APOLLO SEALS: A BASIS FOR THE CREW EXPLORATION VEHICLE SEALS

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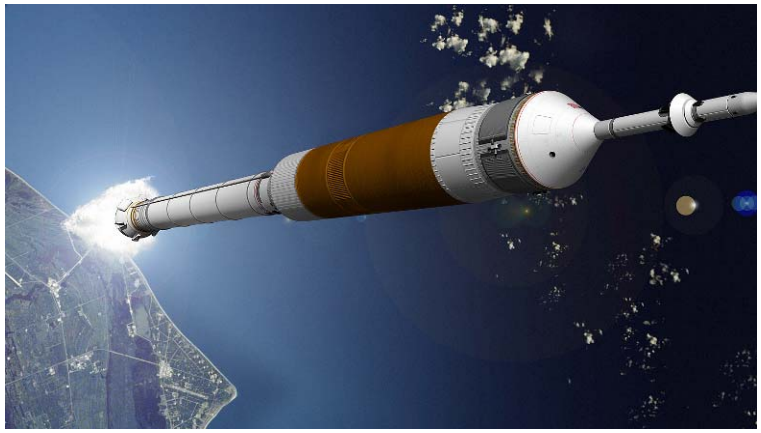
Crew Exploration Vehicle

- NASA's Vision for Space Exploration
  - Replace the Space Shuttle for missions to ISS
  - Return to the Moon
  - Allow manned exploration of Mars
- Apollo-like configuration
  - Blunt-body heat shield
  - Conical backshell
- CEV requires seal development
  - Prevent ingestion of reentry gases
  - Prevent loss of habitable atmosphere
- **<u>NASA GRC approach:</u> Study Apollo as a starting point for CEV seals**



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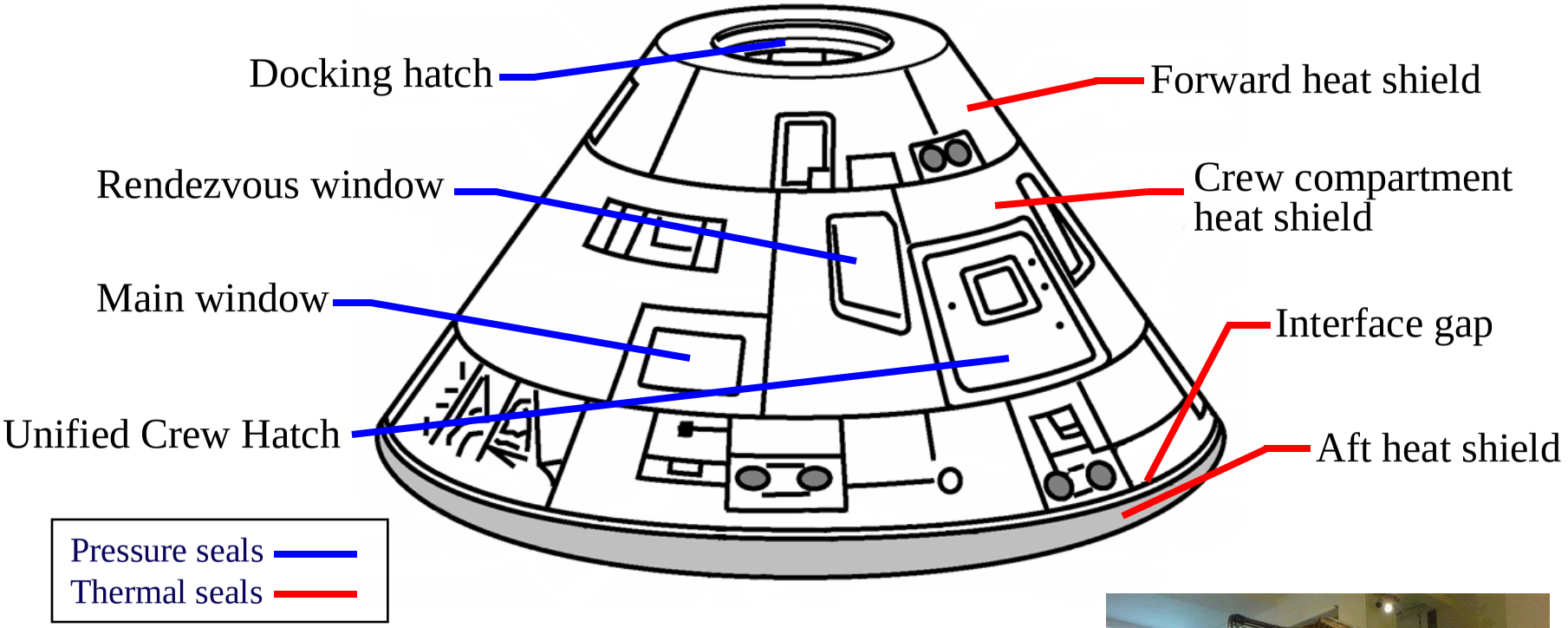
Apollo Command Module



- Designed for manned lunar landing
  - 9 missions to lunar orbit
  - 6 missions to LEO
- Authors investigated Apollo/Skylab 3 on display in GRC Visitor Center

Apollo 10

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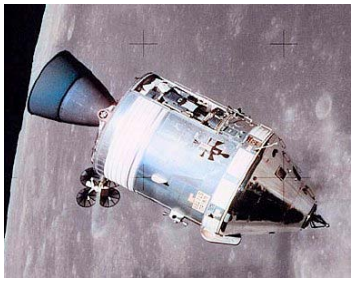
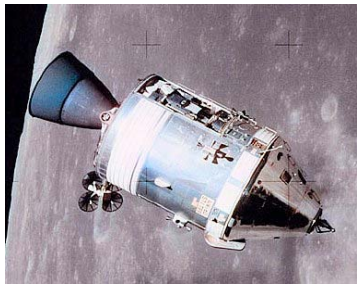
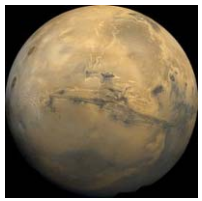
Apollo vs. CEV: Capsule

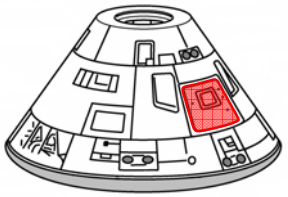
	Apollo	CEV
		
Astronauts	3	3 to 6 LEO 4 Lunar 6 Mars
Maximum Diameter	3.9 m (154 in)	5.0 m (200 in)
Number of missions	1	1*
Landing	Ocean	Land

Apollo vs. CEV: Mission Profile

		Apollo 	CEV 
	**Missions to LEO/ISS**		
	Mission duration	83 days	6 months
	Return velocity	Mach 25	Mach 25
	**Missions to Moon**		
	Mission duration	13 days	14 days (6 months w/ habitat)
	Return velocity	Mach 36	Mach 36
	**Missions to Mars**		
	Mission duration	NA	2.5 years
	Return velocity	NA	Mach 45

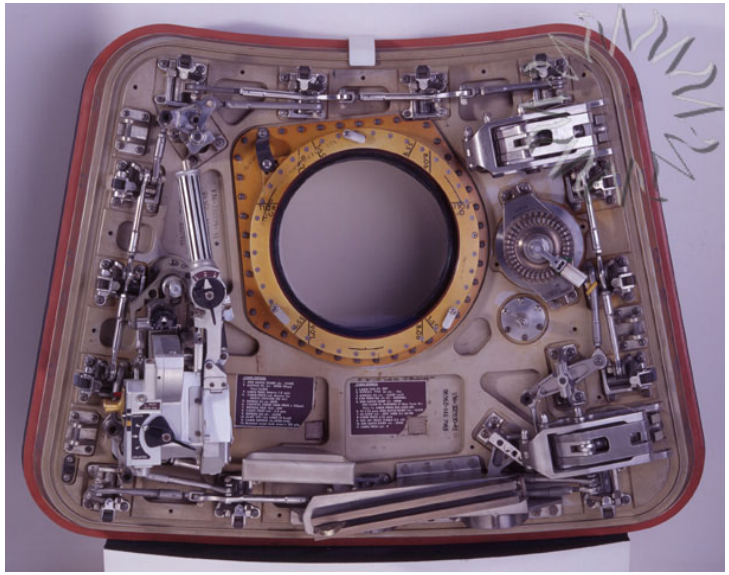
Apollo Pressure Seals

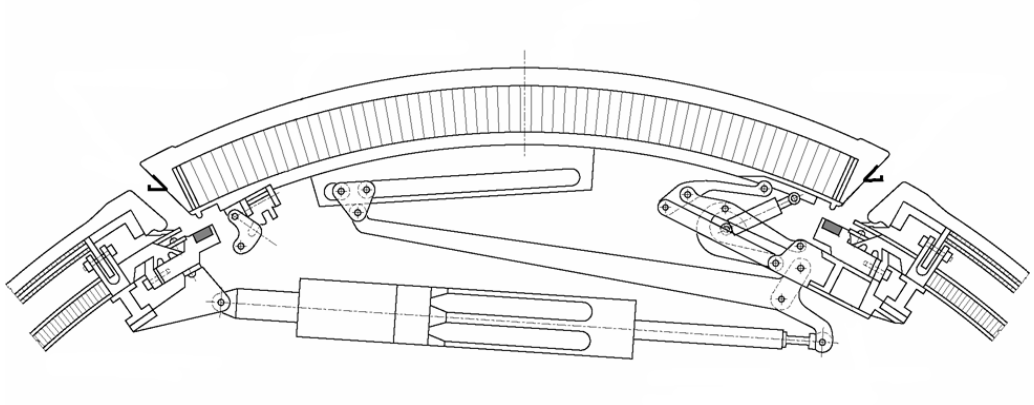
- Prevent loss of habitable atmosphere
  - Lunar missions
    - 5 psia
    - 100% O_2
  - Skylab missions
    - 5 psia
    - 70% O_2, 30% N_2
- Seal locations:
  - Bolted and riveted aluminum panels
  - Unified Crew Hatch
  - Docking system seals
  - Windows

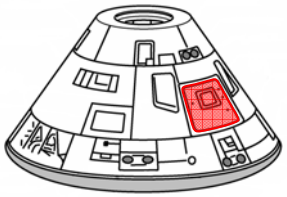


Unified Crew Hatch (UCH)

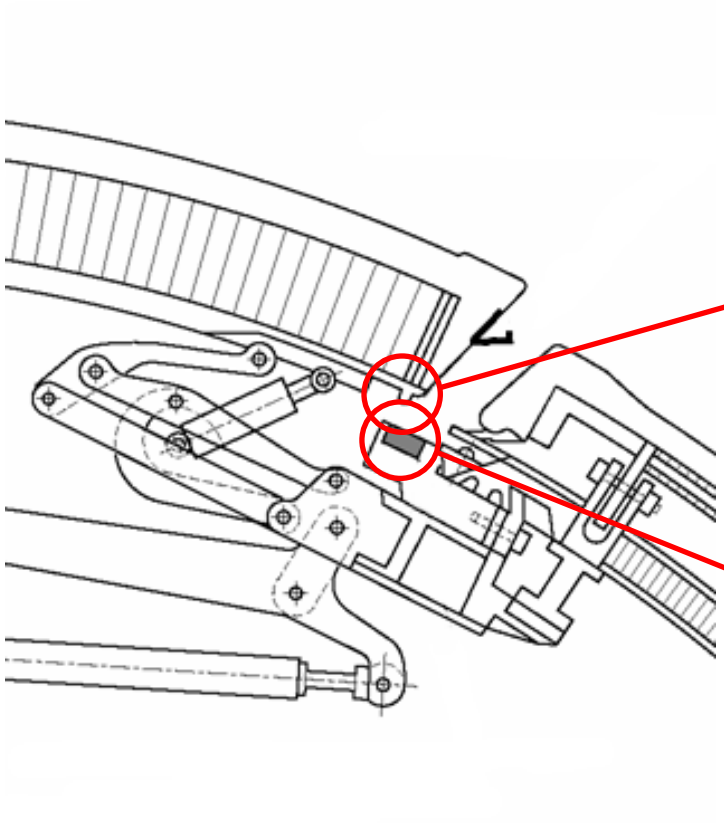
- In response to Apollo 1 fire, combined pressure hatch and heatshield hatch into single hatch (UCH)
- Allowed 30 sec. egress
  - Latches released in 3 sec.
  - Astronauts escape in 30 sec.
- UCH incorporated two seals
  - Pressure seal
    - Metal knife edge
    - Embedded into gasket
  - Thermal lip seal
    - Heat-molded silicone
    - More effective under pressure

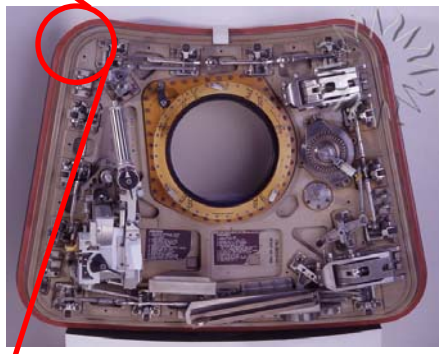


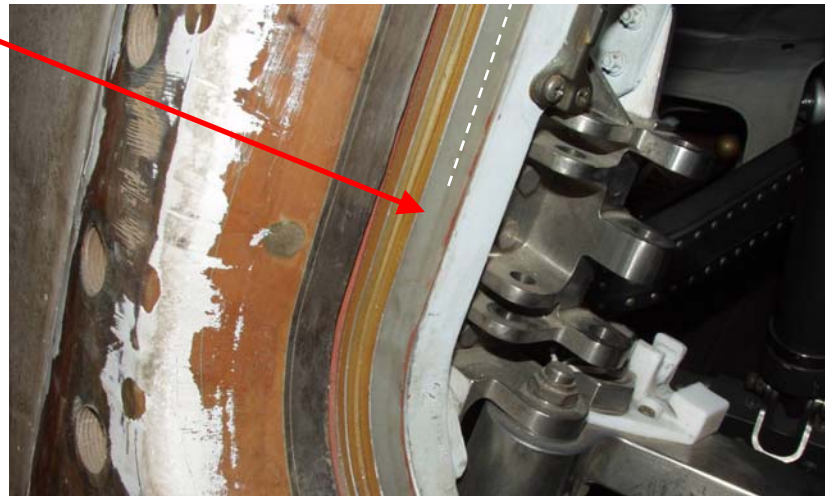


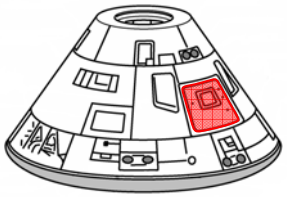


UCH Pressure Seal

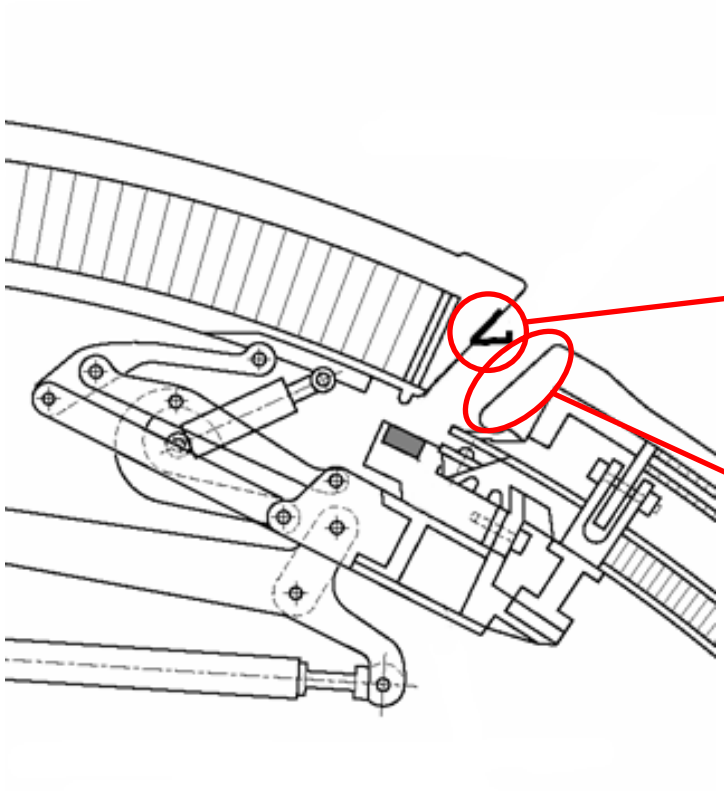


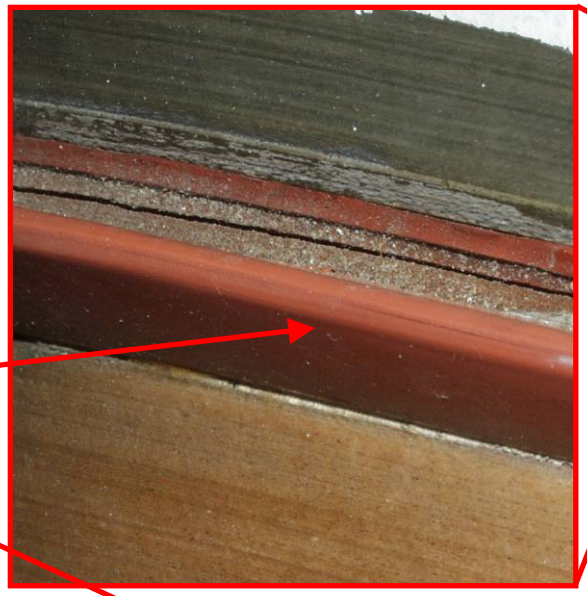


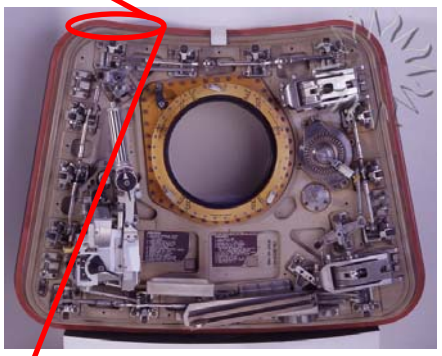


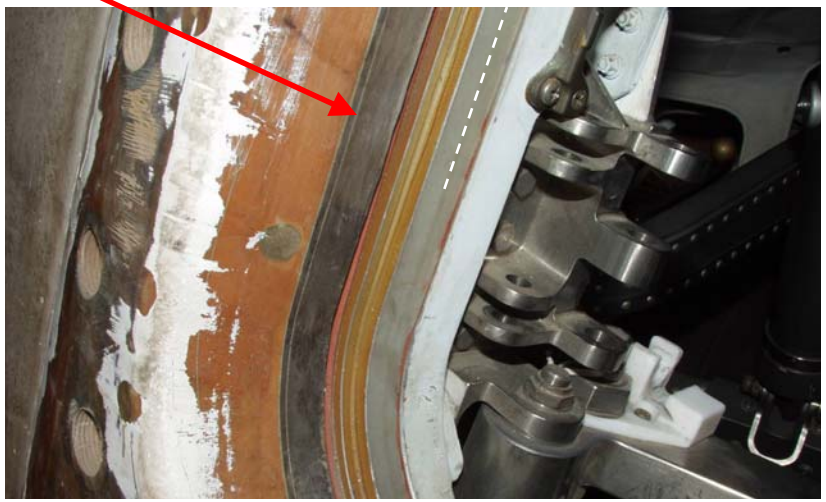


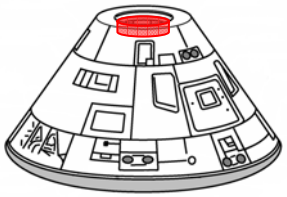
UCH Thermal Seal





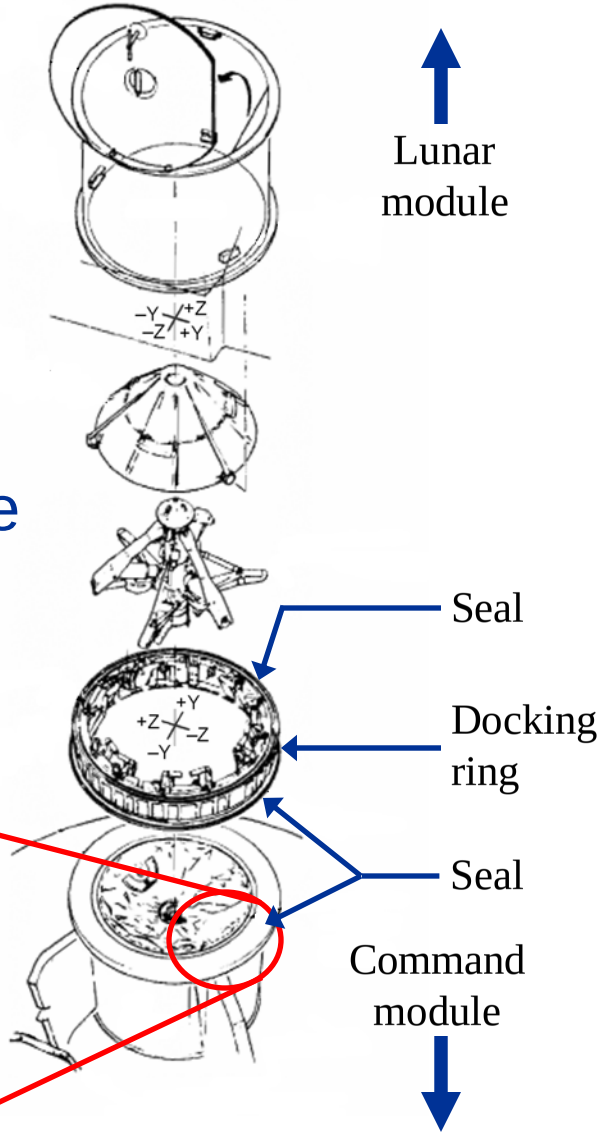






Docking System Seals

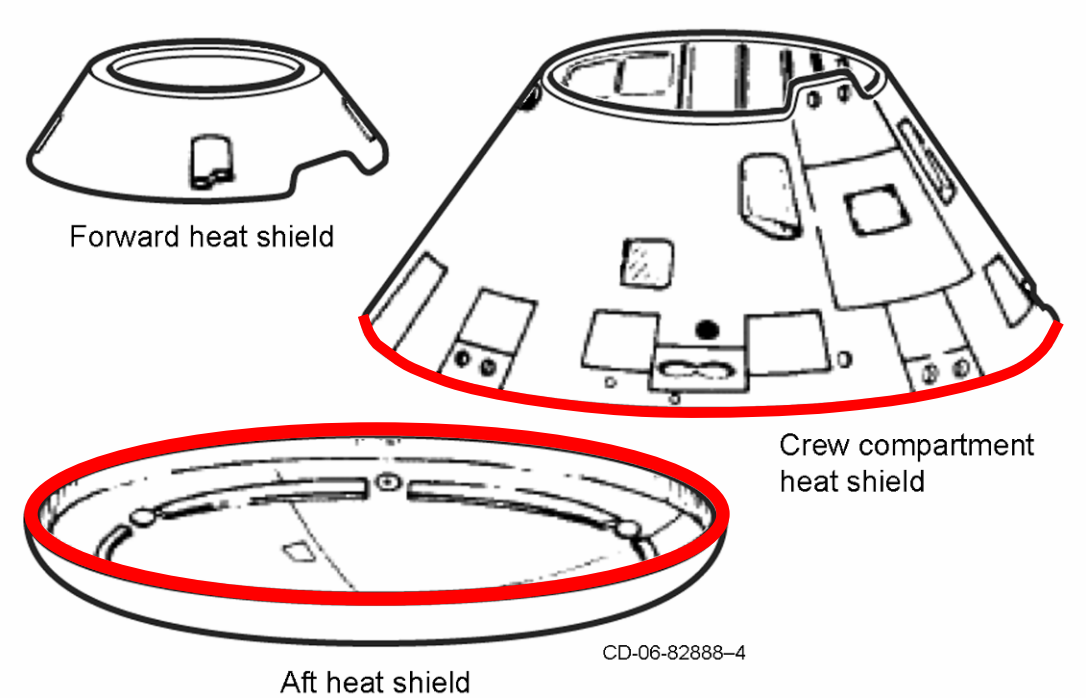
- Docking required several seals
  - CM tunnel hatch
  - CM tunnel to docking ring
  - Docking ring to lunar module tunnel
  - Lunar module hatch
- Docking ring jettisoned with lunar module
- CM tunnel appears to have:
  - Groove for elastomer gasket
  - Metal knife edge



High Temperature Thermal Seals

- Prevent ingestion of hot reentry gases
- Seal locations:
  - Aft heat shield
    - Tension tie bolts
    - Reaction Control System (RCS) oxidizer/fuel dump plugs
  - Crew compartment heat shield
    - Access panels
    - RCS motors
  - Forward heat shield interface gap
  - **Aft heat shield-to-crew compartment heat shield interface gap**
    - Thermal environment
    - Seal design

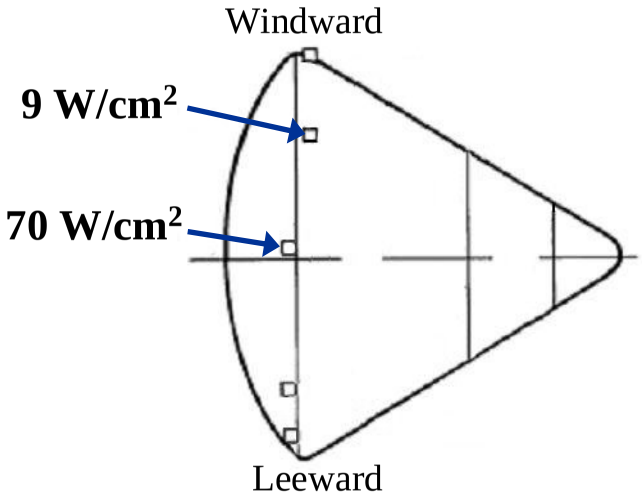
Aft Heat Shield-to-Crew Compartment Heat Shield Interface Gap

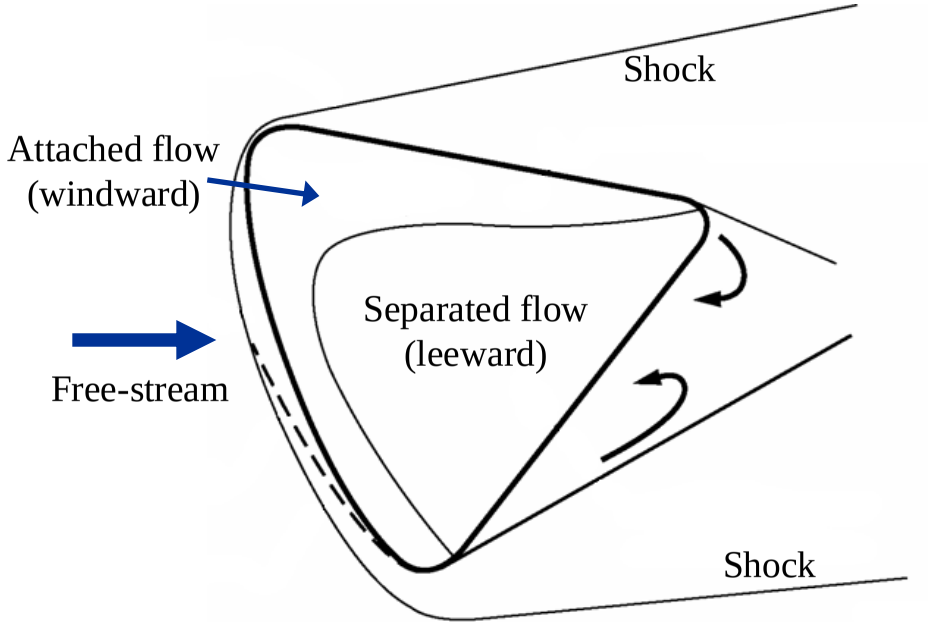


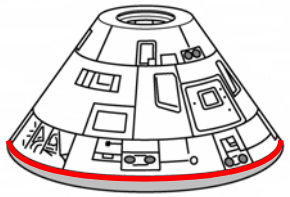
- Seals must resist reentry environment:
  - Silicone gaskets
  - Labyrinth tooth

Interface Gap Thermal Environment

- Thermal environment near gap difficult to predict
  - Very high axial heat flux gradient
  - Circumferential heat flux gradient
- Three-dimensional flowfield
  - Flow partially aligned with gap
  - Pressure gradient around capsule circumference
  - Flow separation near gap

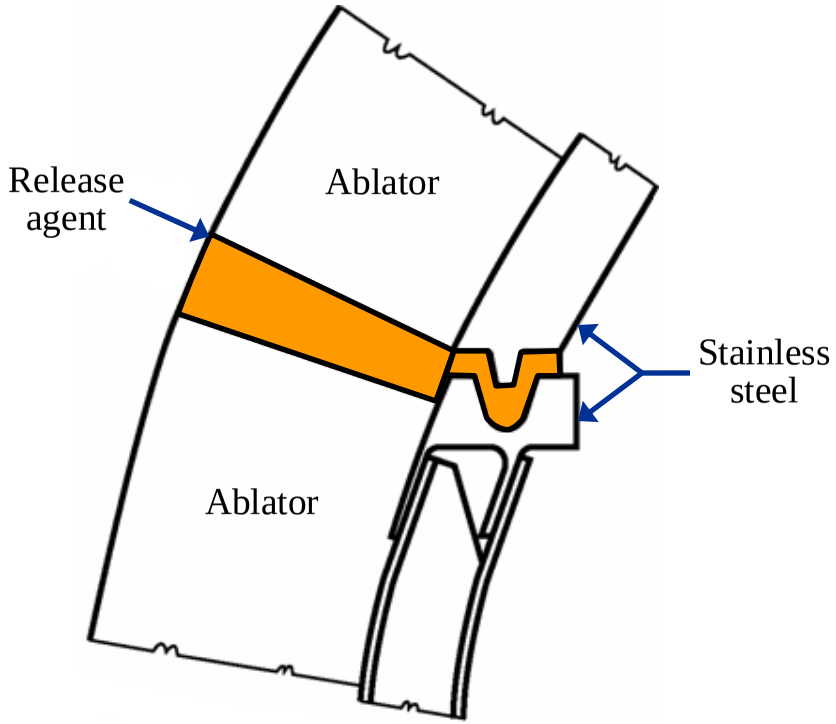






Heat Shield Interface Gap Silicone Gaskets

- RTV silicone used to fill gap
  - High temperature capability
  - Ablative
- Release agent applied to upper gasket surface
  - Assembly of seal
  - Post-mission inspection
- Gasket formed in two parts:
  - Inner gasket between stainless steel structure
  - Outer gasket between ablator



Conclusions

- Apollo seals used as a basis for understanding and designing seals for CEV
  - Pressure seals
    - Knife edge embedded into elastomer gasket
    - Heat-molded silicone seals
  - Thermal seals
    - High temperature silicone seals
- Aft heat shield-to-crew compartment heat shield interface gap
  - Environment difficult to predict
  - Flight experience shows silicone was successful
- CEV seal design
  - Apollo seals may be used as a basis
  - 40 years of advancement may allow new seal designs

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Appendix

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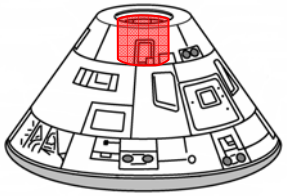
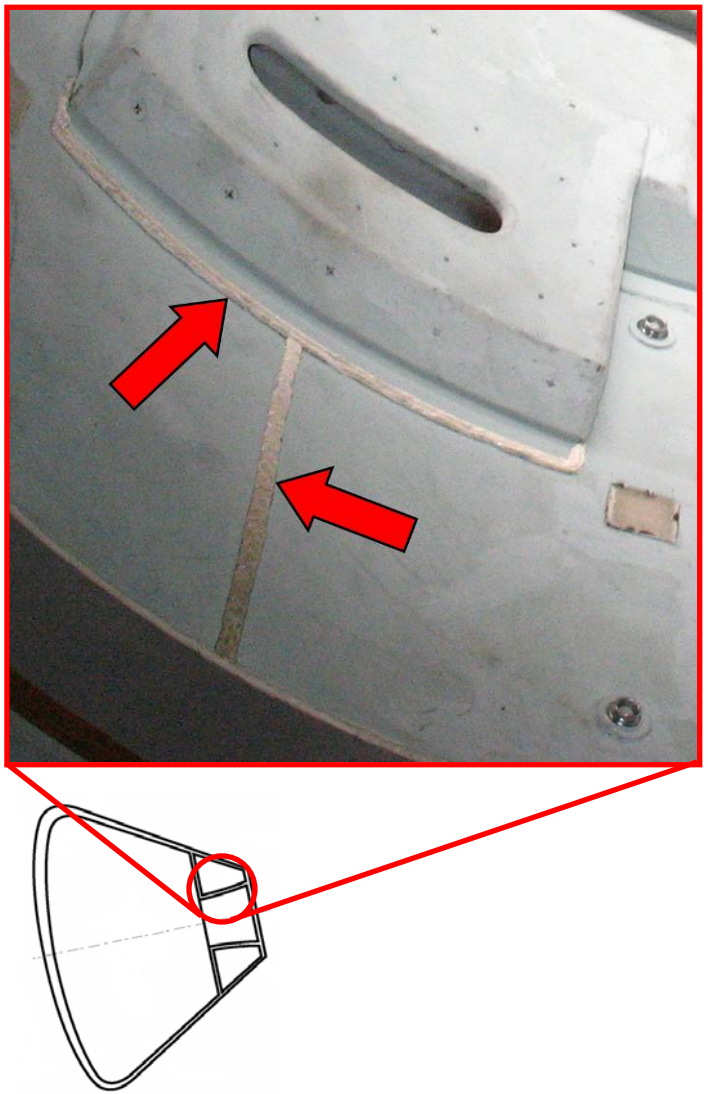
Overview

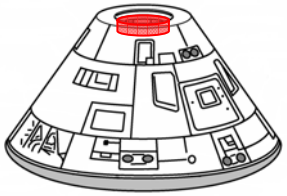
- **Crew Exploration Vehicle compared to Apollo**
  - Overview of the CEV
  - Overview of Apollo command module
  - Differences between Apollo and CEV
- **Overview of Apollo vehicle and seals**
  - Apollo Pressure Seals
    - Crew cabin atmosphere
    - Seals for crew cabin penetrations
  - Apollo Thermal Protection System (TPS) Seals
    - Apollo reentry environment
    - Heat shield penetrations
    - Inter-heat shield gaps



Bolted/Riveted Aluminum Panels

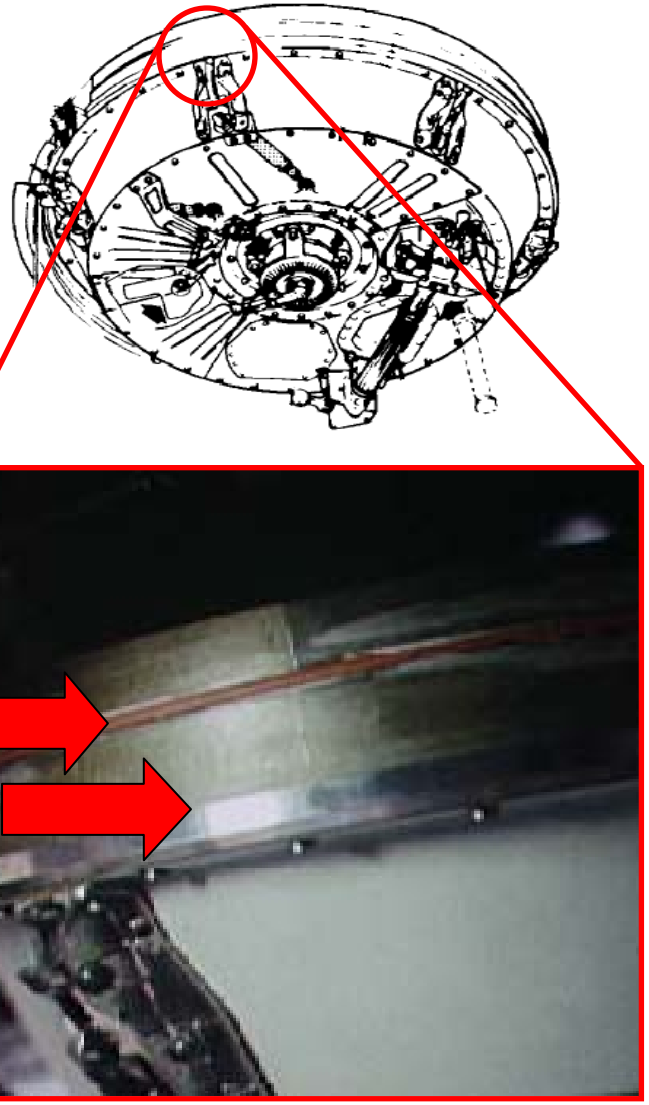
- Panel joints sealed with RTV
  - White RTV used in forward tunnel
  - Acceptable leakage for short mission durations
  - Major source of atmospheric loss
- Recommendations for long-duration spacecraft
  - Incorporate welded panels
    - Reduce leakage
    - Eliminate seal degradation
  - Easily replaceable seals

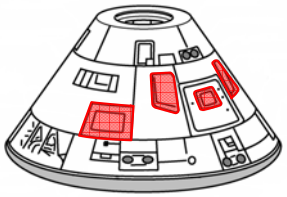




Forward Tunnel Hatch Seals

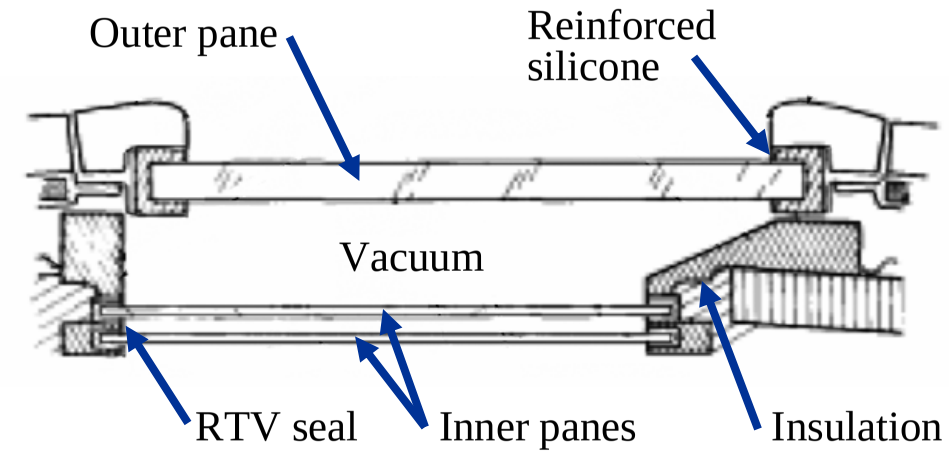
- Pressure seal
  - Metal knife edge on hatch
  - Elastomer gasket inside tunnel
  - Cabin pressure compressed knife edge into gasket
- Thermal seal
  - High-temperature silicone O-ring
  - Low thermal loads

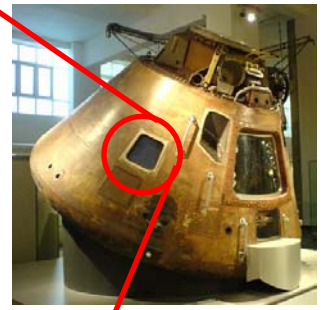


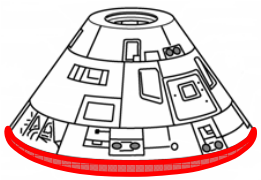


Command Module Windows

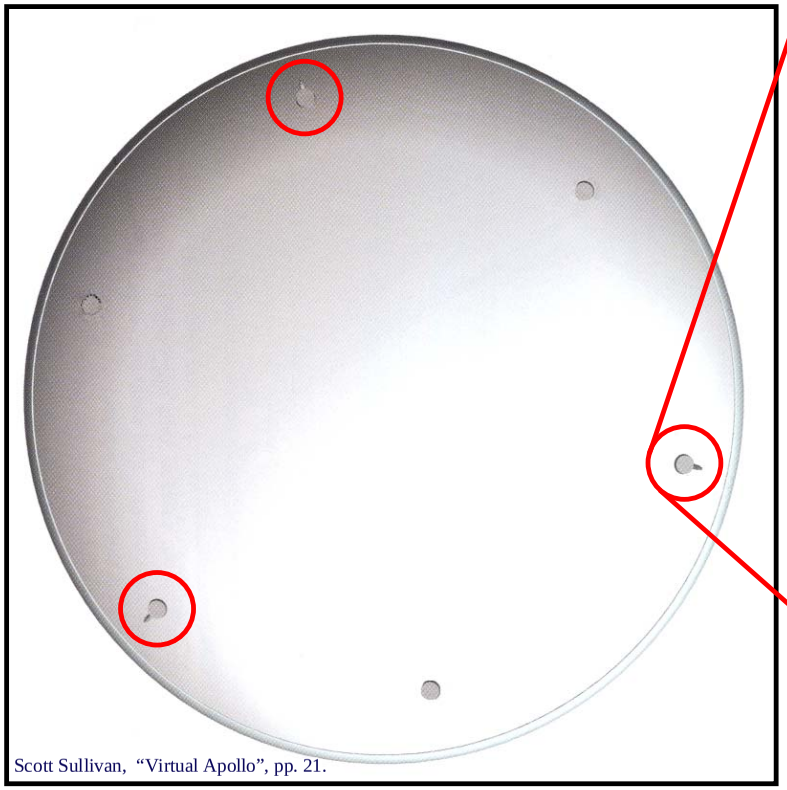
- Two inner pressure panes
  - Aluminosilicate material
  - Inner gap filled with nitrogen
  - Sealed with RTV
- Insulating layer
  - Multilayer fiberglass insulator
  - RTV coating
  - Bonded to capsule with RTV
- Outer thermal protection pane
  - Fused amorphous silica
  - Sealed with glass cloth-reinforced heat-cured silicone
  - Bonded with RTV



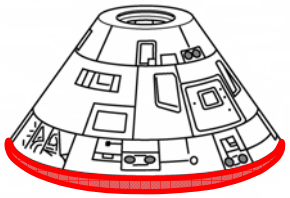




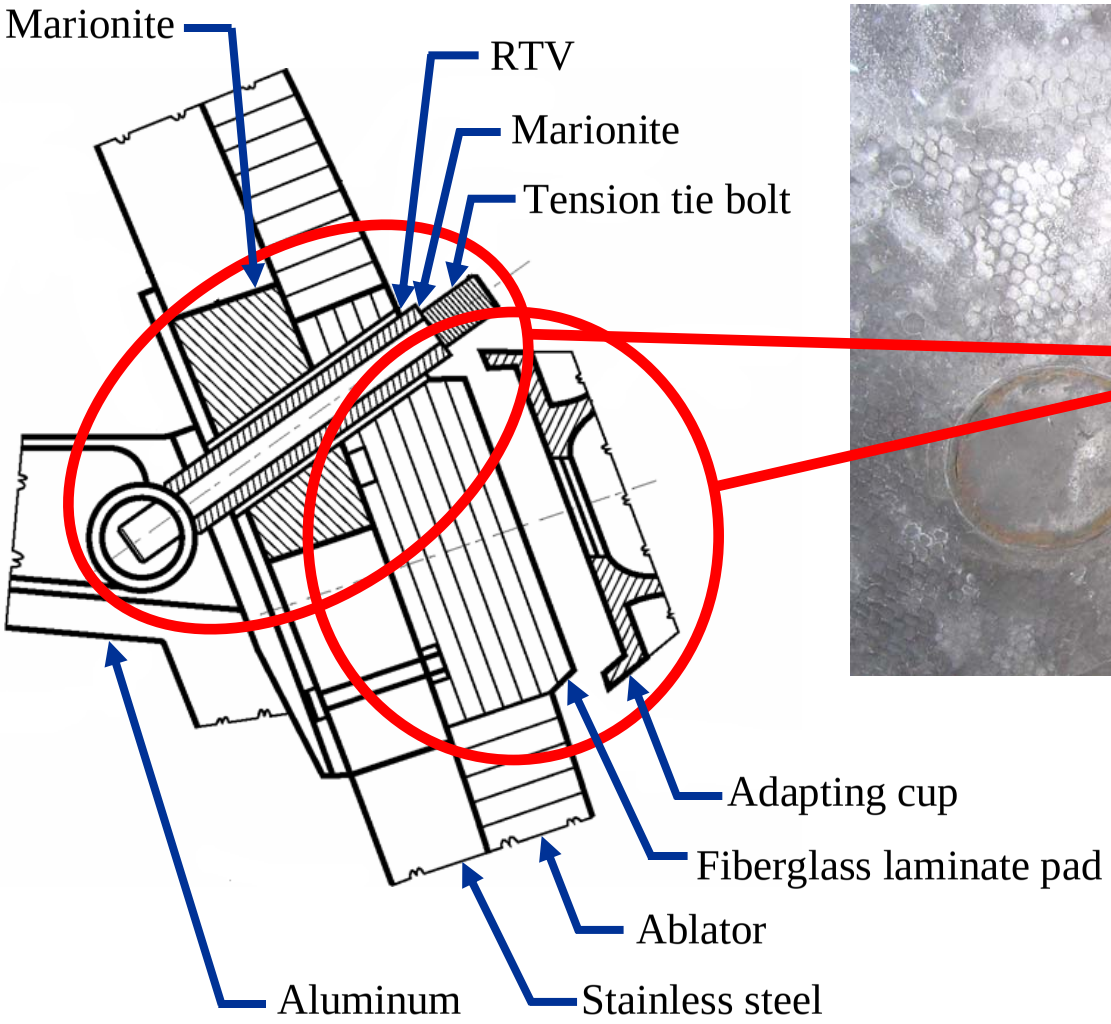
Compression/Shear Pads

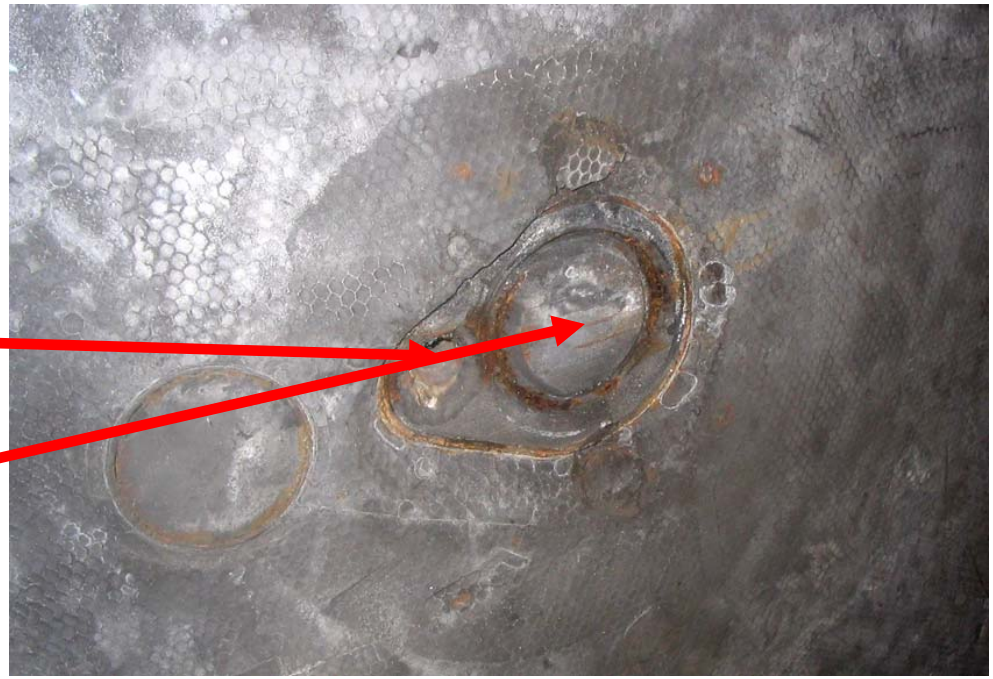


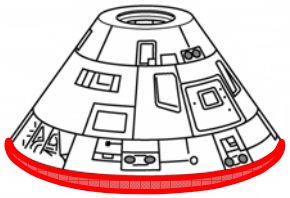
Scott Sullivan, "Virtual Apollo", pp. 21.



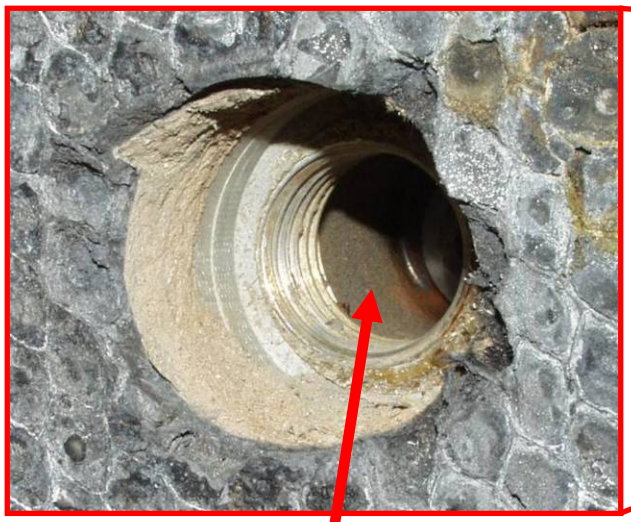
Compression/Shear Pads and Tension Tie Bolts

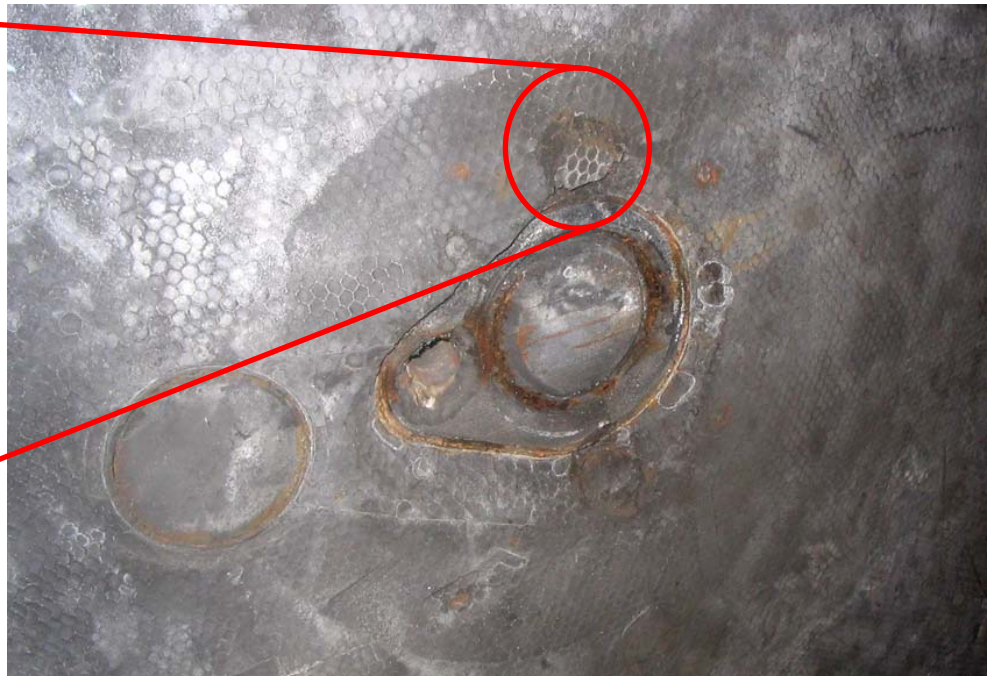


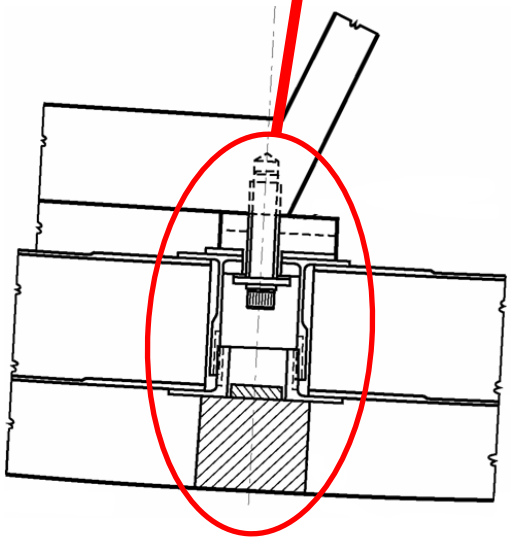


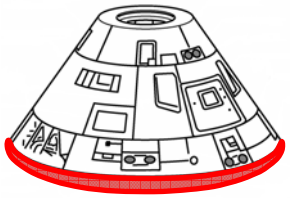


Ablator Plugs and Heat Shield Fasteners



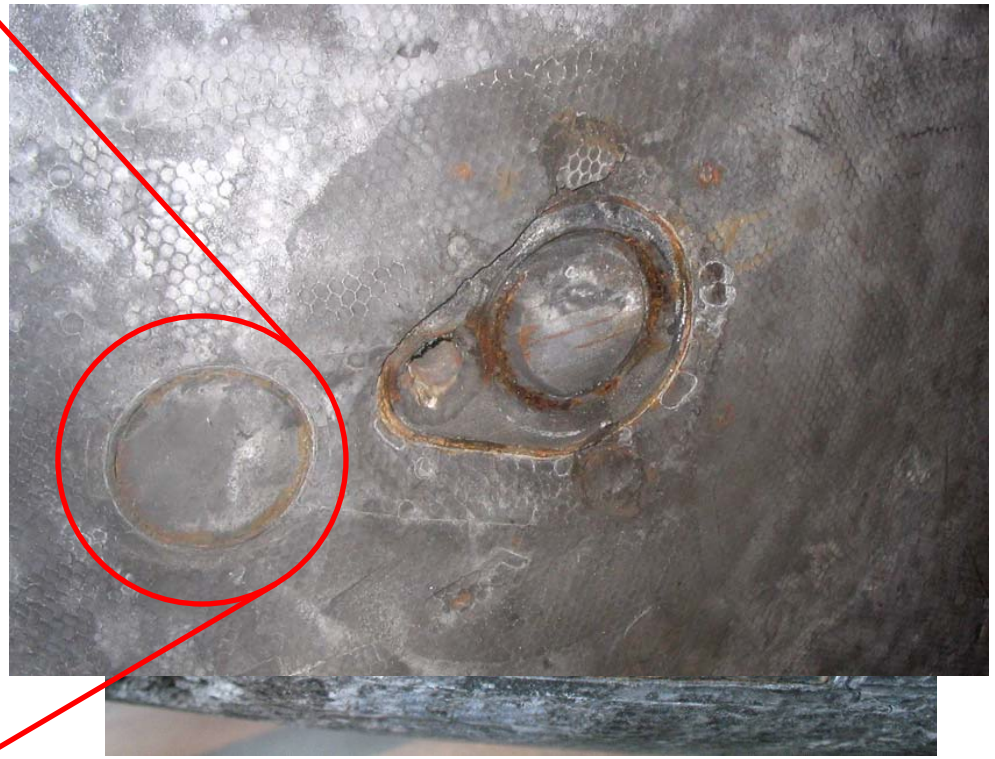




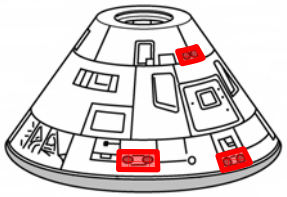


RCS Fuel/Oxidizer Dump Plugs

Oxidizer Dump Plug

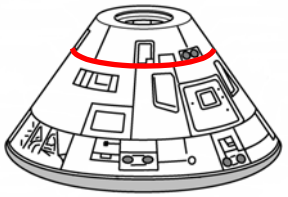


Fuel Dump Plug

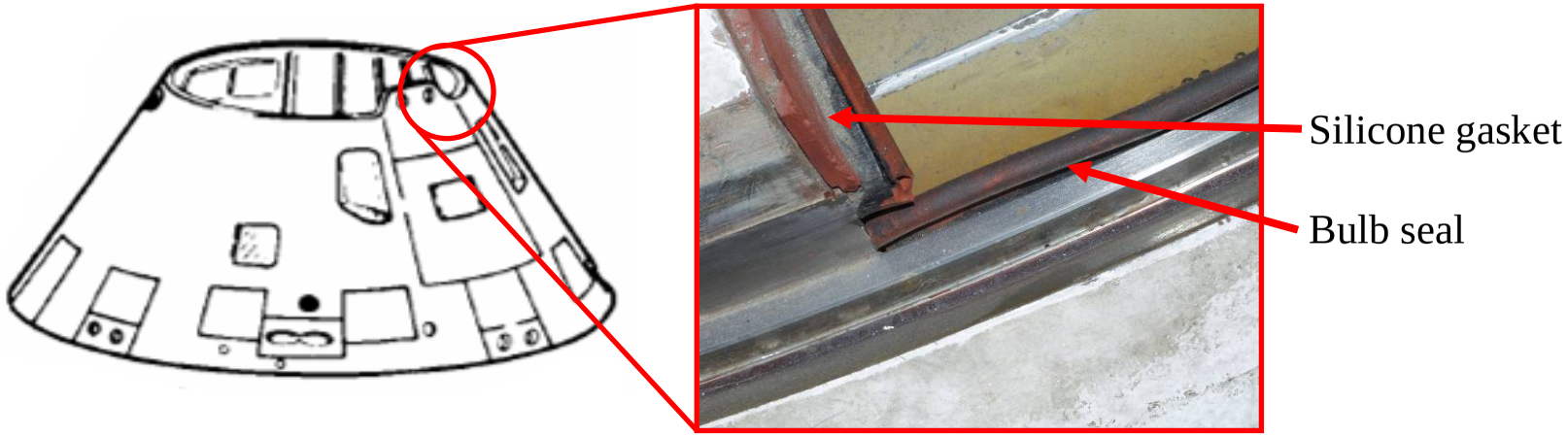


Access Panels and RCS Motors

- RTV used to seal gaps in:
  - Reaction Control System (RCS) motors
  - Access panels
- Visual inspection of seals
  - Little evidence of ablation
  - Low heat flux
  - Post-mission razor cuts



Crew Compartment Heat Shield-to-Forward Heat Shield Interface Gap



- Low heat flux at gap
- Forward heat shield jettisoned
  - Seal could not adhere heat shields together
  - Forward heat shield not recovered
- Gap sealed with heat-cured silicone bulb seal
- RCS motor perimeter sealed with silicone gasket

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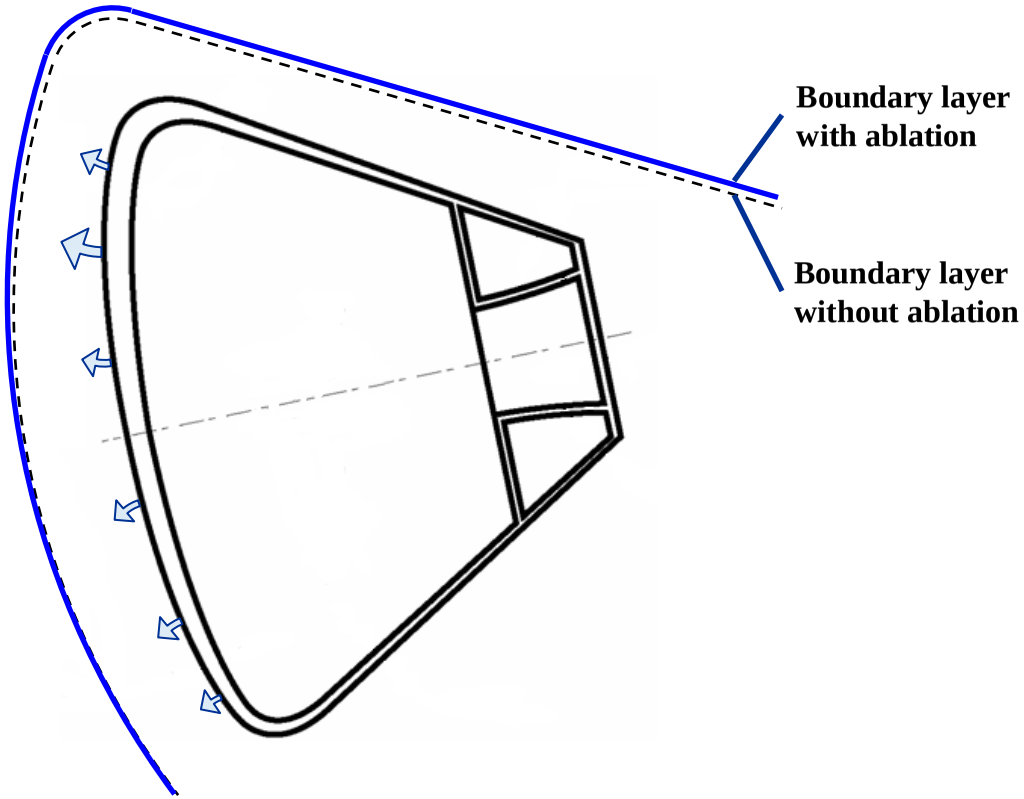
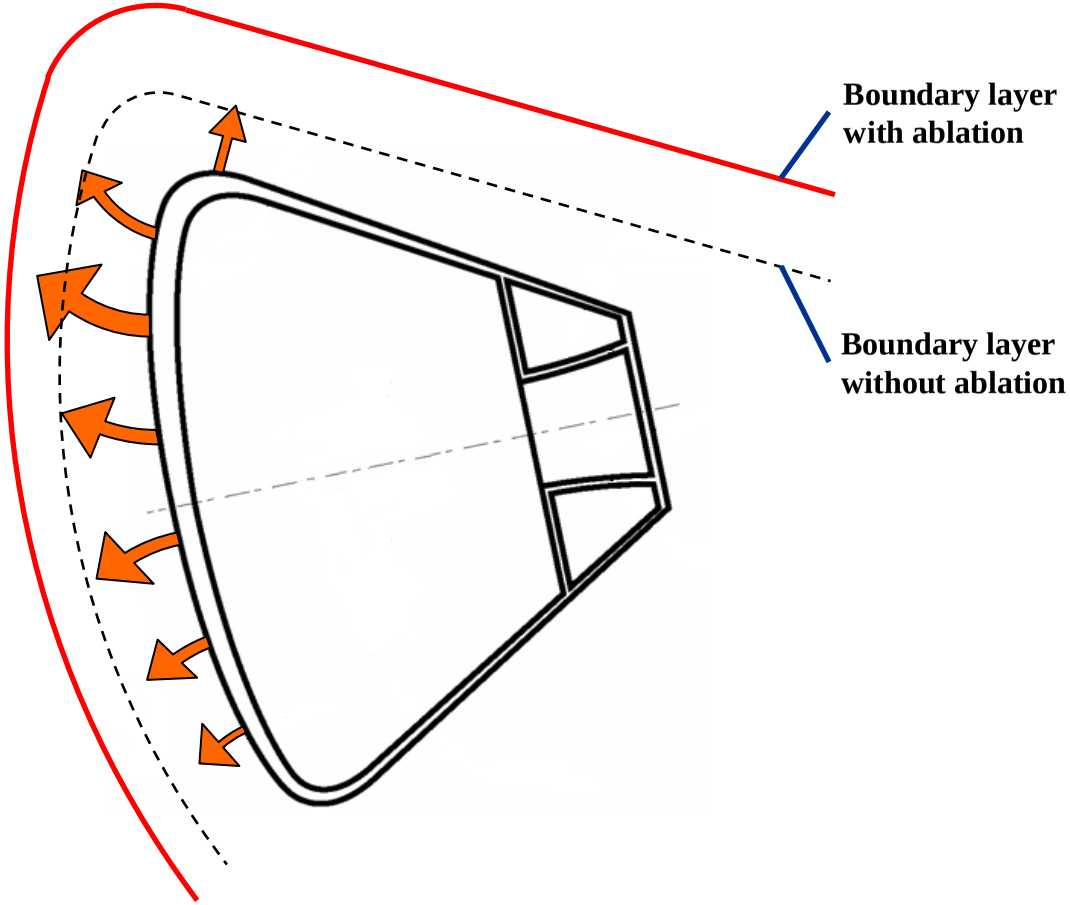
Reentry from LEO



- Flight pressure measurements agreed with flight models
- Ablation minimally altered boundary layer
- Heat transfer to vehicle affected by local ablation

Superorbital Reentry



- Pressure measurements lower than flight models
- High ablation rate altered boundary layer
- Pressure and heat flux on conical heat shield reduced