway



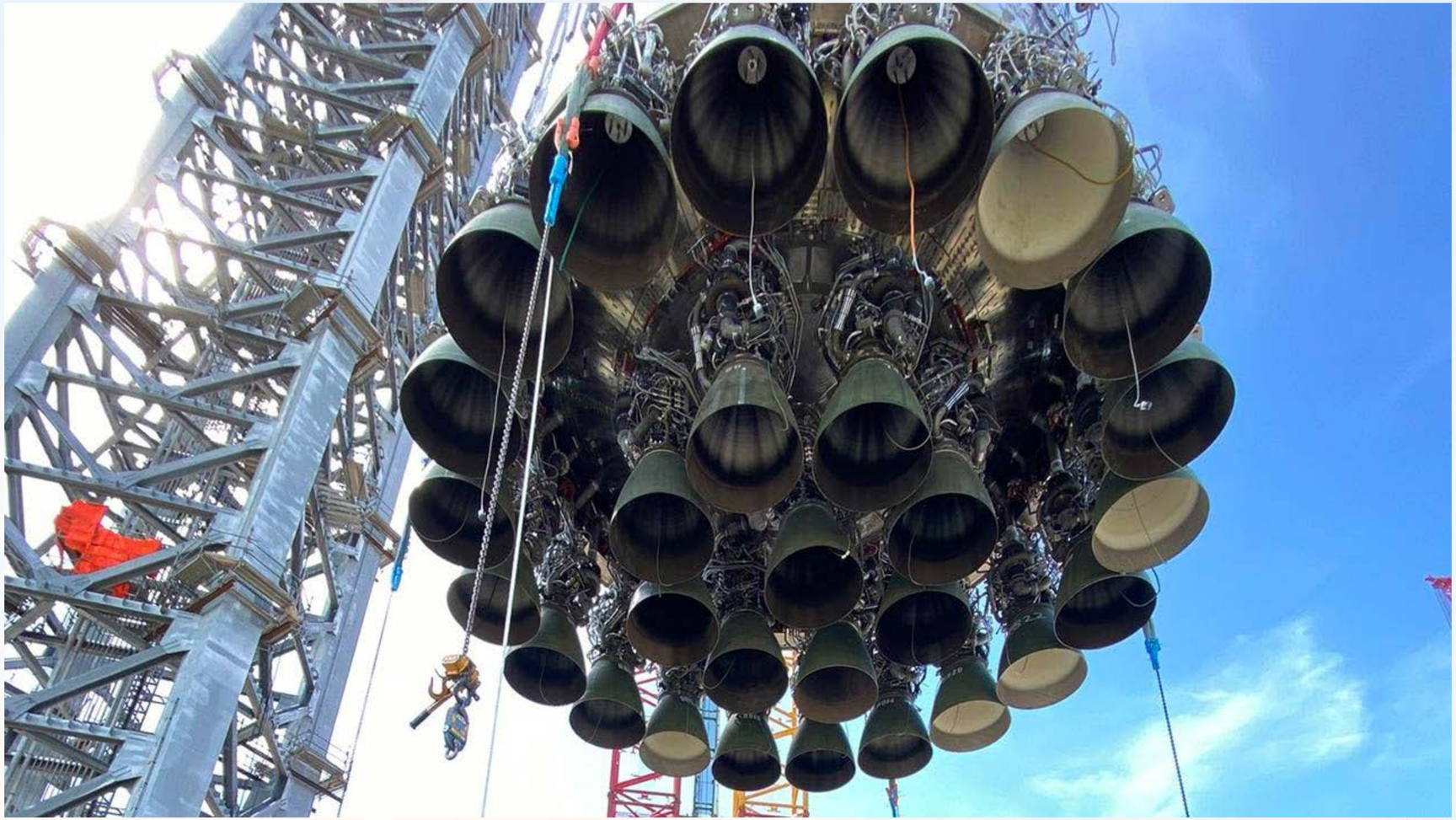
Saturn V S-II Stage Engine Cluster



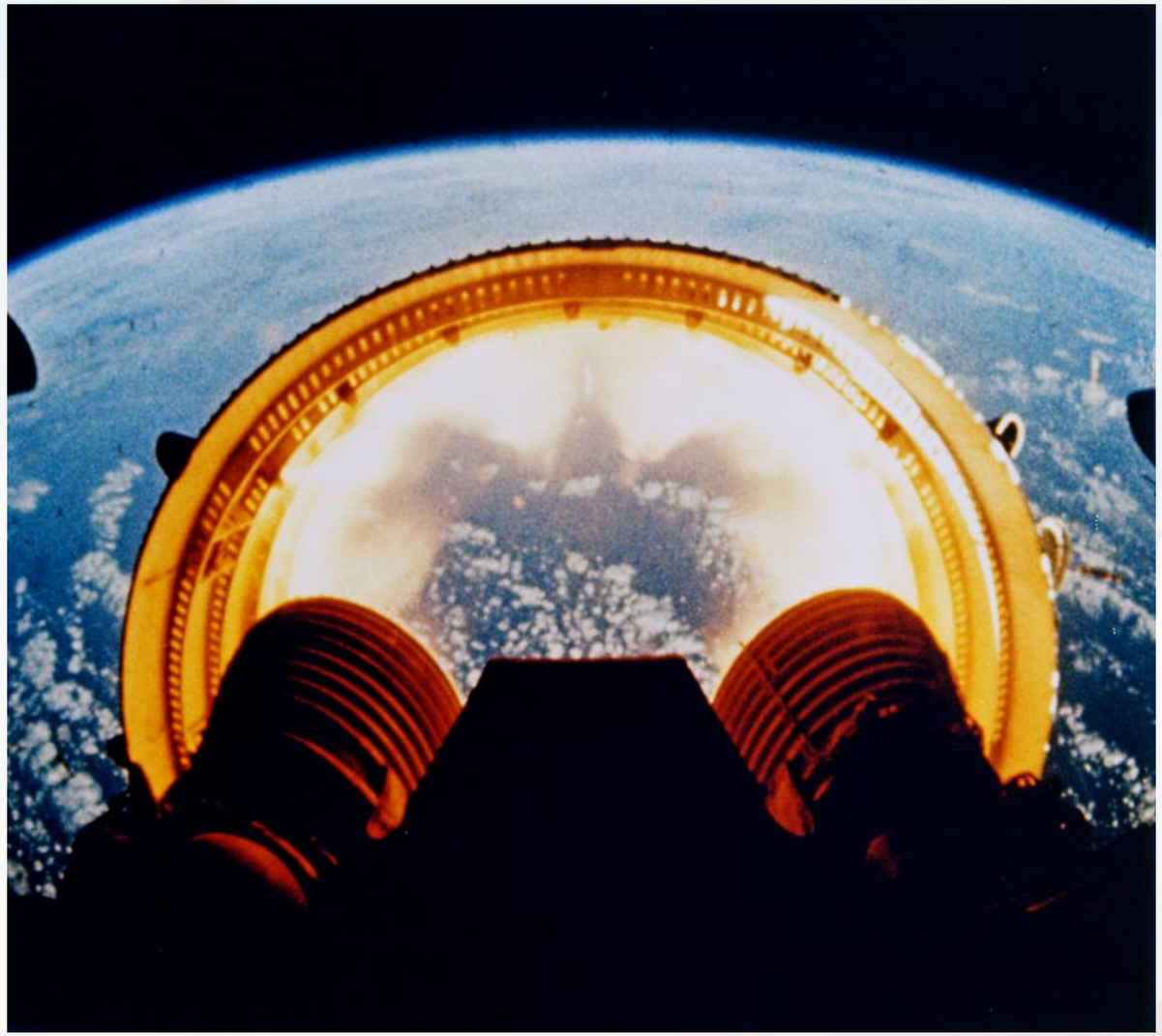
Saturn V S-II Thrust Structure Detail



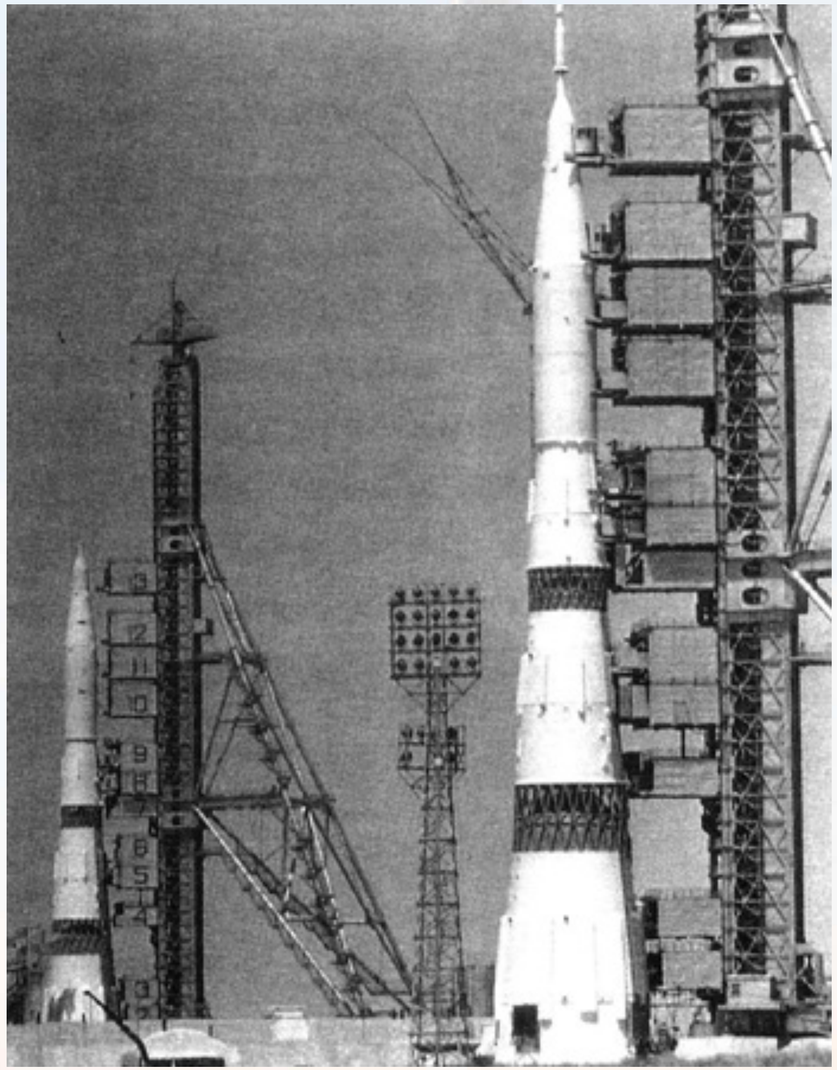
SpaceX SuperHeavy #4

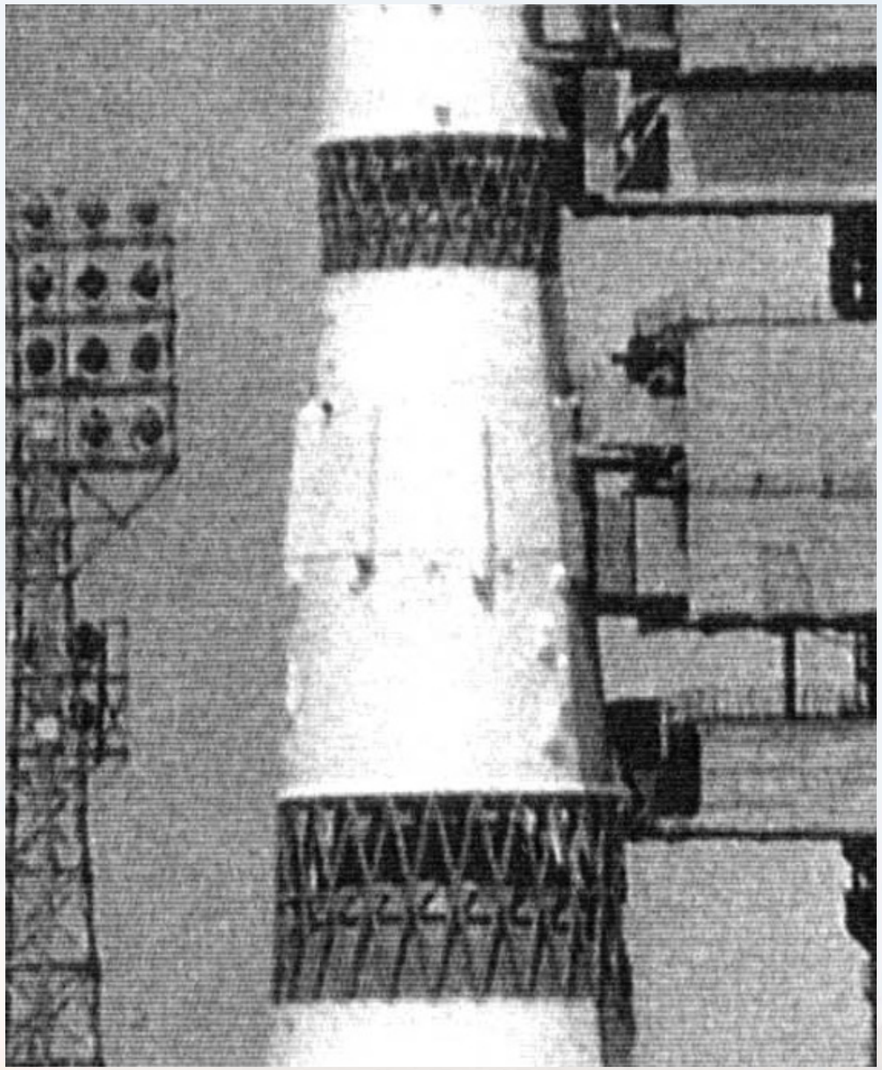


Saturn V S-II Interstage Jettison



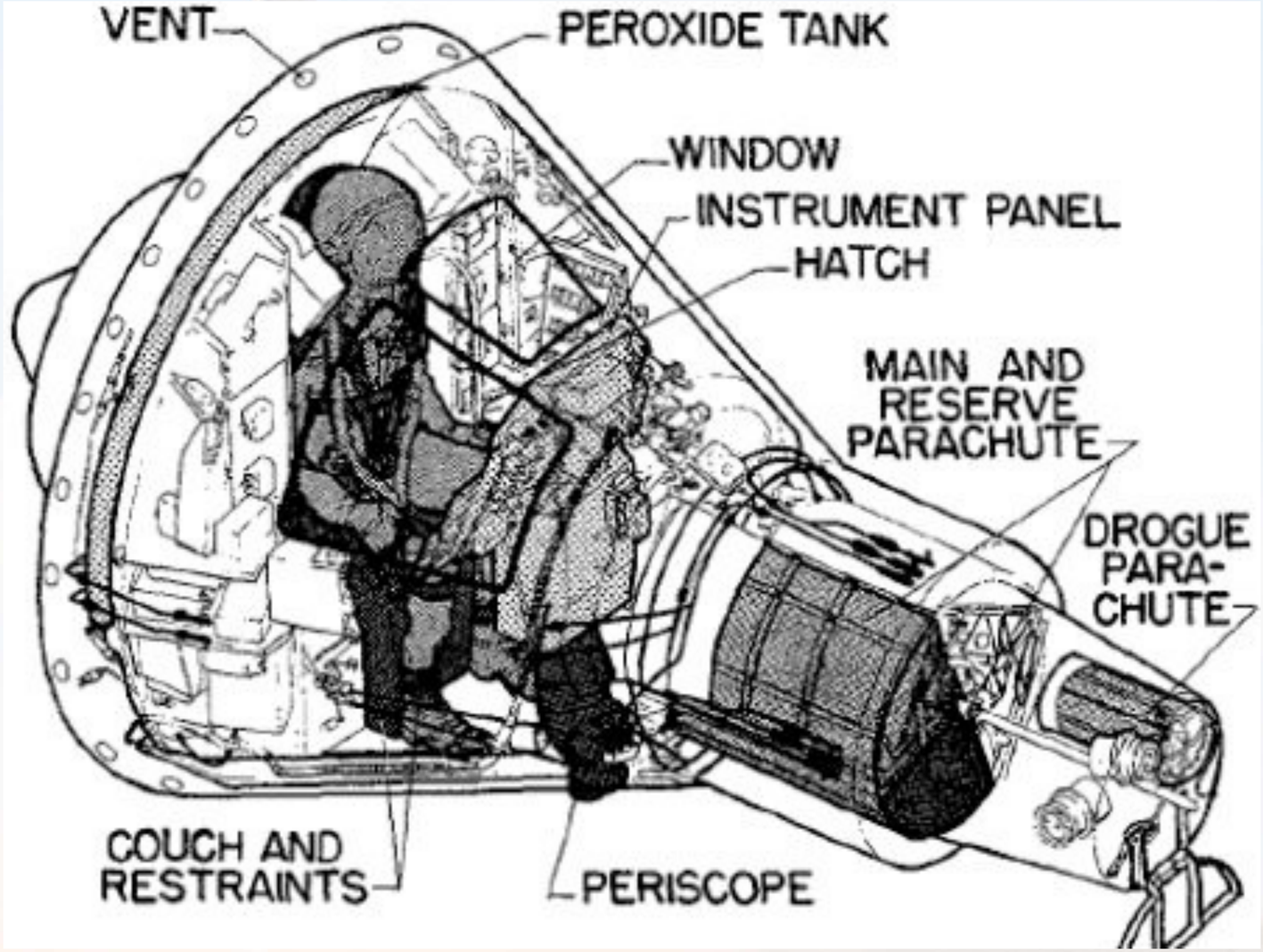
N-1 Launch Vehicle Interstages



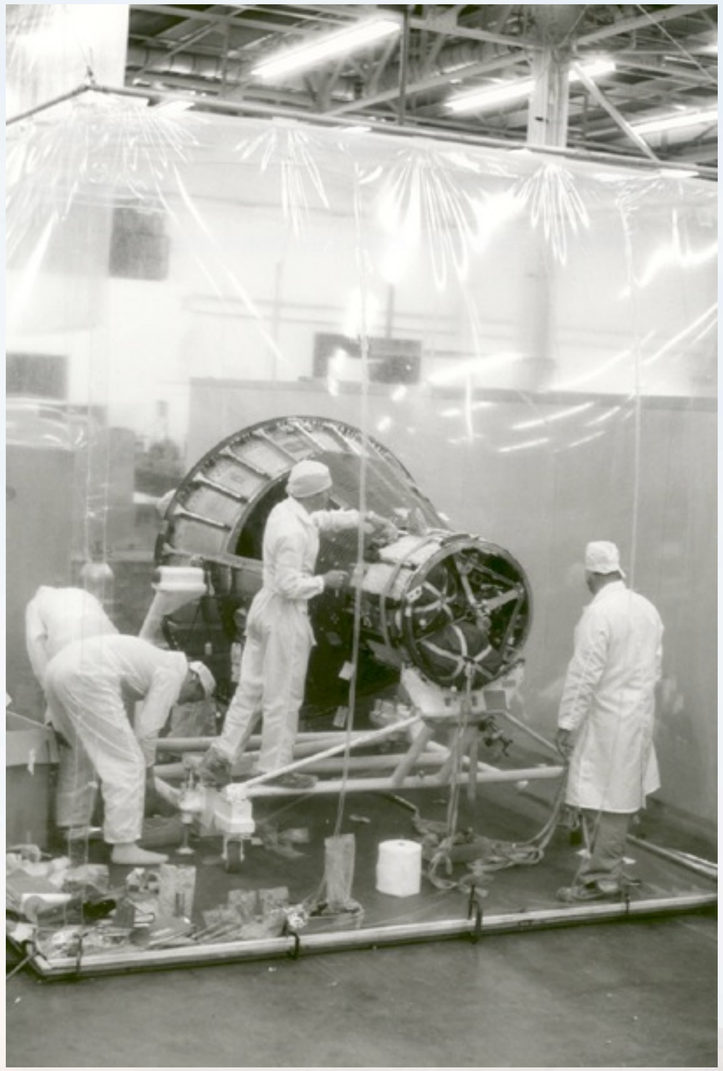


Saturn V S-IVB/J-2 Thrust Structure

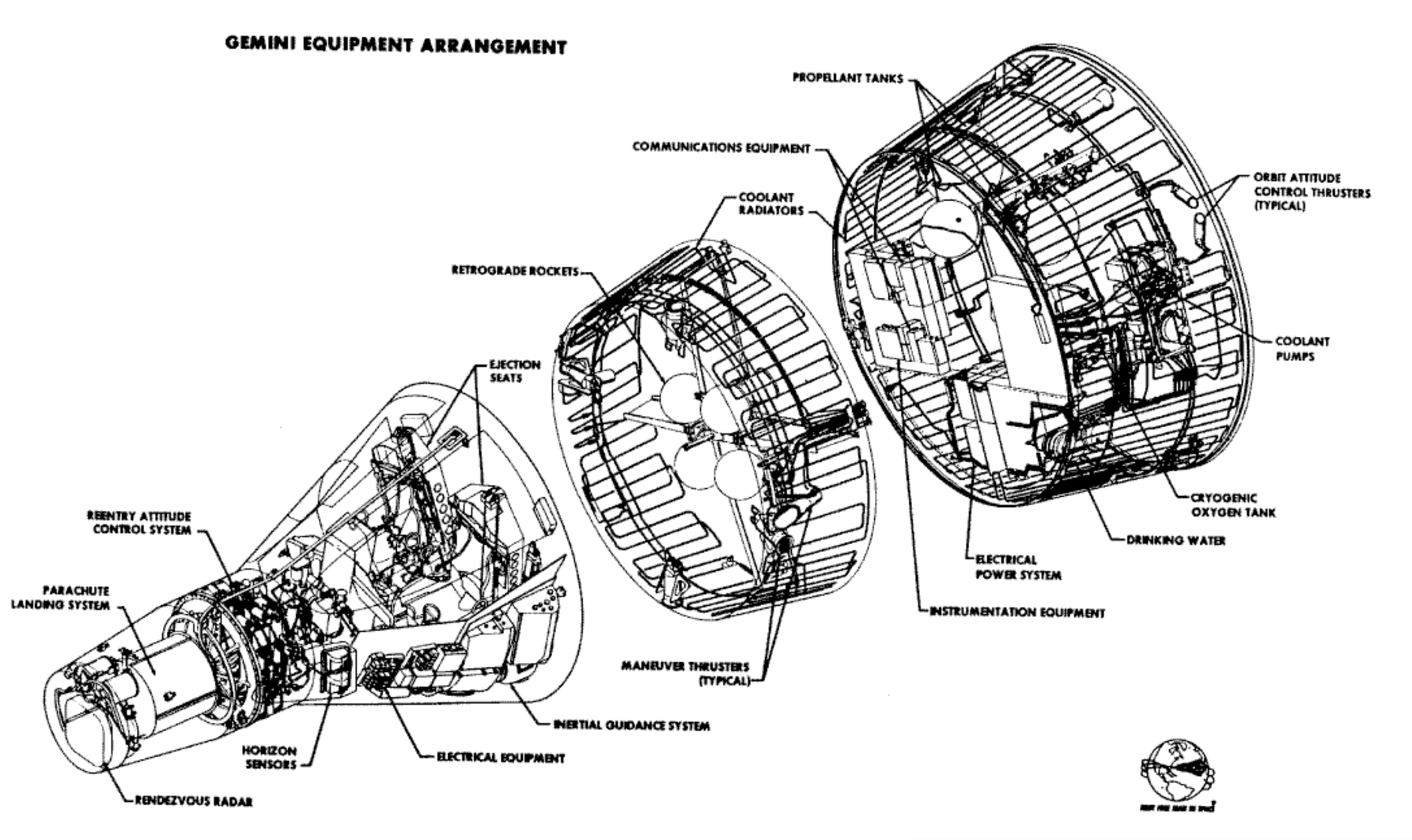
Mercury Spacecraft Layout



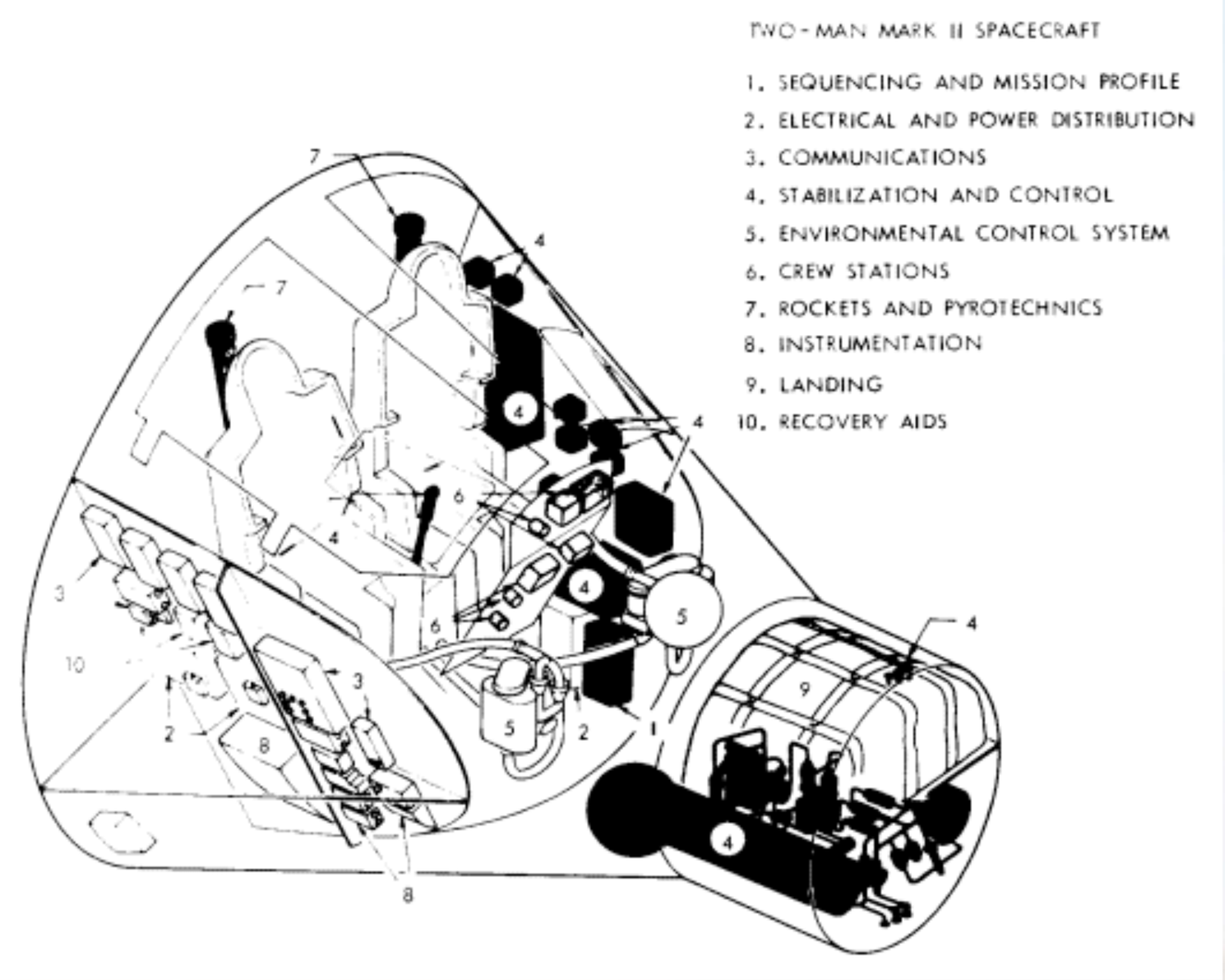
Mercury Spacecraft Assembly



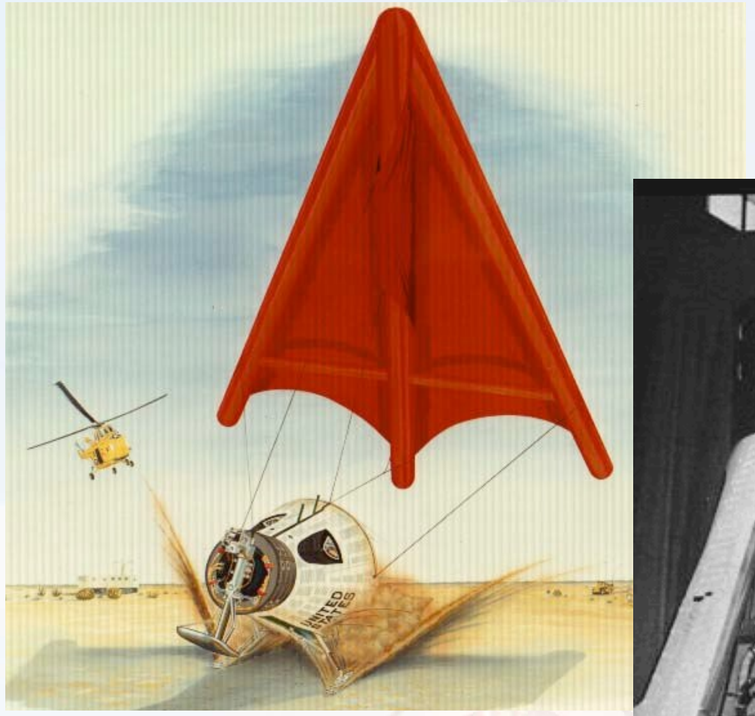
Gemini Spacecraft Equipment Arrangement

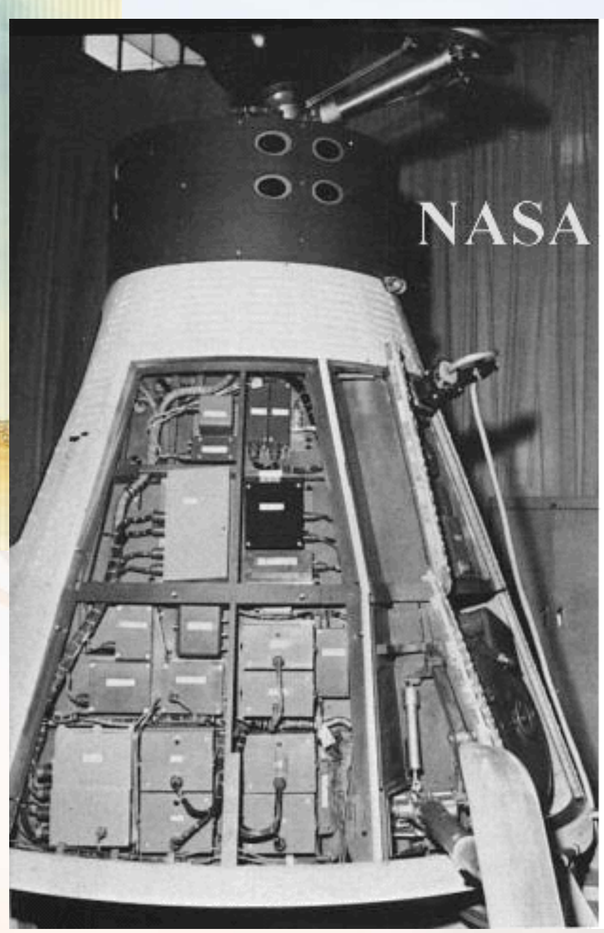


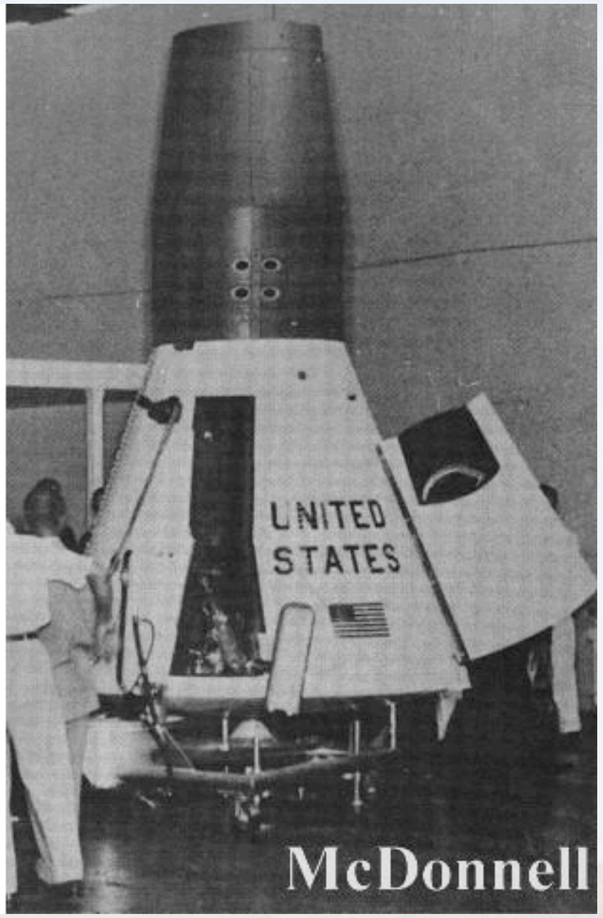
Gemini Spacecraft Layout



Landing Gear - External Equipment Bays

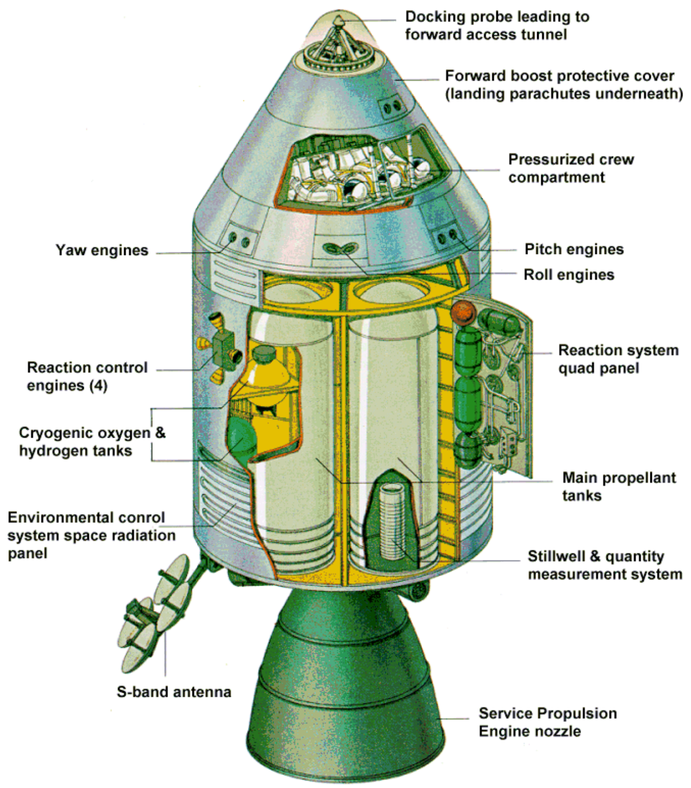






Apollo Spacecraft Components

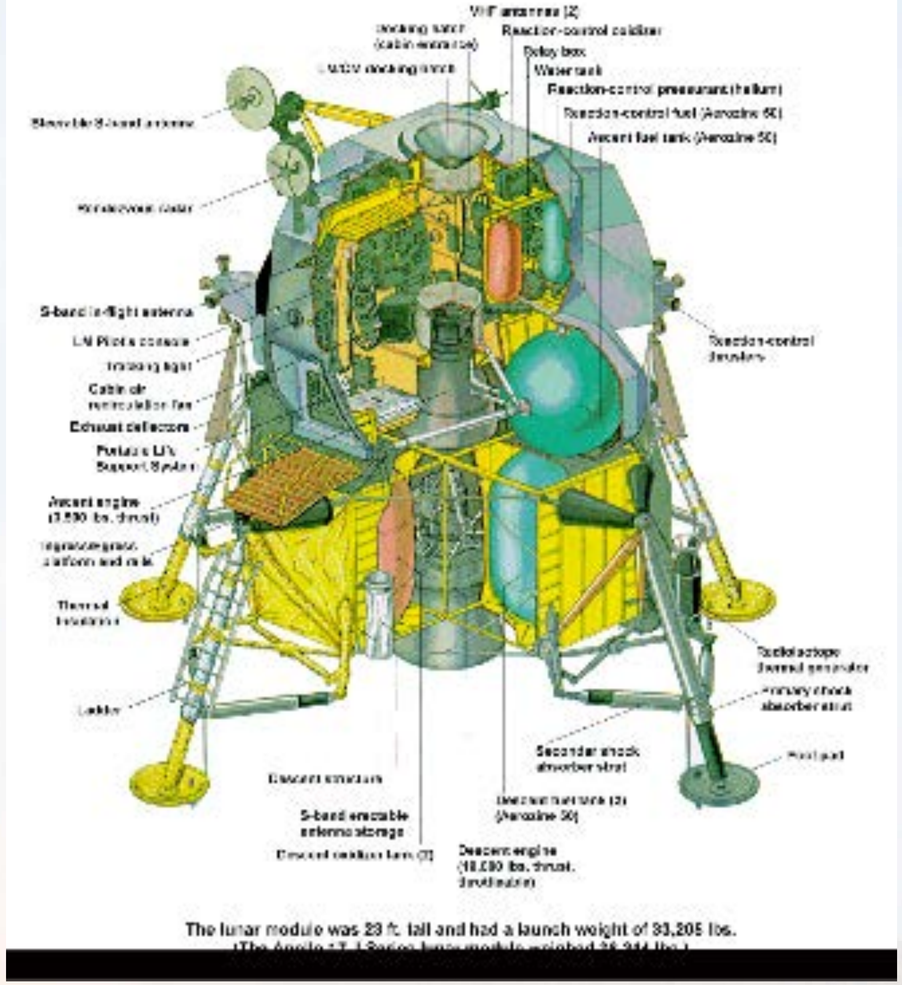
Apollo Command and Service Modules



Apollo CSM Facts

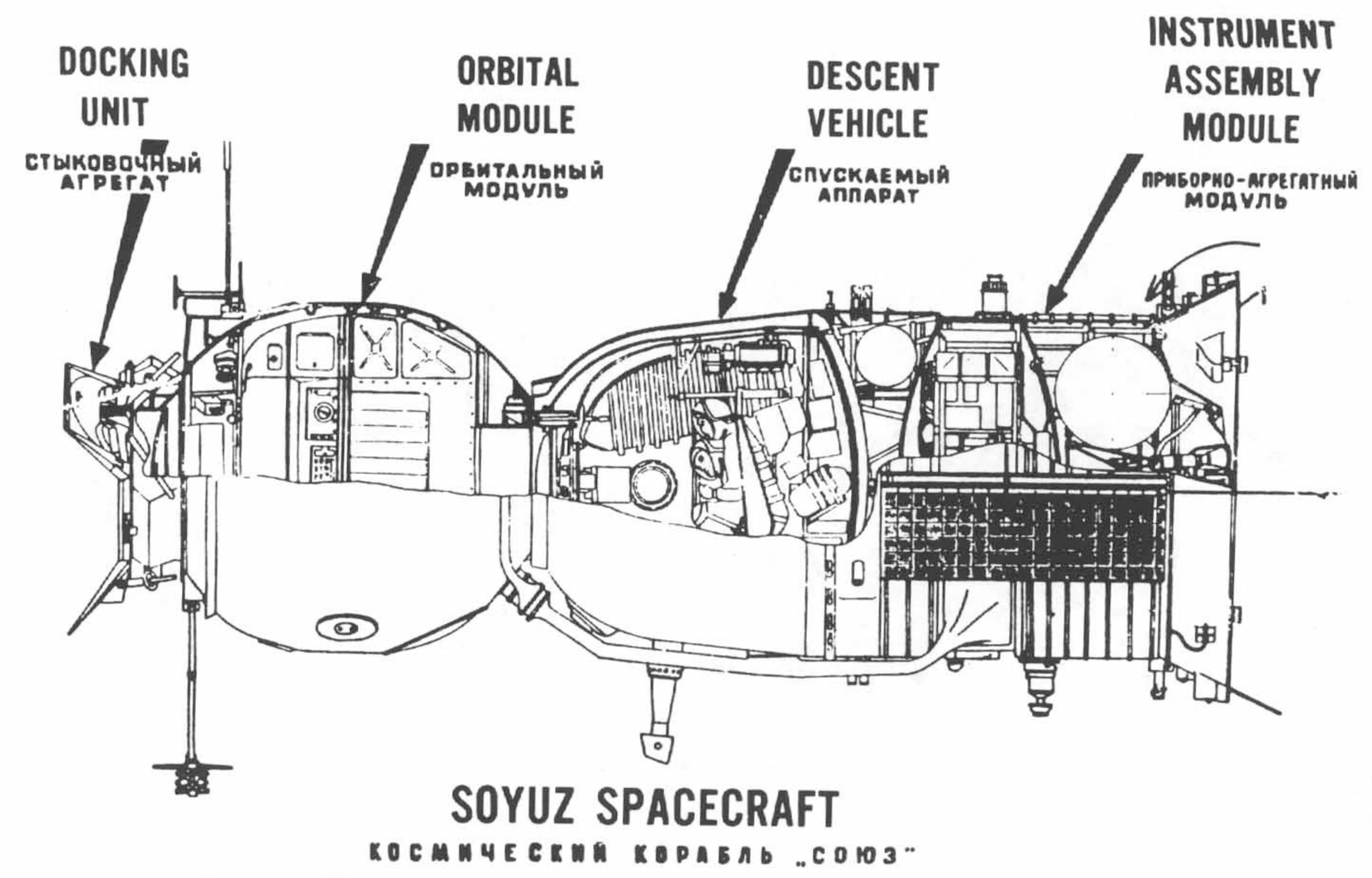
The Apollo Command Module was 10.6 ft. tall and 12.8 ft. at its maximum diameter, and typically weighed 13,090 lbs. with astronauts. The Service Module was 24.3 ft. tall and 12.8 ft. in diameter and weighed 54,074 lbs.. The Service Propulsion System engine delivered a thrust of 20,500 lbs..

Apollo Lunar Module

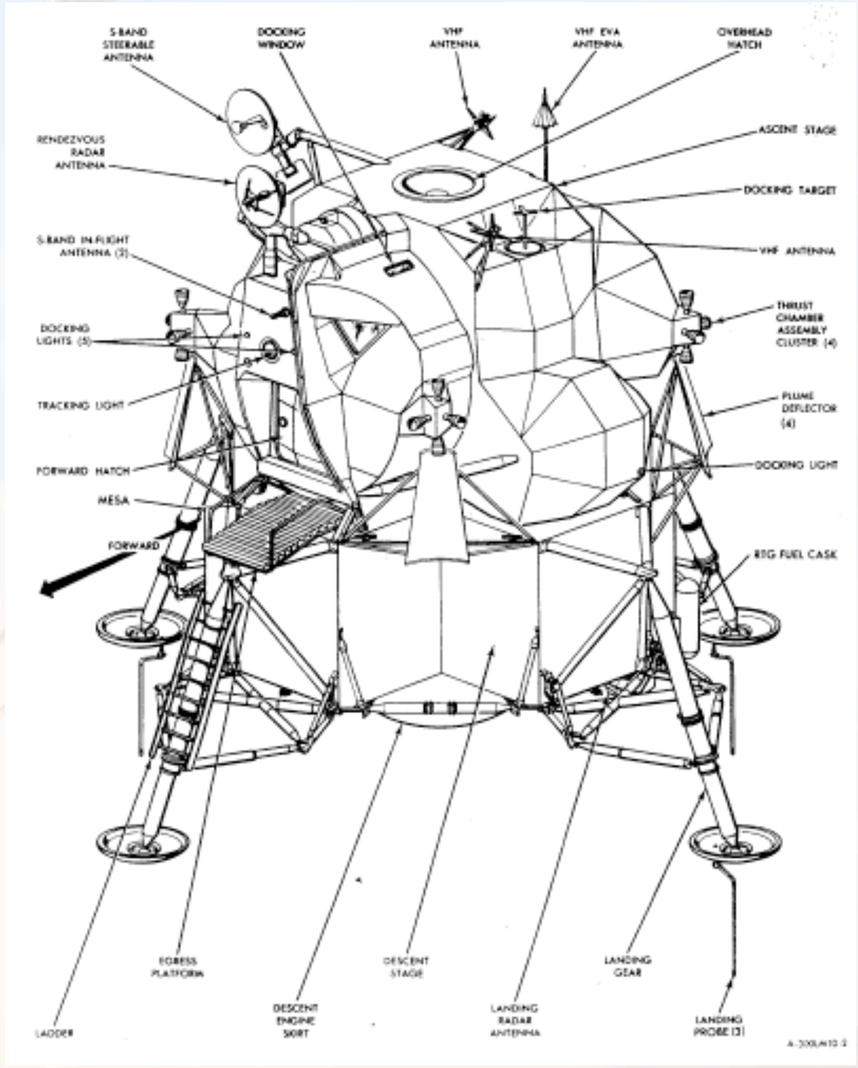


The lunar module was 23 ft. tall and had a launch weight of 33,205 lbs.

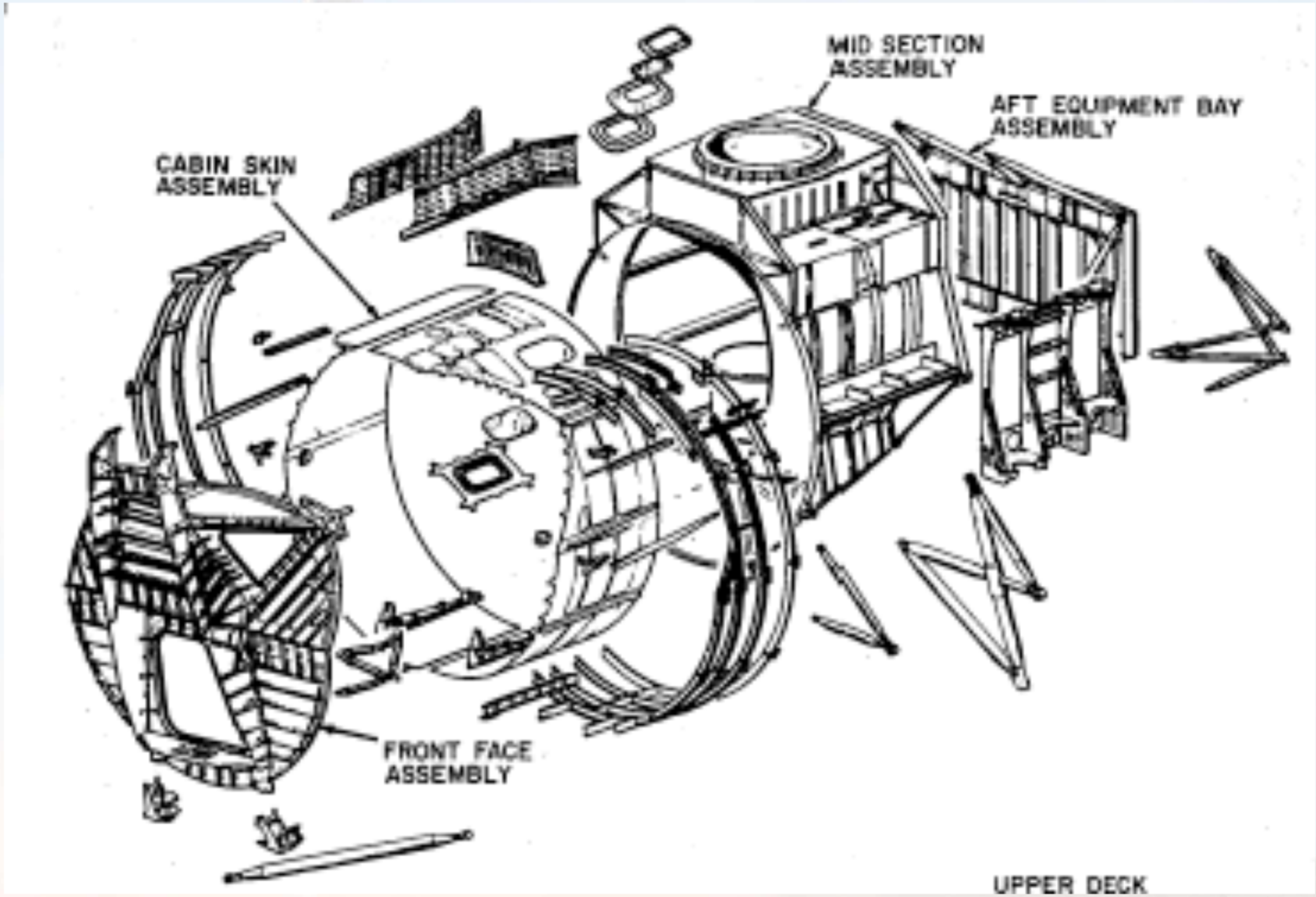
Soyuz Spacecraft Design



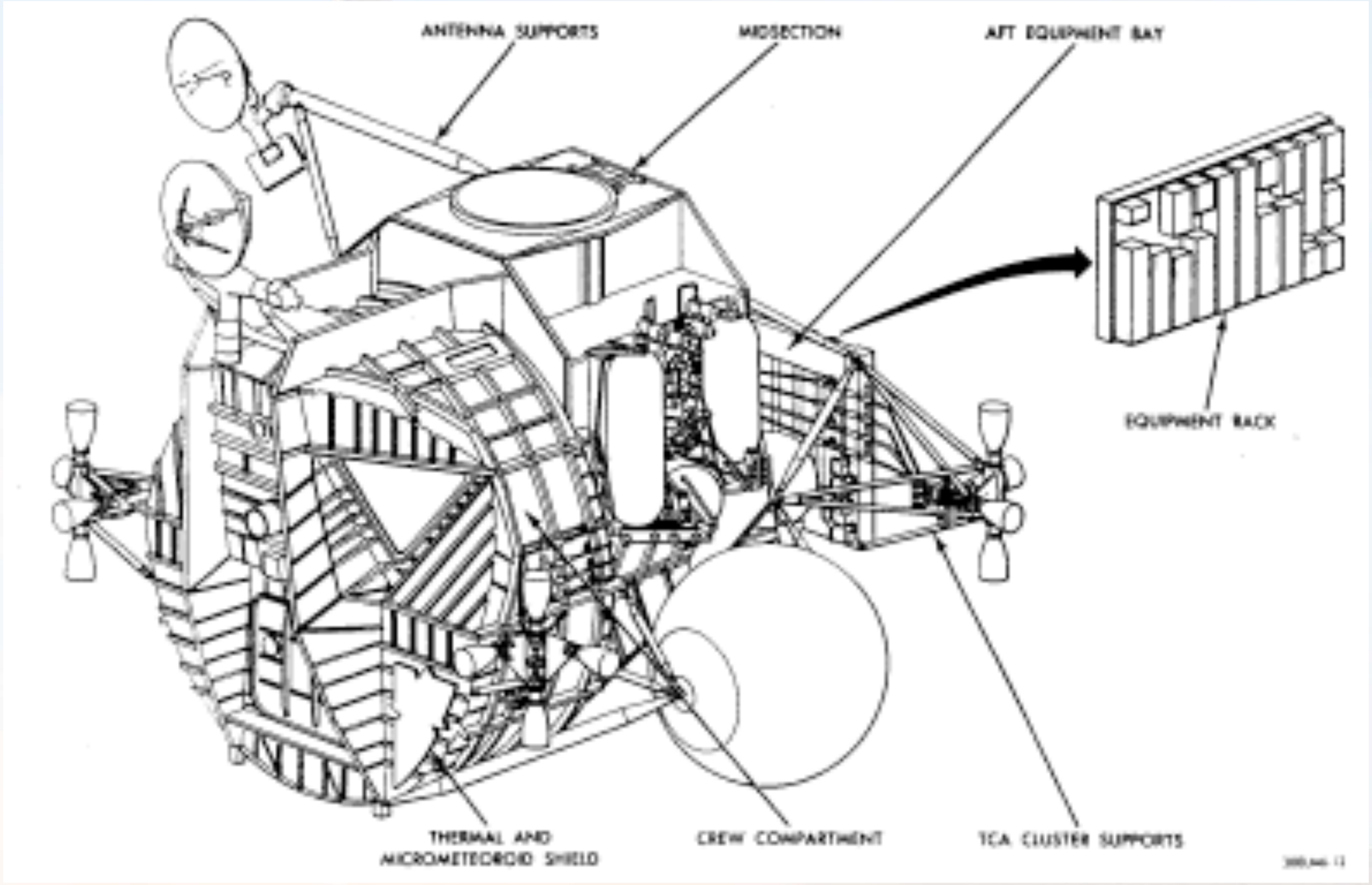
Lunar Module Overall Configuration



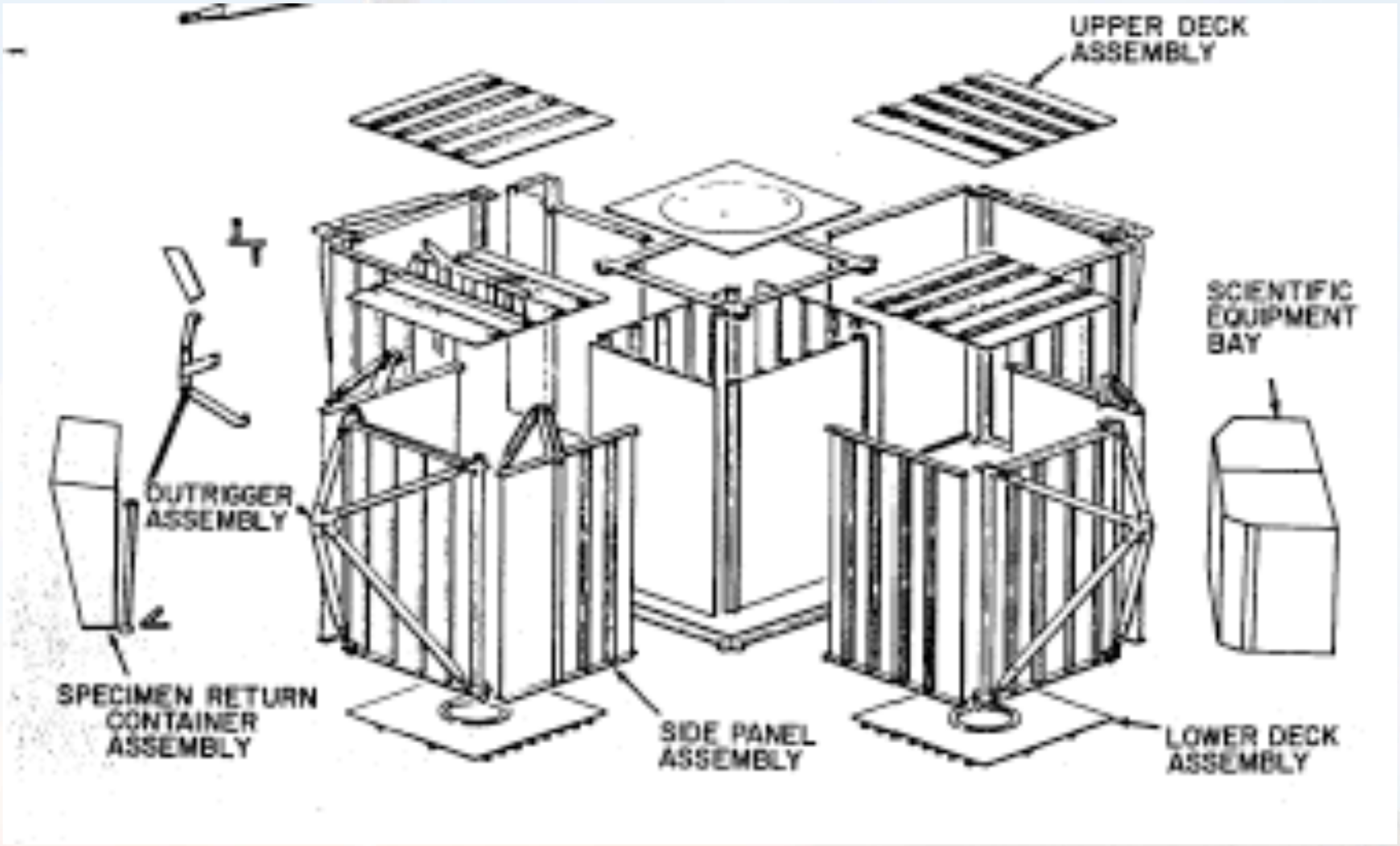
Lunar Module Ascent Stage Structure



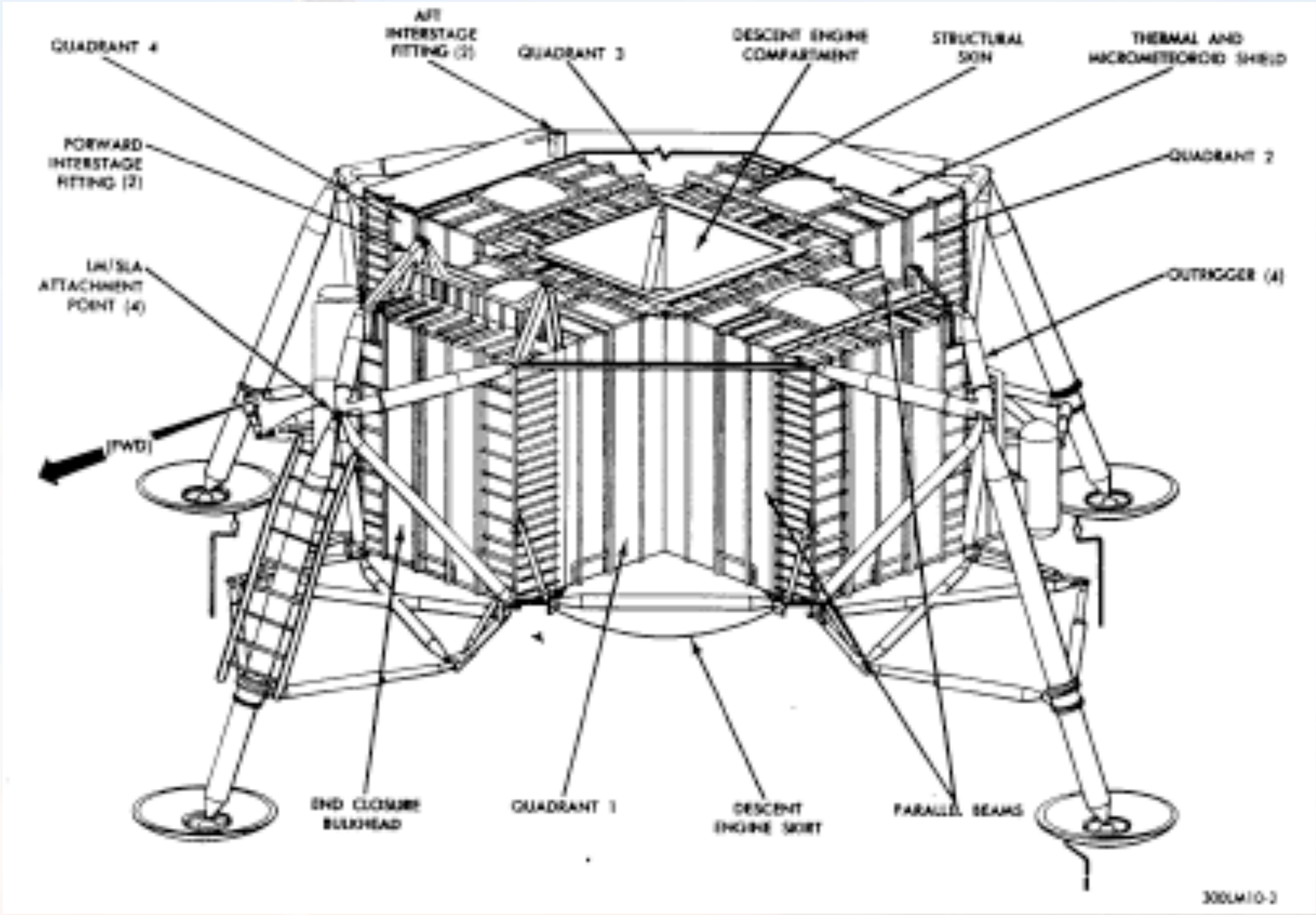
Lunar Module Ascent Stage Structure



Lunar Module Descent Stage Structure



Lunar Module Descent Stage Structures



Soviet Lunar Lander Concepts

Рис. 4. Вариант ЛК

Рис. 5. Вариант ЛК

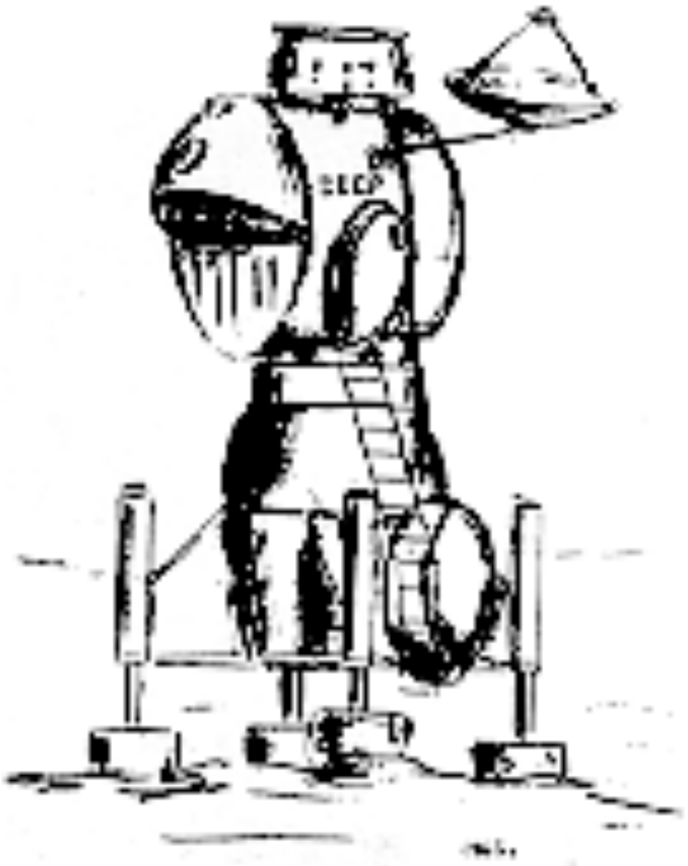
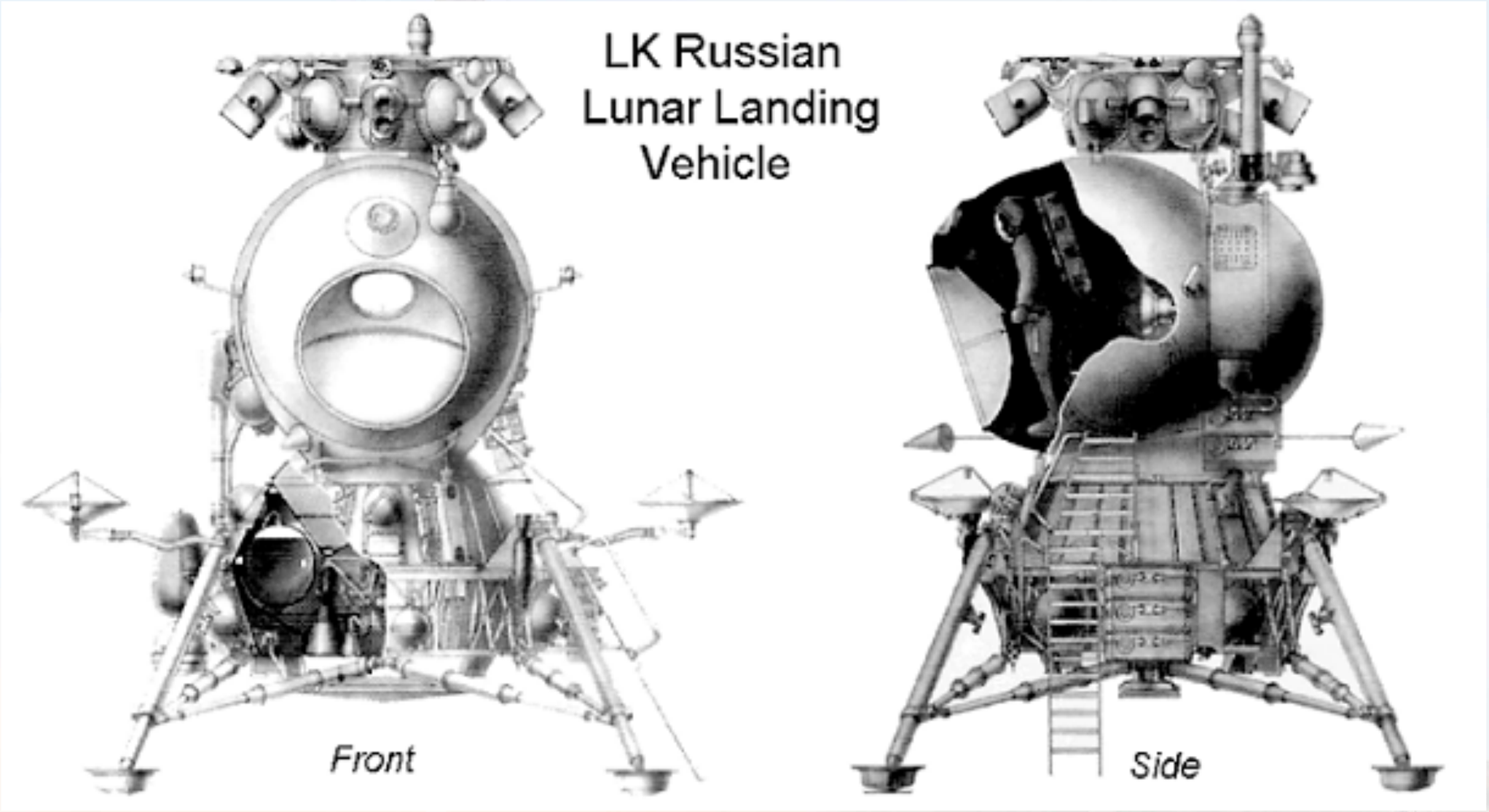


Рис. 6. ЛК в представлении В. Шажурова

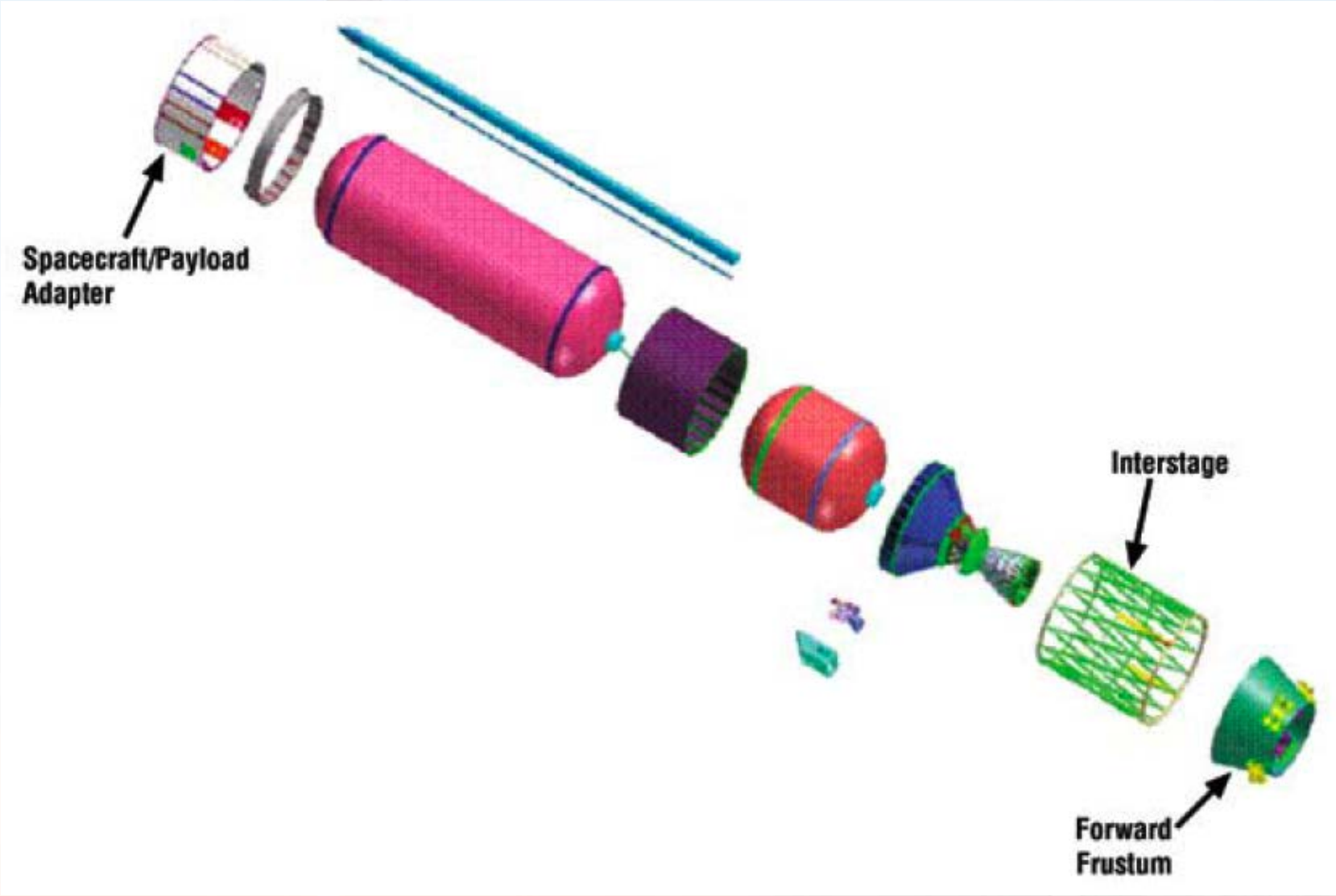
LK Lunar Landing Vehicle



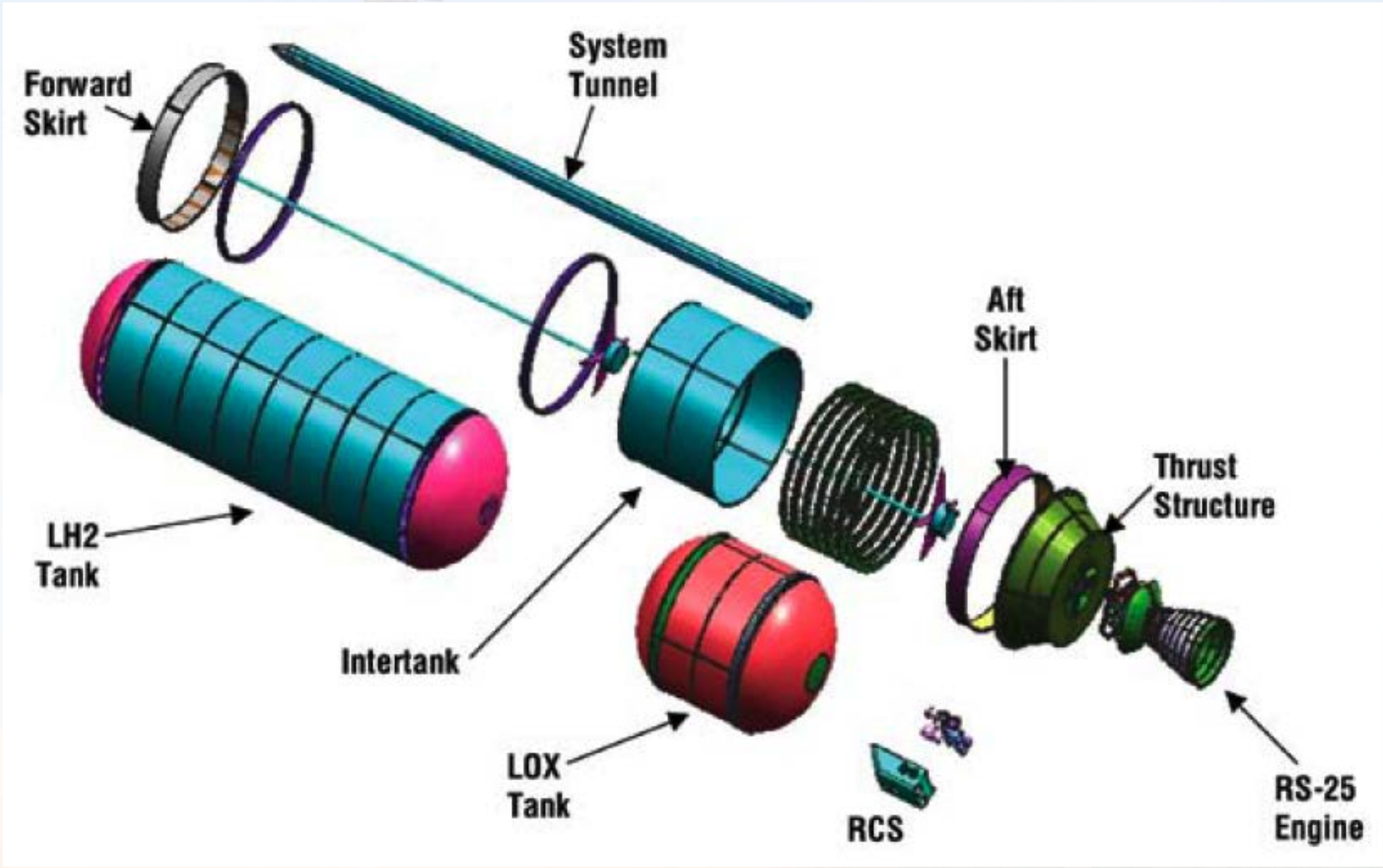
LK Spacecraft on Moon

Project Constellation Structural Examples

CLV Upper Stage Components



CLV Upper Stage Structural Elements

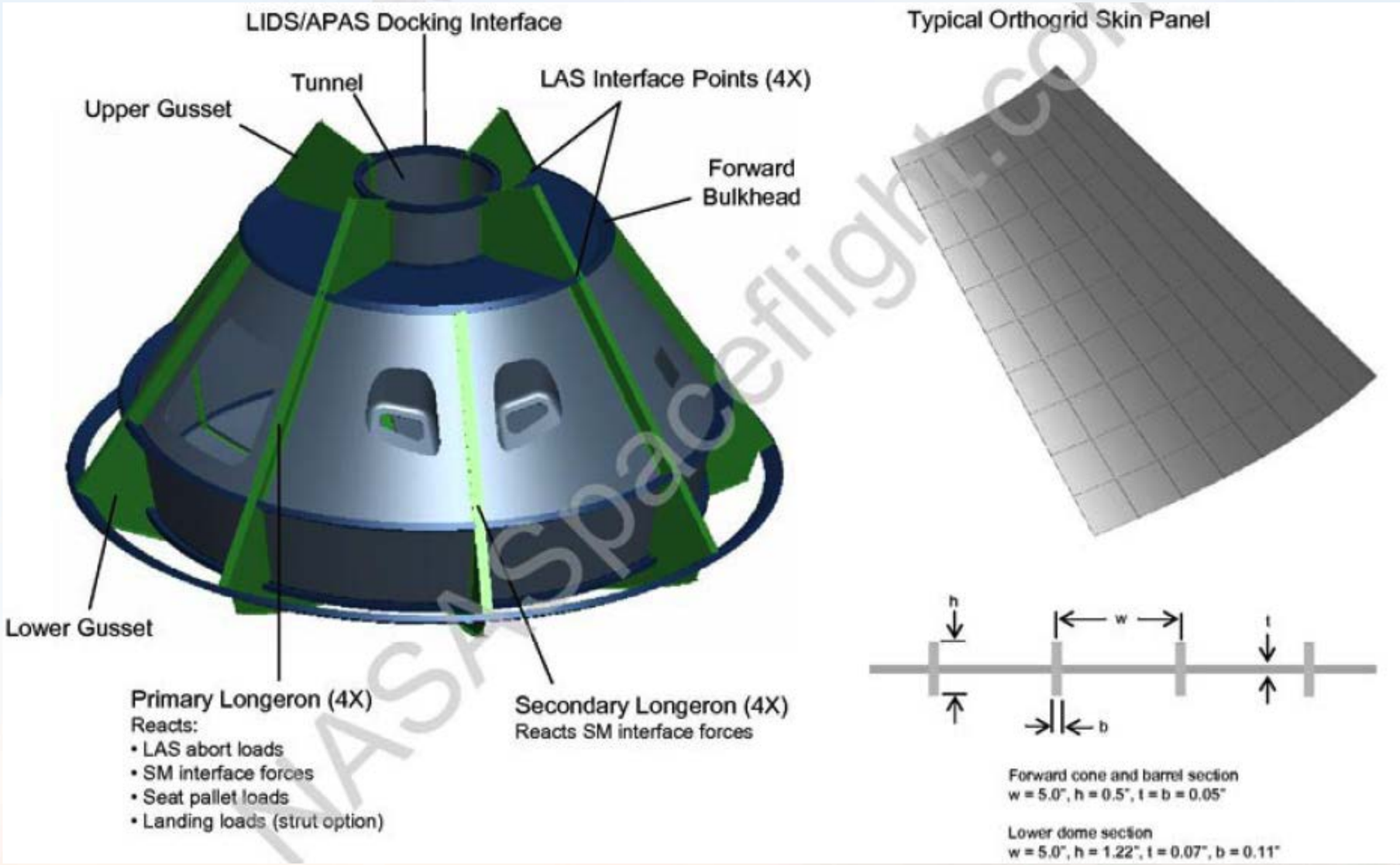


Design Overview - CEV Crew Module

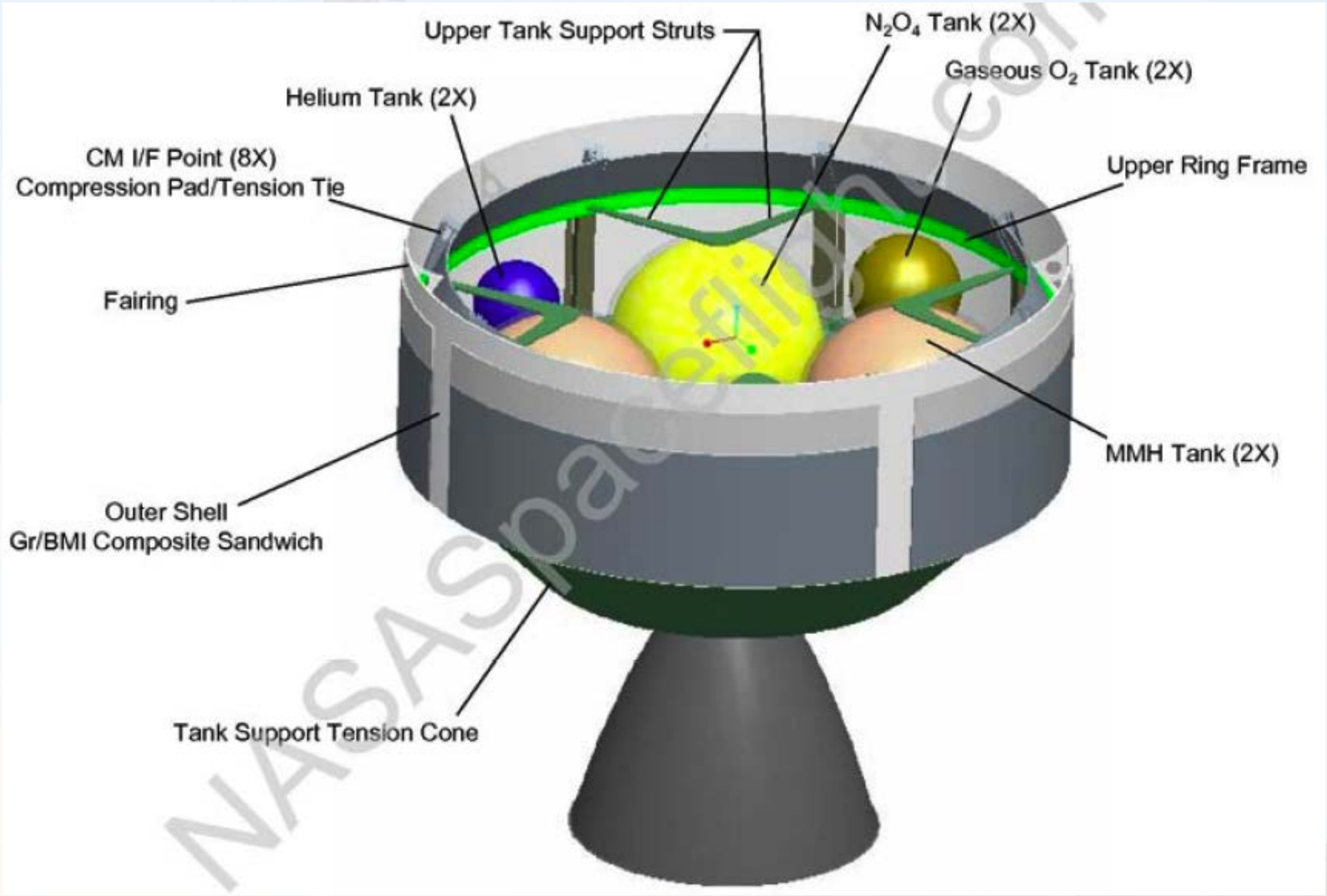
- **Pressurized Crew Compartment**
  - Ring frame / longeron / skin panel construction
  - 2195-T8 aluminum-lithium alloy frame and shell (SSP External Tank alloy)
  - 4 structural interface points for LAS at forward bulkhead
  - 4 primary longerons, 4 secondary longerons
  - 8 structural interface points to Service Module (compression pad / tension tie)
  - Roll-formed orthogrid side walls
  - Spin-formed aft dome
  - Integrally-machined forward bulkhead
  - Structure assembled using friction stir welding process

- **Aeroshell**
  - Honeycomb sandwich panel construction
  - Graphite / BMI composite facesheets for backshell and forward bay cover
  - Backshell rigidly attached to pressure vessel for load sharing (8 removable panels)
  - Forward bay cover jettisoned prior to chute deploy
  - Titanium facesheets and core used for heat shield carrier structure (TPS ADP – Ames/LaRC)
  - Heat shield jettisoned prior to airbag inflation

Pressurized Module Structural Details

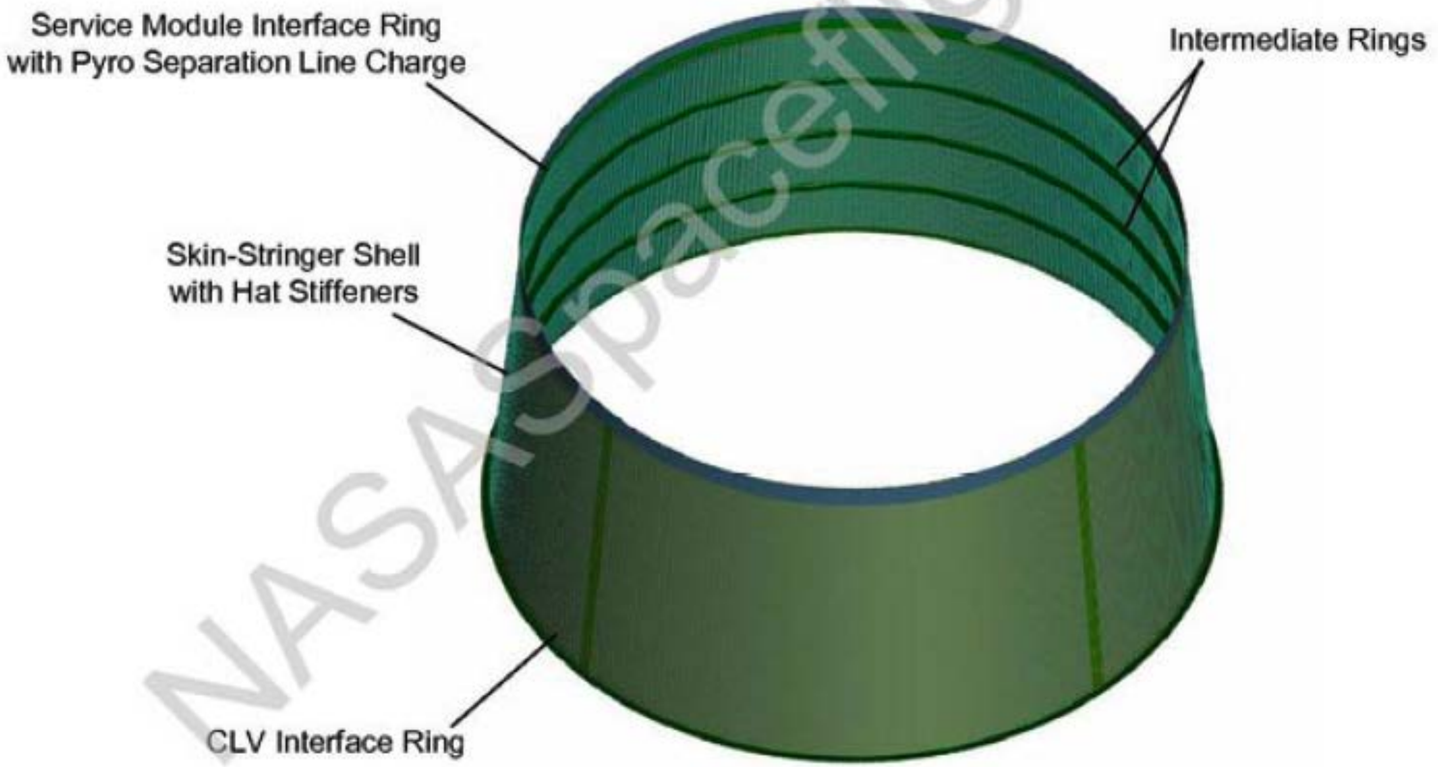


Service Module Structural Design

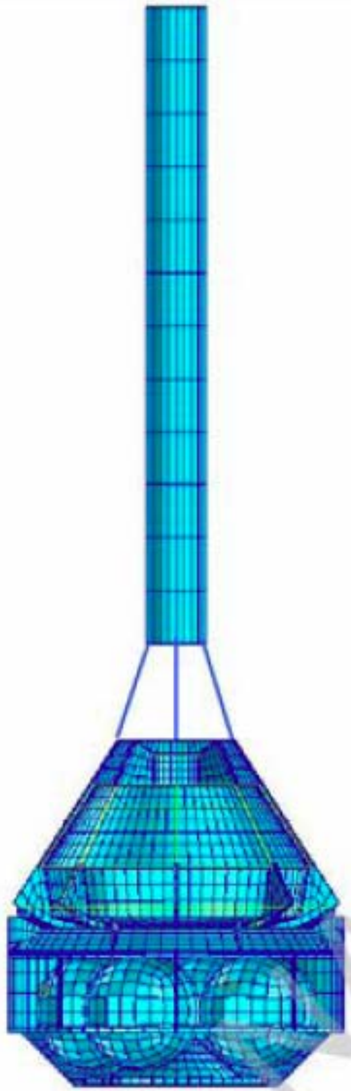


Launch Vehicle Adapter Structure

- Skin-stringer design with 240 internal longitudinal hat stiffeners and 3 intermediate rings
- Skin, stiffeners, and intermediate rings fabricated with 7075 aluminum sheet (0.032")
- Upper and lower ring frames provide structural interface to service module and launch vehicle



FEA Load Cases

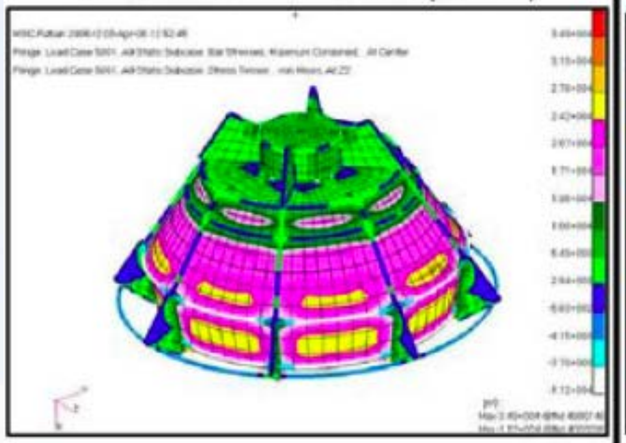


Mission Phase	Load Case	Description	Magnitude	CM	SM	LVA
Lift Off	Lift Off	Inertial load factors	Axial = 3.3/-2.0g's Lateral = 1.5g's (RSS)	X	X	X
1st Stage Ascent	Max Accel with Q-bar	Inertial loads and dynamic pressure	2.6g's, 350 psf	X	X	X
	Max Q-bar with Accel	Inertial loads and dynamic pressure	1.75g's, 832 psf	X	X	X
	Max Load	Inertial loads and dynamic pressure	2.5g's, 510 psf	X	X	X
2nd Stage Ascent	Max Accel	Inertial load factor	Axial = 5.0g's	X	X	X
Pad Abort	LAS Thrust	Acceleration	15 g's	X		
	Blast Overpressure	Quasi-static pressure (0° symmetric blast & 45° oblique blast assessed)	20 psi	X		
	Combined LAS Thrust and Blast	Acceleration and applied pressure	15 g's, 20 psi	X		
On-Orbit Ops	Cabin Pressure	Applied internal pressure	16.0 psi (ISS)	X		
	TLI Burn (EDS Thrust)	Eyeballs-out acceleration and cabin pressure	1.4 g's (burnout), 9.5 psi	X	X	
	LOI Burn (LSAM Thrust)	Eyeballs-out acceleration and cabin pressure	0.53 g's (burnout), 9.5 psi	X	X	
	TEI Burn (SM Thrust)	Eyeballs-in acceleration and cabin pressure	0.49 g's (burnout), 9.5 psi	X	X	
Atmospheric Entry	ISS Nominal Direct	Applied dynamic pressure with inertia relief	272 psf	X		
	ISS Ballistic	Applied dynamic pressure with inertia relief	836 psf	X		
	Lunar Skip	Applied dynamic pressure with inertia relief	366 psf	X		
	Lunar Ballistic	Applied dynamic pressure with inertia relief	1001 psf	X		
	Unpressurized Entry	Cabin crush pressure due to venting lag	1 psi	X		
Recovery and Landing	Drogue Chute Line Loads	Acceleration	5g's in 40° cone about X-axis	X		
	Main Chute Line Loads	Acceleration	5g's in 20° cone about X-axis	X		
	Landing	Nominal attenuation at 25 ft/sec (acceleration)	8g's reacted at CM pressure vessel	X		

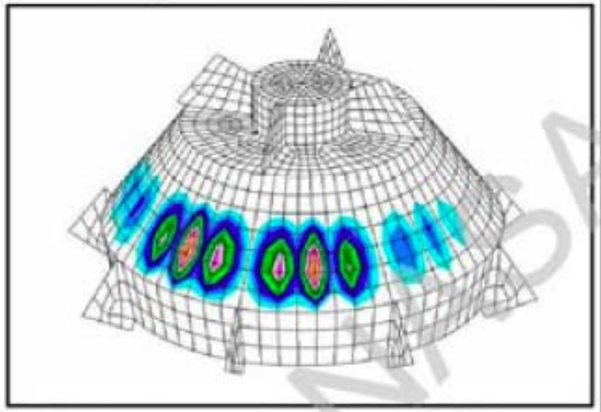
Crew Module FEA Sample Results

Crew Cabin ΔP

Von-Mises Stress – Cabin Pressure (ISS Case)



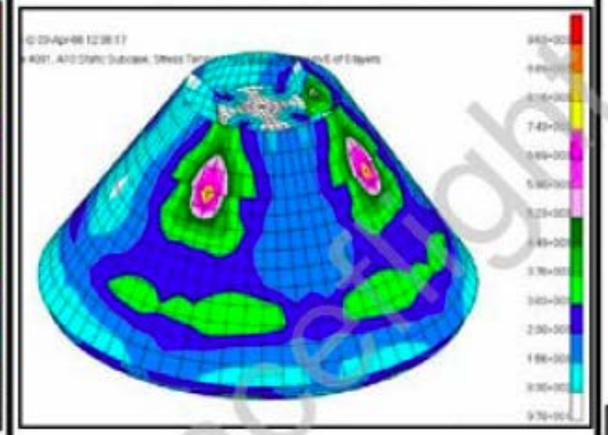
Buckling Mode – External Crush Pressure



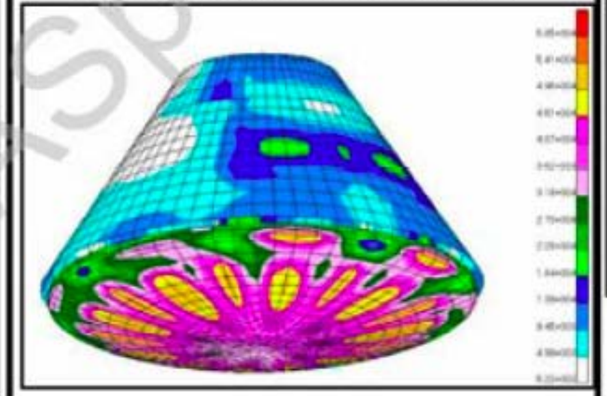
Critical crush pressure for skin buckling = 2.3 psi
(Unpressurized entry, establishes venting requirement)

Pad Abort

Max Facesheet Stress – LAS Thrust Case



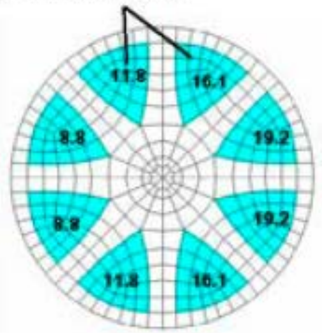
Max Facesheet Stress – Blast Overpressure



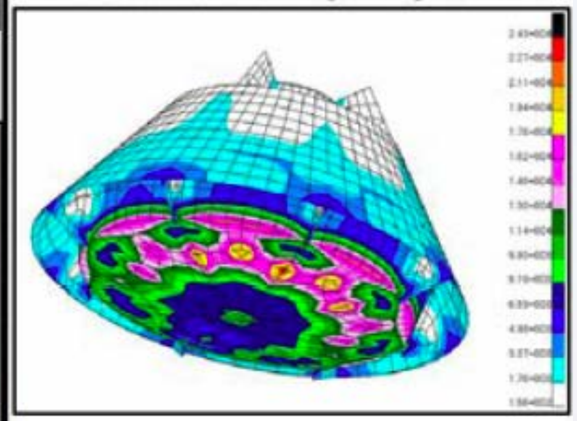
Nominal Landing

24 ft/sec, 8g attenuation

Airbag pressure footprint
(average pressure in psi)

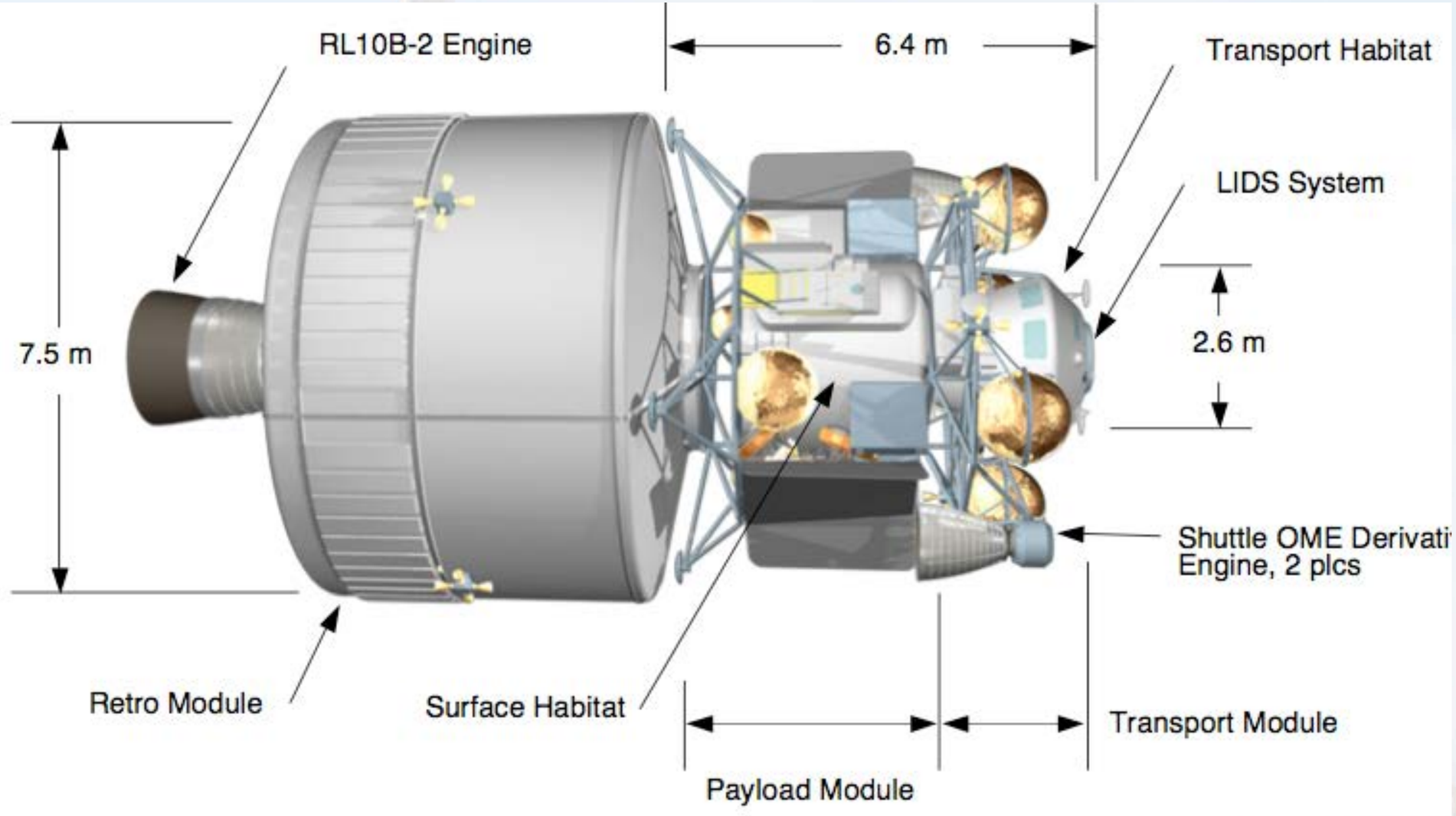


Von-Mises Stress – Airbag Landing Loads

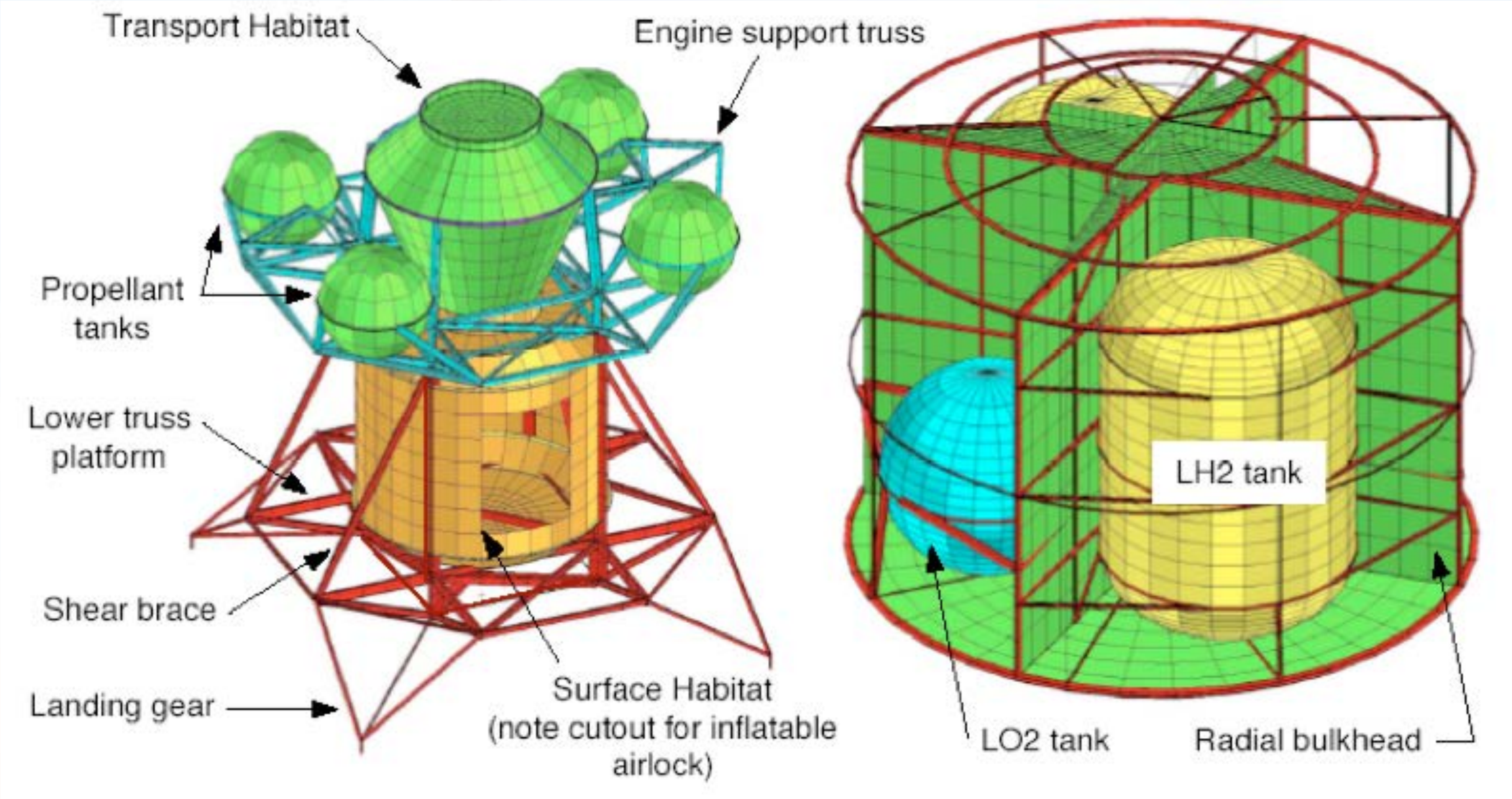


- Internal cabin pressure case sizes aft bulkhead until landing attenuation level exceeds 18g's (vertical landing scenario with no horizontal component)
- LS-Dyna analysis required to capture dynamic nonlinear contact effects as well as horizontal velocity

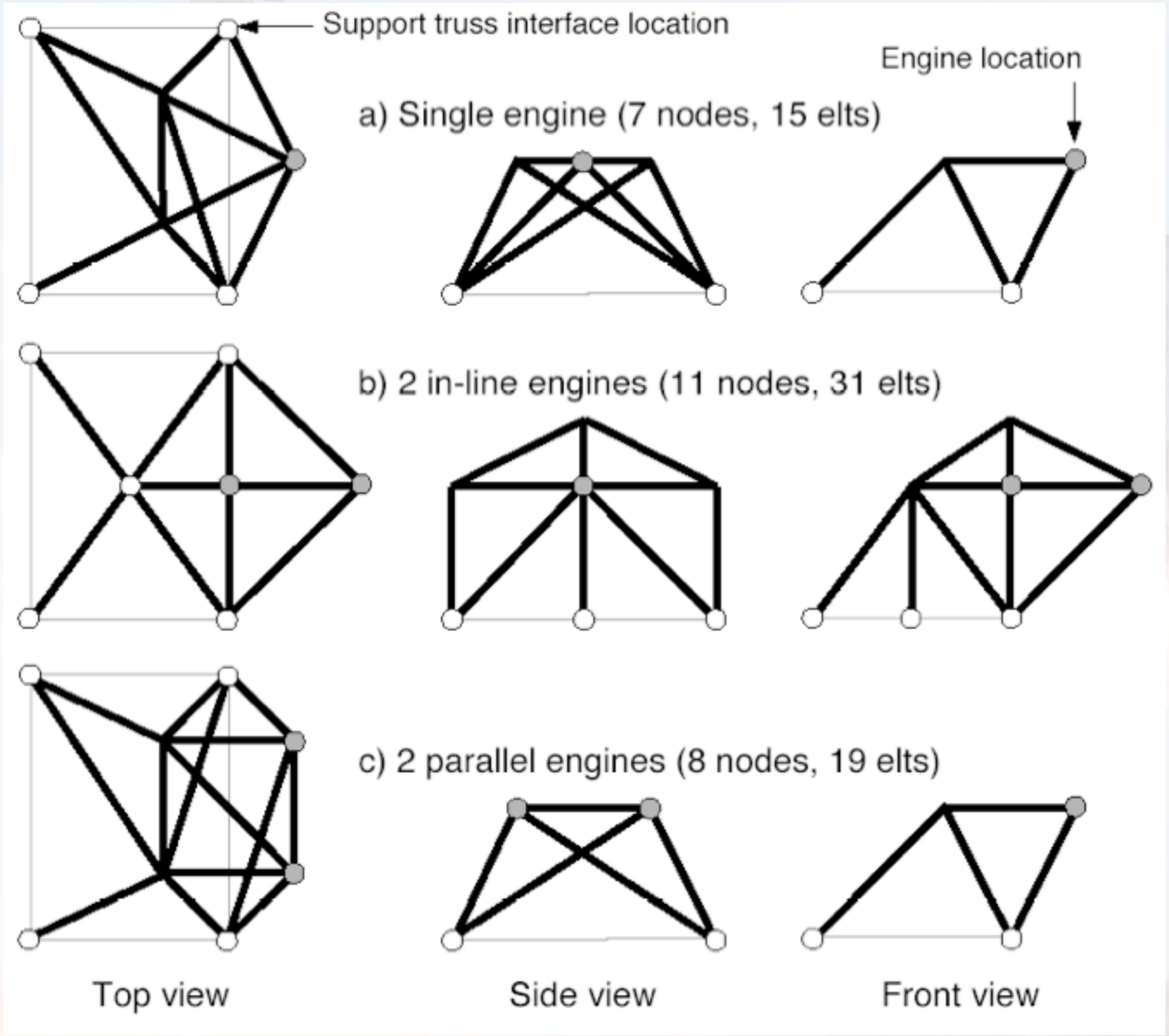
Descent Assisted, Split Habitat (DASH)



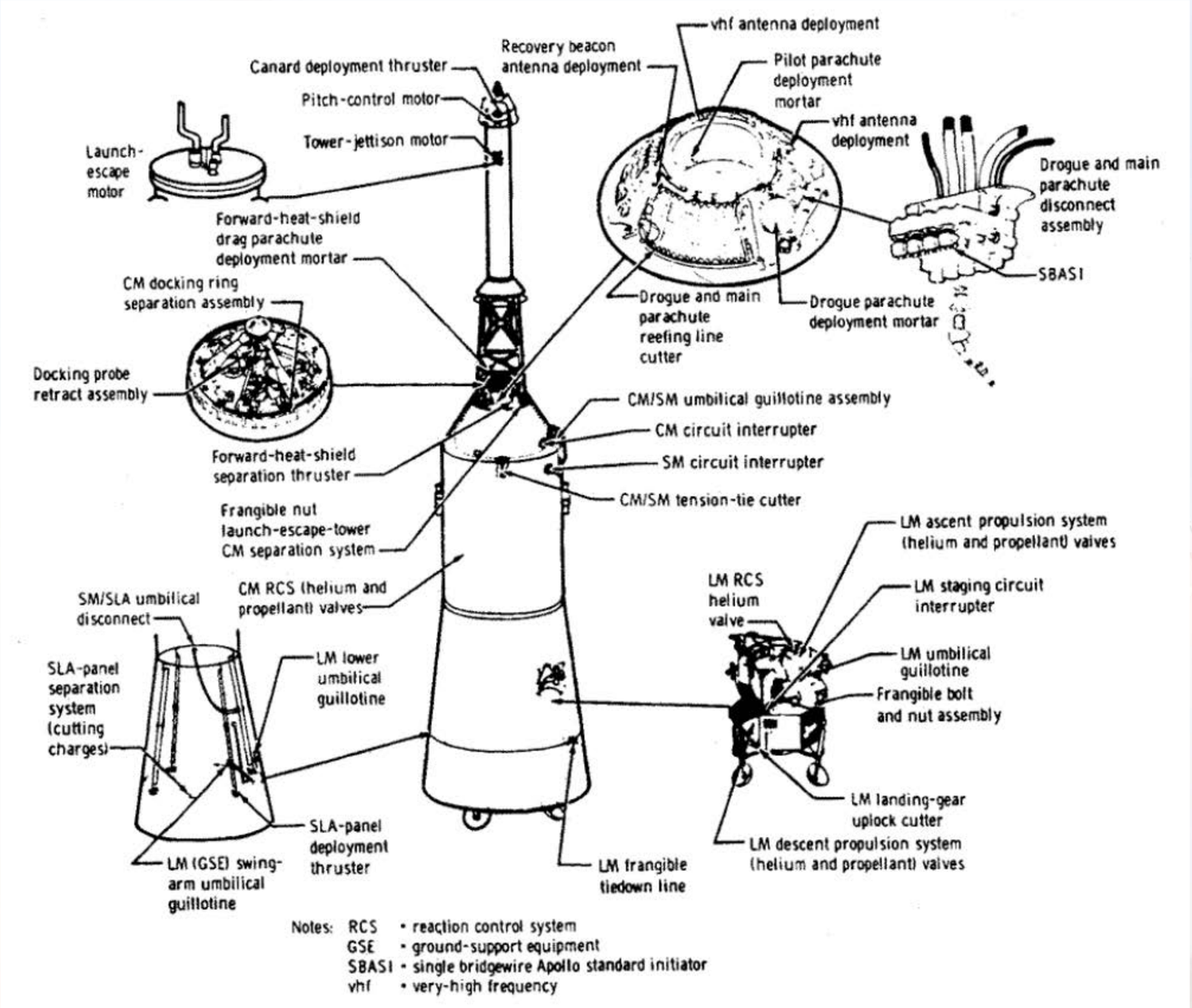
DASH Lander Structural Components



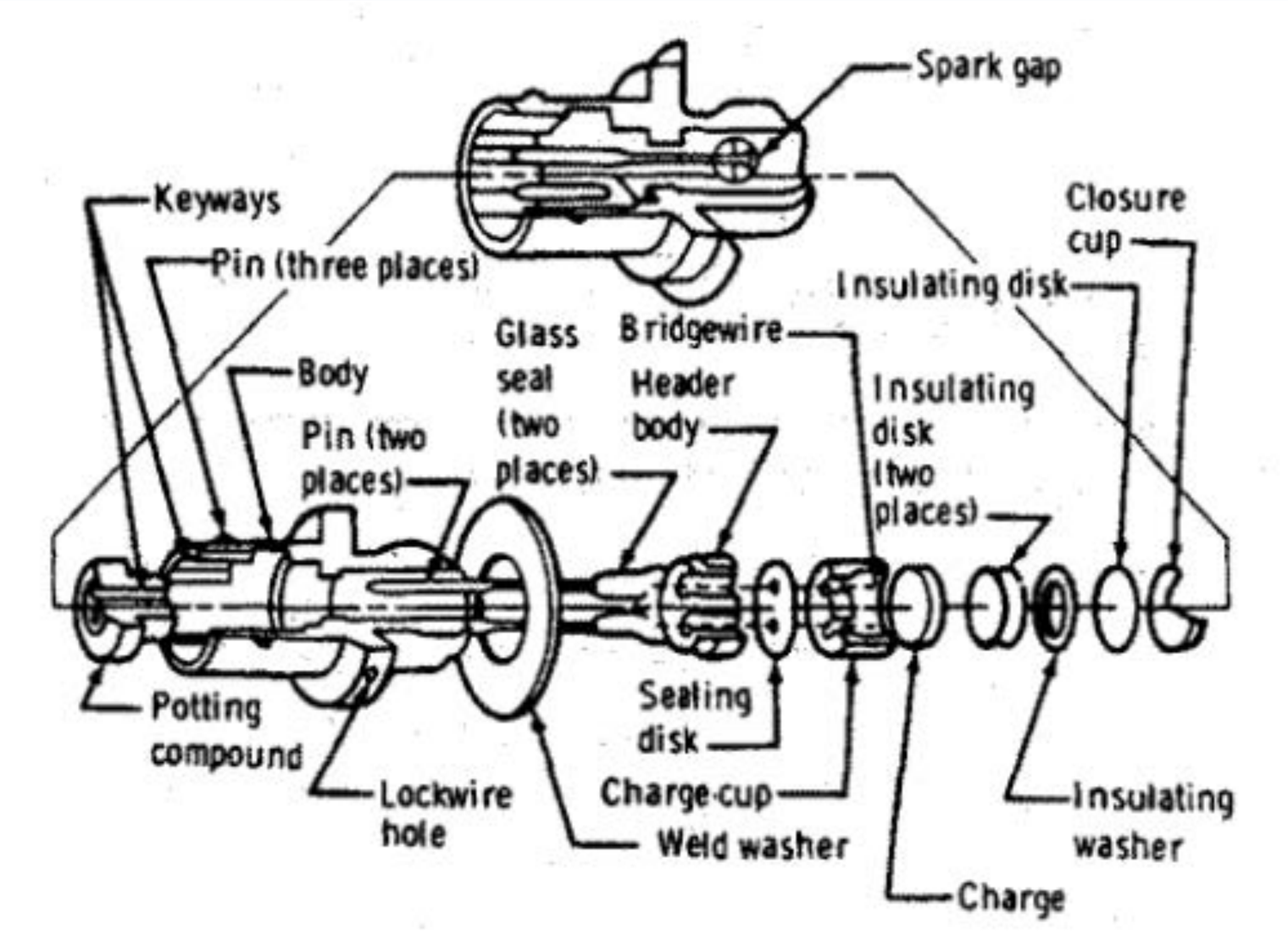
DASH Engine Support Truss Concepts



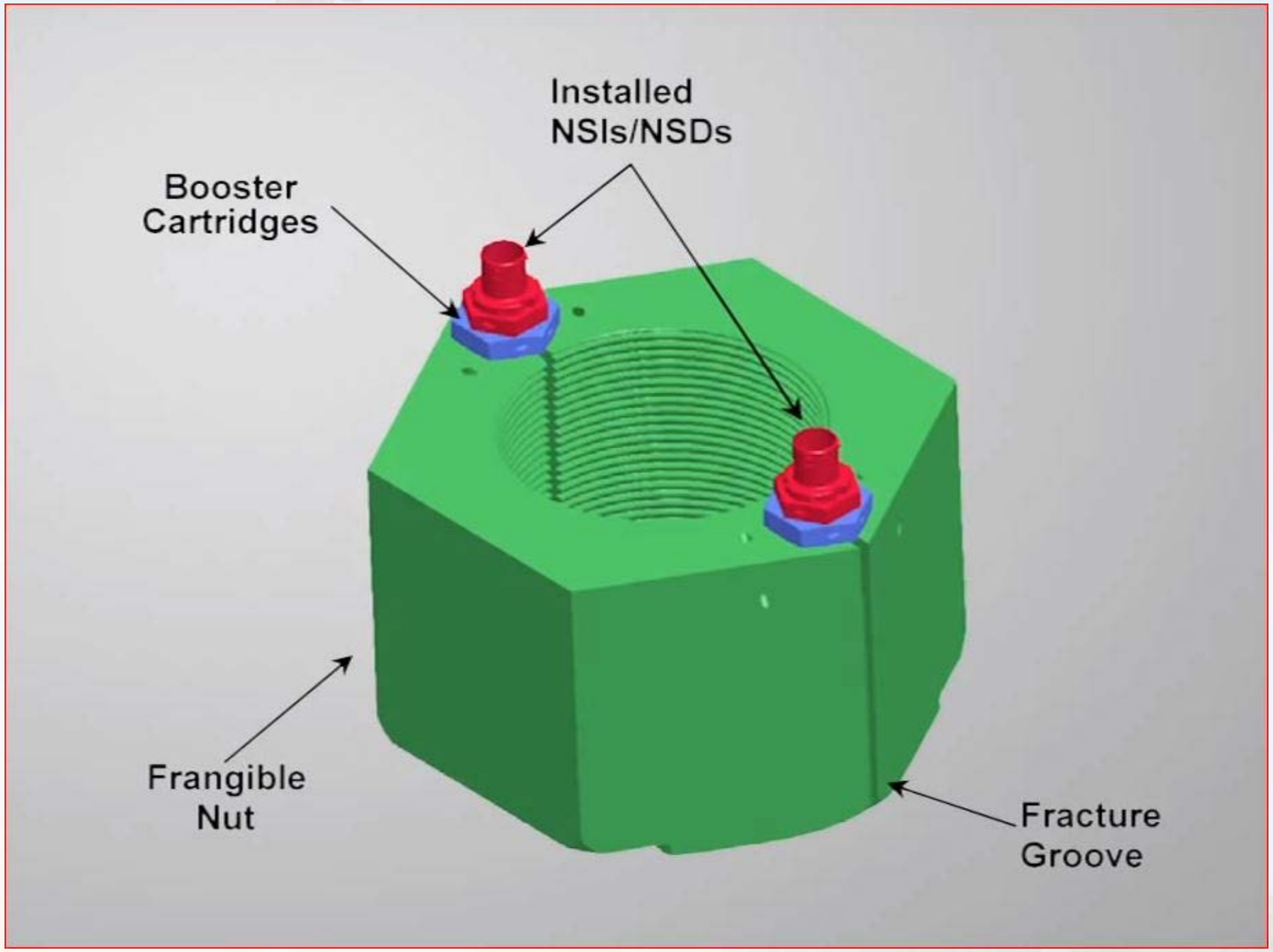
Apollo Pyrotechnic Device Locations



Single Bridgewire Apollo Std. Initiator

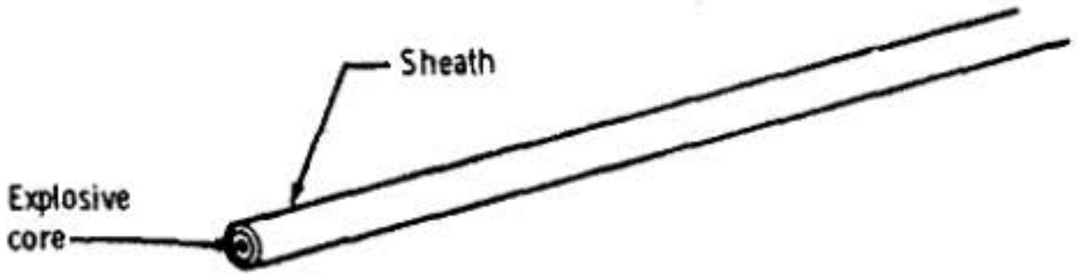


Space Shuttle SRB Explosive Nut

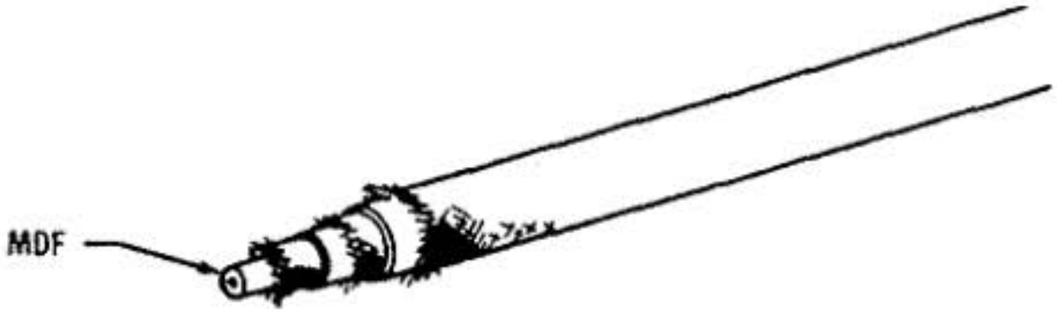


Space Shuttle SRB Explosive Nut

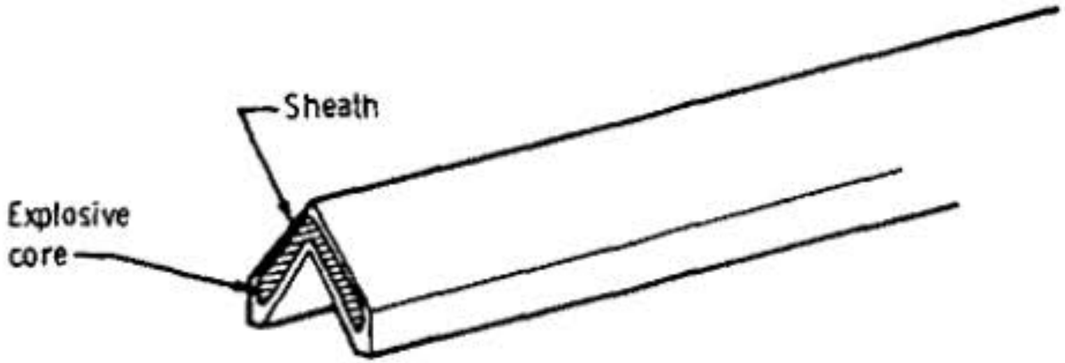
Pyrotechnic Devices



(a) Mild detonating fuse.

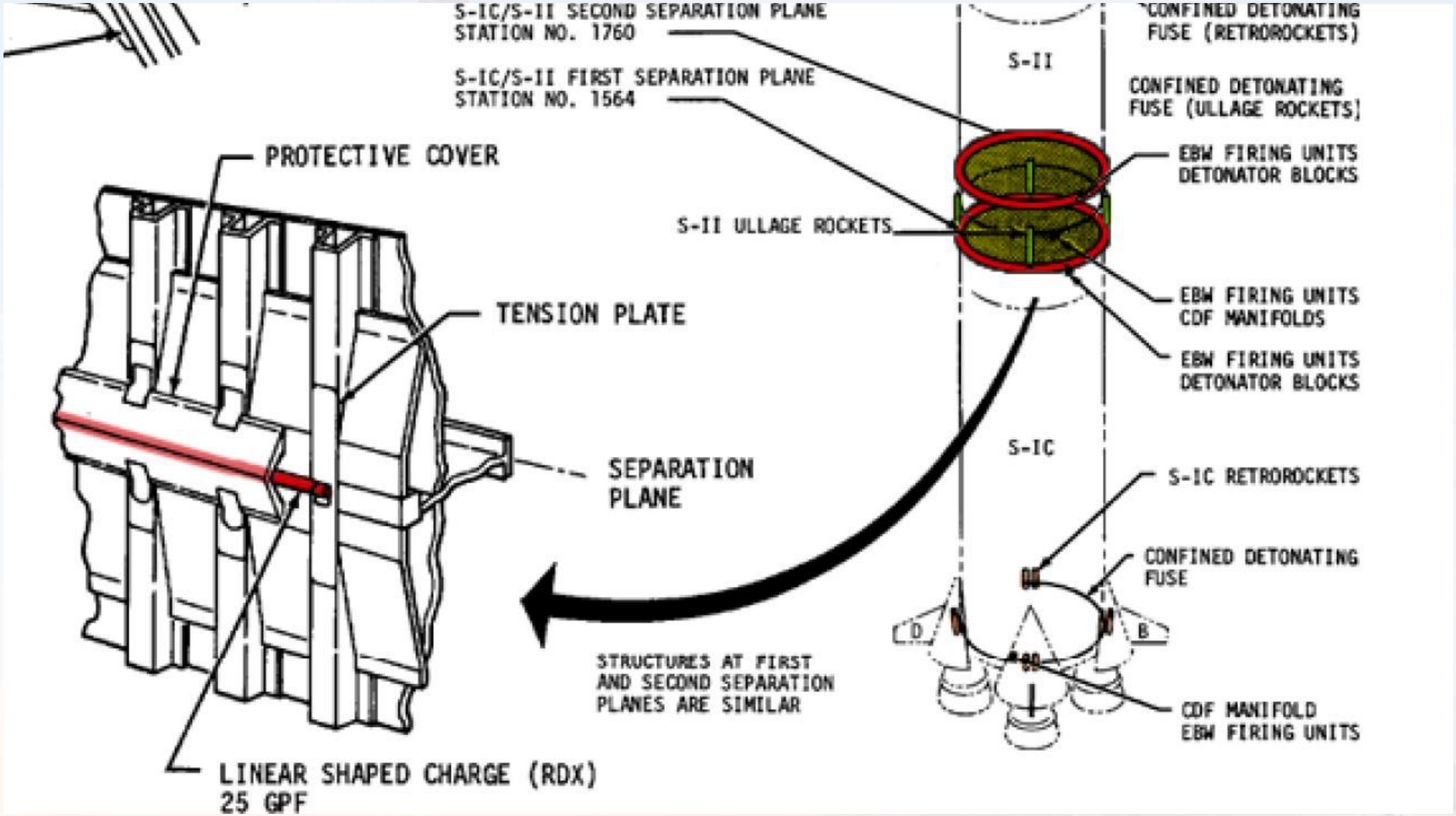


(b) Confined detonating cord.



(c) Linear-shaped charge.

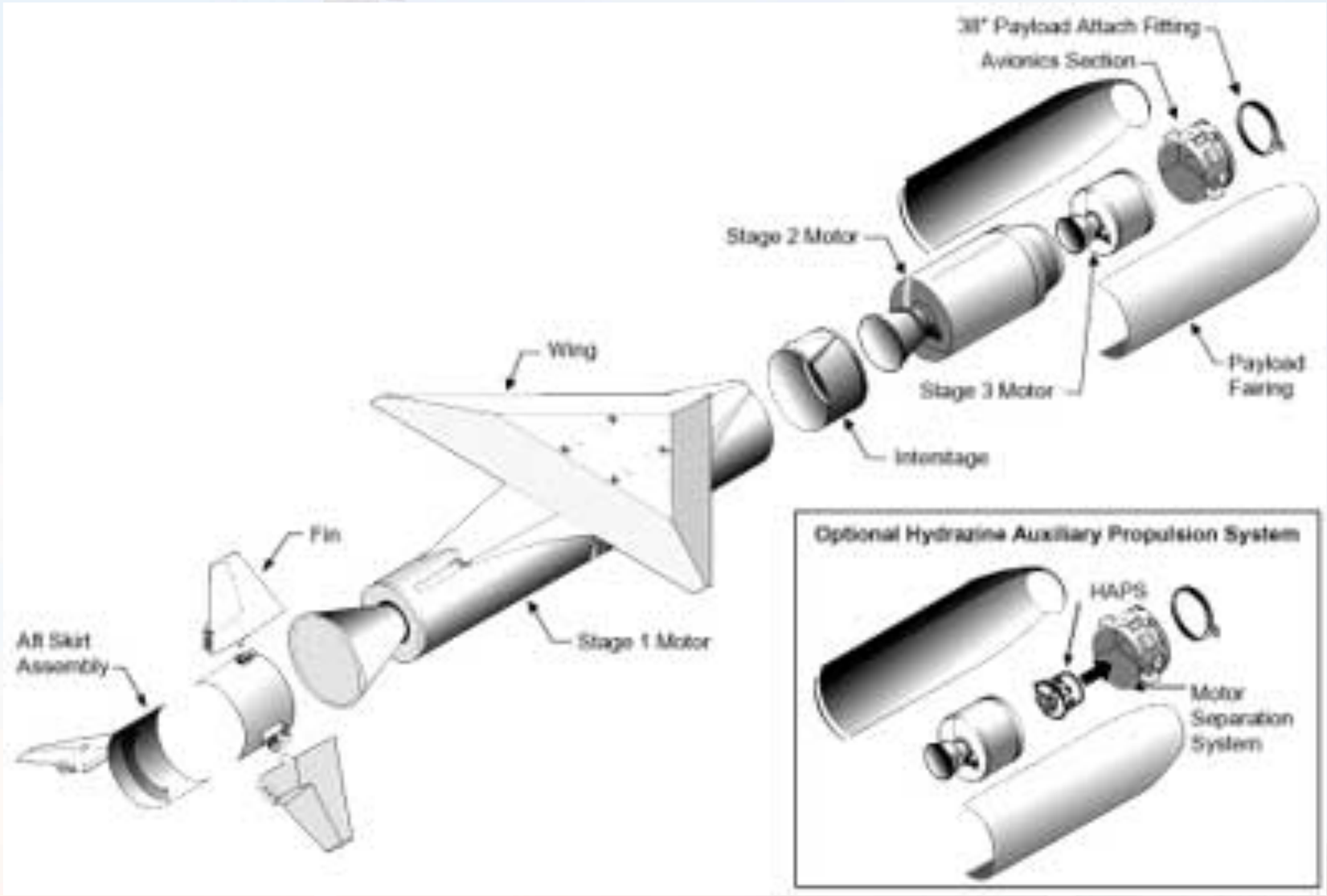
Stage Separation Linear Shaped Charges



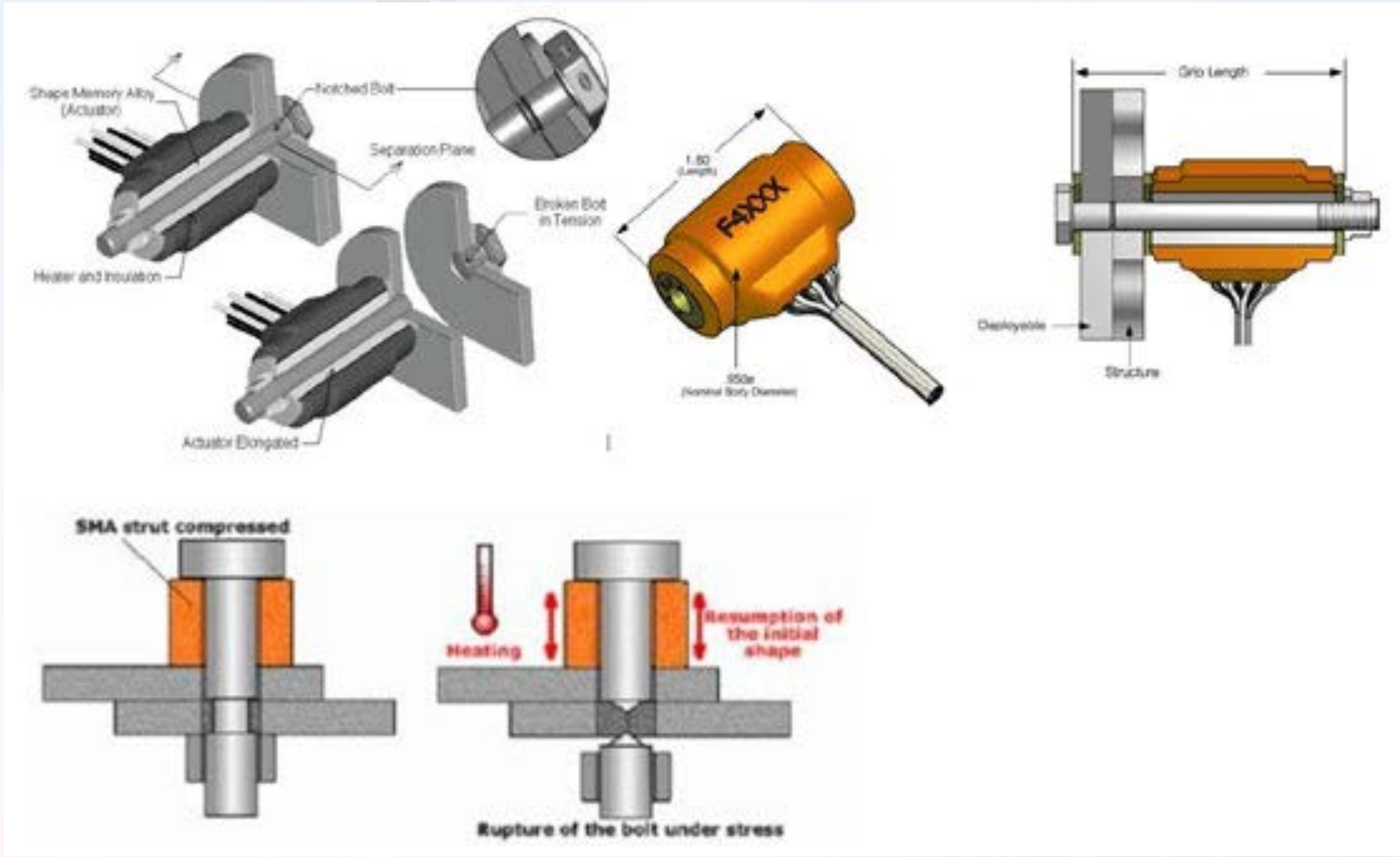
Saturn V Linear Shaped Charge Test

Pegasus First Stage Burn

Pegasus Structural Configuration



Frangibolt Actuator



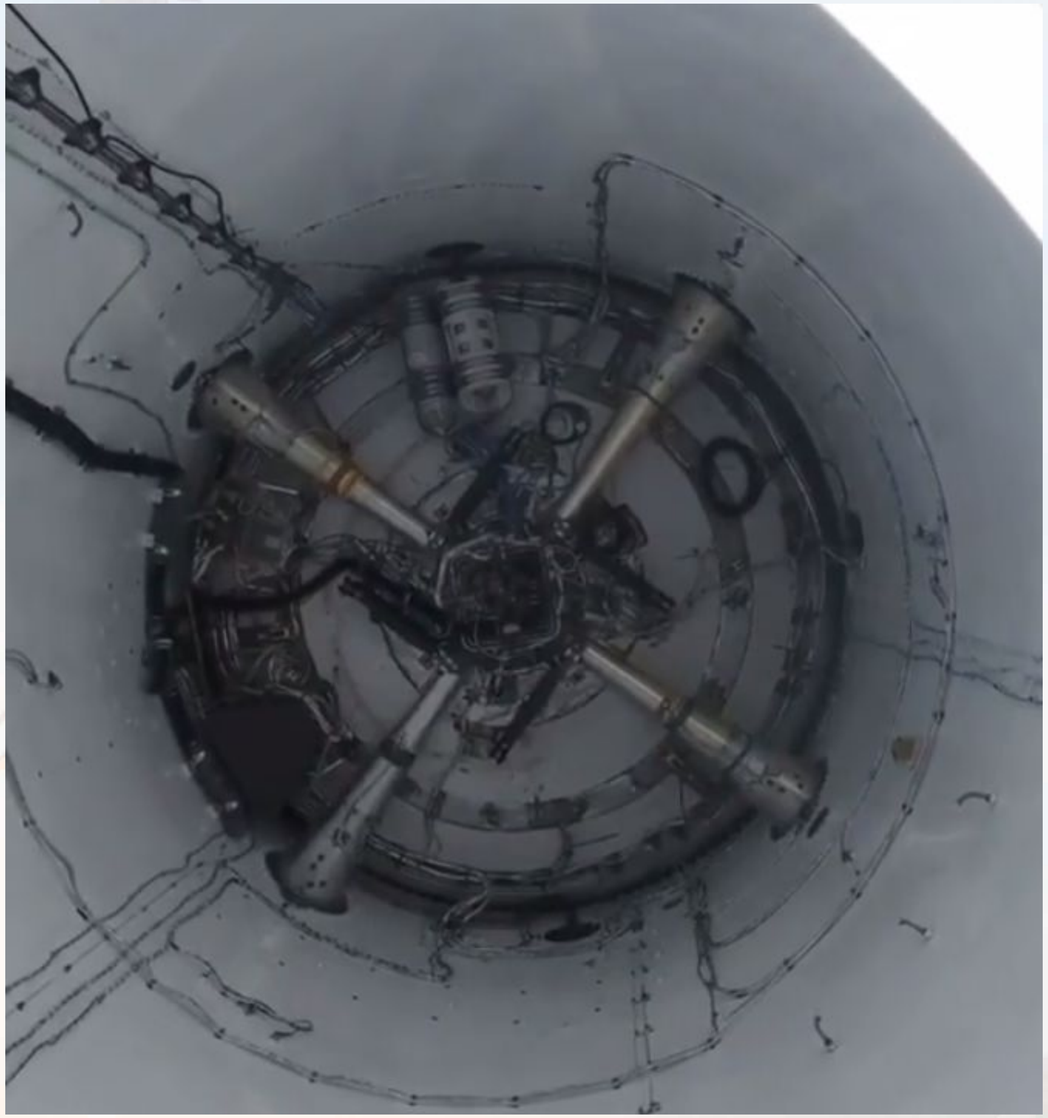
Paraffin Pin Pullers

Other Actuator Technologies

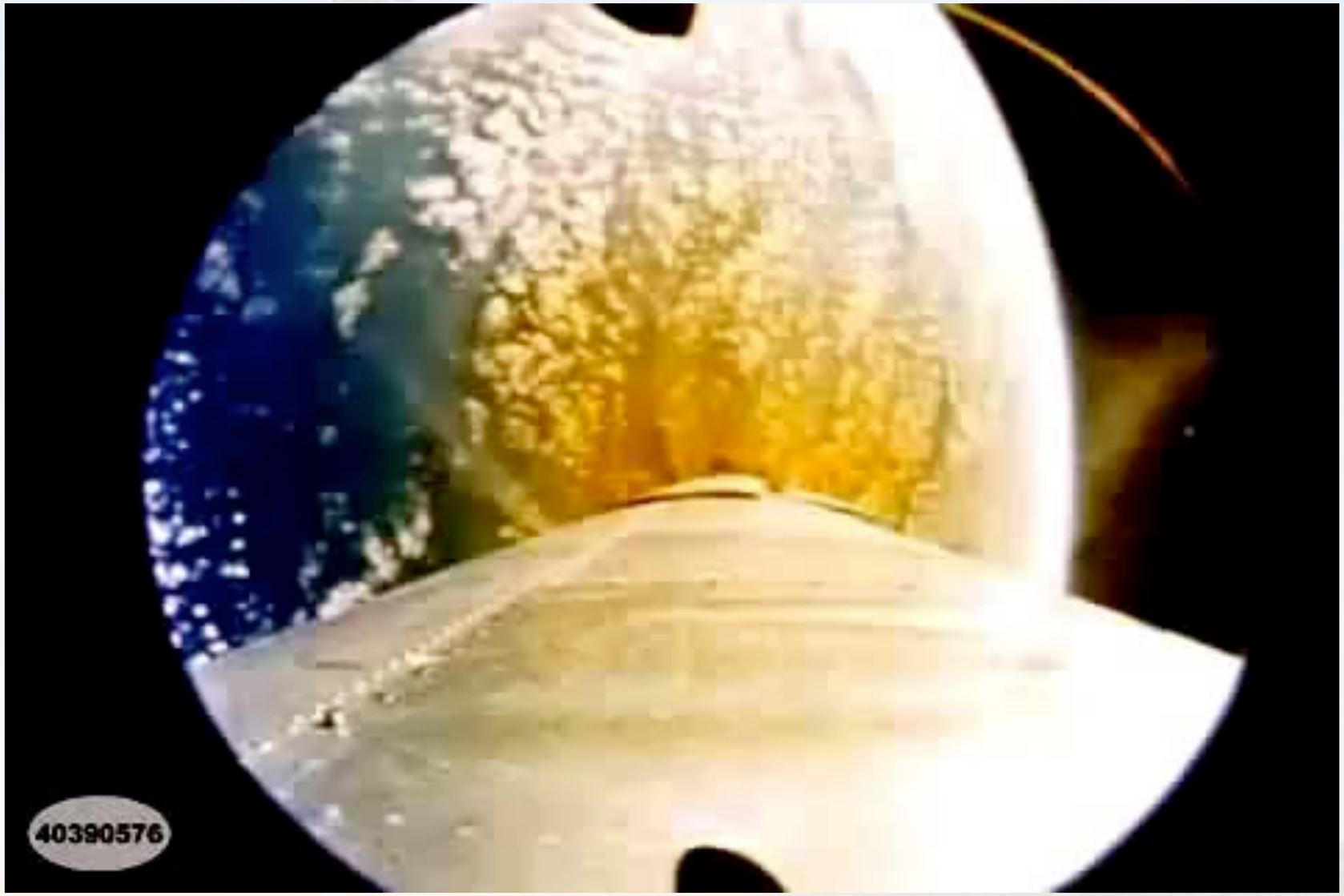
- Pneumatics
- Hydraulics
- Electromechanical actuators

Falcon 9 Pneumatics

Falcon 9 Electromechanical Systems (Grid Fins)



Titan II “Fire in the Hole”



Starship Hot Staging