# OVERVIEW OF CEV THERMAL PROTECTION SYSTEM SEAL DEVELOPMENT

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## Overview of CEV Thermal Protection System Seal Development

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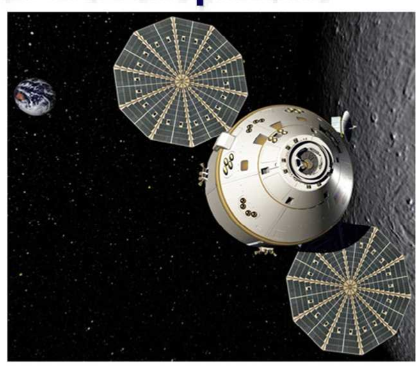

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## Outline

- Background
- HS-to-BS interface seal development
  - Objective and approach
  - Design
  - Testing and modeling
  - Results
- Compression pad seal development
  - Objective and approach
  - Design
  - Testing
- Summary

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## Orion CEV Compared to Apollo CM

| | Apollo | Orion |
|---|---|---|
| |  |  |
| **Crew** | 3 | 3-6 LEO/ISS<br>4 Lunar<br>6 Mars |
| **Max. Diam.** | 12.8 ft | 16.5 ft |
| **Height** | 11.4 ft | 10.8 ft |
| **Dry Weight** | 12,800 lbs | 19,250 lbs |
| **Volume** | 218 $ft^3$ | 692 $ft^3$ |
| **Seals** | Silicone RTV, elastomers* | Ceramic fiber thermal barriers, elastomer seals, gaskets, foams/sponge |

* See "Review of Seal Designs on the Apollo Spacecraft", ***Journal of Spacecraft and Rocket***, Vol. 45, No. 5, pp. 900-910

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Apollo seals: High temp RTV (very good for sealing, good ablative properties, not much stroke), Max leakage rate ~5 lb/day, stiffer support structure → structural movements minimized

Orion seals: ~30% bigger in diameter, Because some missions may be up to 6-mo. or even longer, leakage requirements are much more stringent

# Heat Shield-to-Back Shell Interface Seal System

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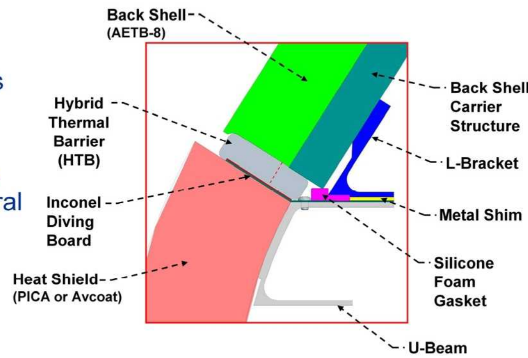
## Requirement and Attributes

**Sealing system required to:**

Protect internal structures and systems from excessive temperatures → Minimize interface gaps (flow paths) to prevent ingestion of high enthalpy reentry gases

**Sealing system attributes:**

- Withstand high temperatures (>2500°F)
- Minimize ingestion of reentry gases
- Apply minimal loads to opposing sealing surfaces
- Accommodate large gap variances due to build tolerances and structural movements
- Compact design
- Robust configuration
- Easily installed/replaced

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Highlight seal design is recent

Seal is attached to Inconel diving board for easy of installation

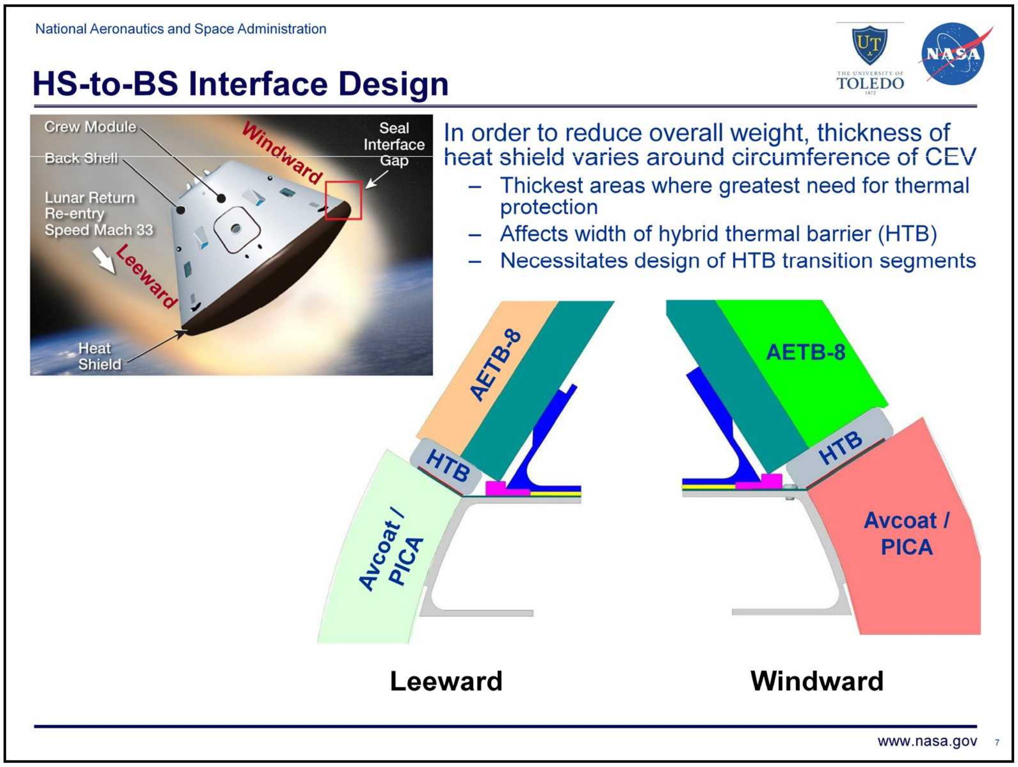
## Objective & Approach

### Objective:

Develop required databases to support successful design and implementation of the CEV heat shield-to-back shell interface seal

### Approach:

- Identify candidate seal designs
- Perform tests to screen and validate seal candidates
  - Coupon-level
  - Arc Jet
- Conduct thermal analyses to aid in design
- Provide recommendation to prime contractor




During reentry, heat distribution is non-uniform

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# Phase I: Early Design Evaluations

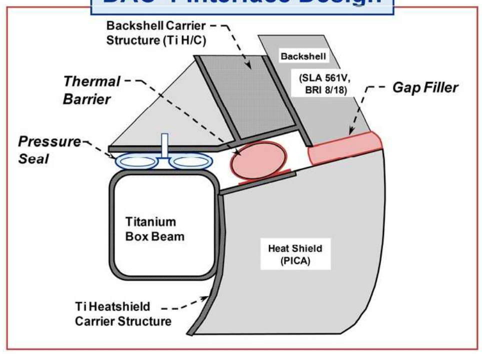
Purpose: Initial screening of seal design in simulated mission profile across different gap scenarios
- Small gap opening (+0.05 in.)
- Large gap opening (+0.10 in.)
- Large gap closing (-0.19 in.)

Seal Configuration: Separate gap filler, spring tube thermal barrier, double bulb elastomer pressure seal

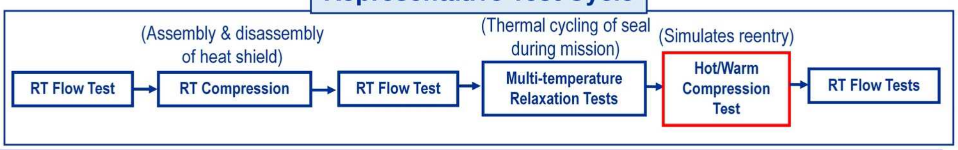
Tests and Analyses:
- RT flow tests
- RT compression tests
- Multi-temp. compression tests
- High temp. compression tests
- Thermal modeling

Status: Complete

## DAC-1 Interface Design




## Representative Test Cycle

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Seal design has evolved continuously since project inception

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## Phase I: Results Summary

- **Loads**
  Goal: ≤ 20 psi
  - Gap filler: 8 - 12 psi (57% compression)
  - Thermal barrier: 3 - 4 psi (20% compression)
  - Pressure seals: 5 – 7 psi (43% compression)
- **Leakage rates**
  Note: Leakage rates reported at 1.0 psid
  - Gap filler: 0.3 – 6.8 SCFM/in.
  - Thermal barrier: 0.4 – 1.3 SCFM/in.
  - Pressure seals: $5.8 \times 10^{-5}$ – $1.1 \times 10^{-2}$ SCFM/in.
    - Less than 3% of that for the thermal barrier / gap filler
    - Effective gaps: 0.0004 – 0.003 in.
- **Temperature**
  - Elastomer pressure seal exhibited most sensitivity to temperature extremes (next slide)
  - Gap filler showed limited load retention at 2600°F
  - Spring tube thermal barrier exhibited good load retention at 1100°F

**Gap Filler**

**Spring Tube Thermal Barrier**

**Elastomer Pressure Seal**

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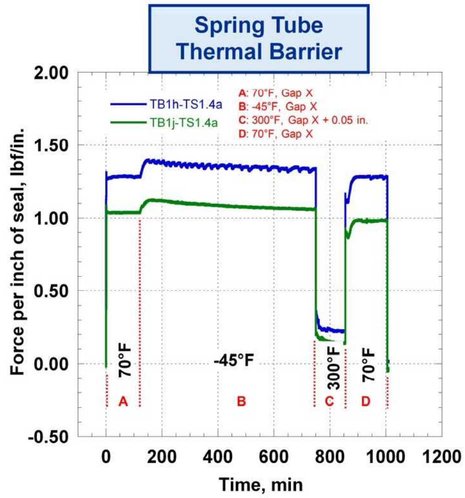
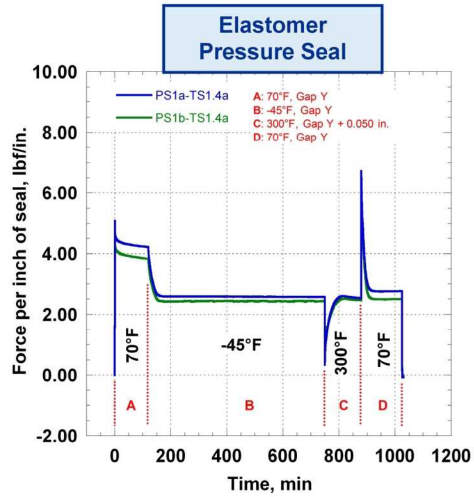
Results are applicable to next generation (HTB) seals

# Phase I Example Results: Load vs. Mission Profile




- During all mission phases, seals maintained contact with opposing surfaces

## Phase II: Evaluations

Purpose: Testing of evolved seal design in representative interface configuration

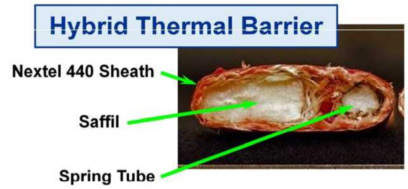
Seal Configuration: Integrated hybrid thermal barrier, silicone foam gasket

Tests and Analyses:

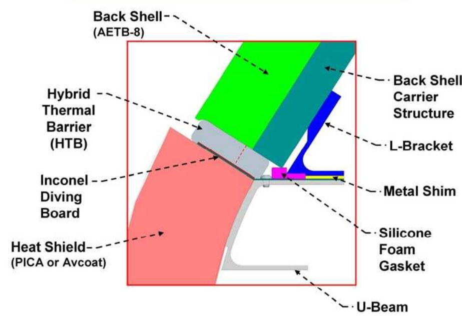
- Exploratory compression tests
- Alt. TPS material flow tests
- Alt. TPS material seal compression tests
- QARE rig tests
- Seal attachment evaluations
- Installation verification tests
- Ongoing thermal analyses

Status: In process

**Hybrid Thermal Barrier**




**DAC-2 Interface Design**



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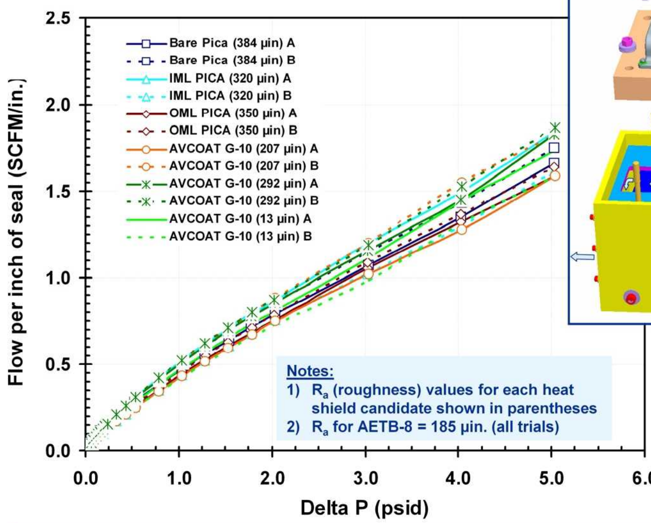
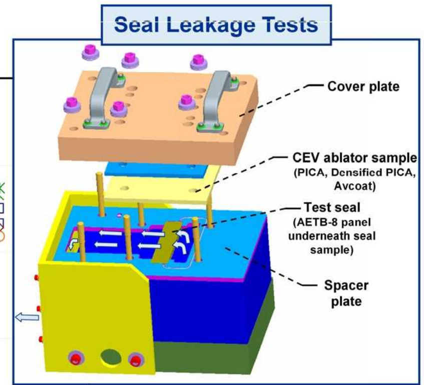
# Phase II Results:
# Hybrid Thermal Barrier Flow Results



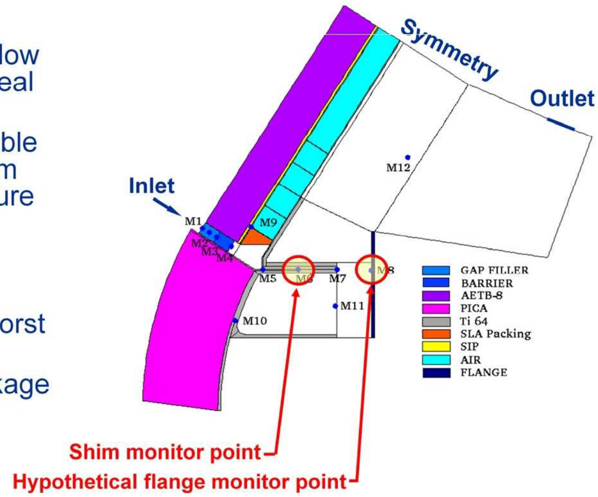
# Thermal Modeling: Background

## Goals of analysis:

- Develop model simulating flow and heat transfer through seal system
- Establish bounds on allowable leakage through seal system based on internal temperature limits

## Parameters:

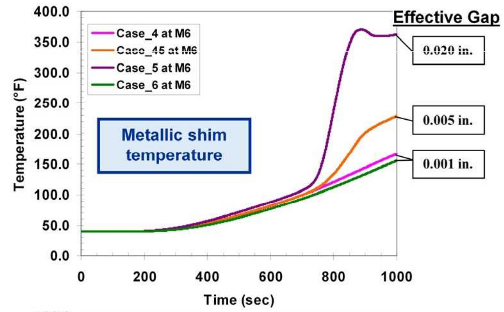
- Thermal model based on worst case (windward) geometry
- Pressure seal effective leakage varied
  - 0.001 in.
  - 0.005 in.
  - 0.020 in.
- Key Monitor Points

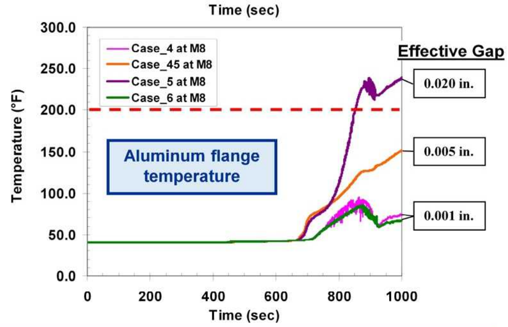



**Orion seal thermal model geometry (PICA version)**

# Thermal Modeling: Representative Results

- Results shown for PICA heat shield configuration (0.375 in. gap height)
- Monitor point on shim (M6)
  - Examined temperature of edge of pressure seal
  - Temperatures below 550°F bond line limit for all cases
  - Lower temperatures realized with better pressure seals
- Monitor point on flange (M8)
  - Examined temperature of gas impinging upon hypothetical aluminum flange (e.g., helium or RCS tank)
  - Temperature limit defined by RCS tank requirements; may be 125-200°F range



# Compression Pad Seals

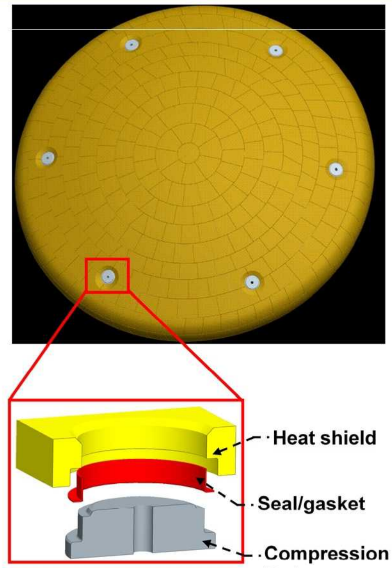
# Compression Pad Seal Development

**Compression Pads (CP)**

- Role: Main structural connection points between CEV and SM
- Need for seals
  - CP's are different material than heat shield
  - CP's are exposed to very high heating rates

**Approach & Seal Evaluations**

- Objective: Provide seal recommendation
- Seal attributes
  - Similar to HS-to-BS seal plus…
  - Ablation rate similar to HS and CP's
- Candidates: Silicone foam (or other) materials
- Preliminary testing
  - Compression test (low and high temp.)
  - Flow tests
  - System level arc jet tests



# Summary

- NASA GRC supporting design, development, and implementation of numerous seal systems for the Orion CEV
  - HS-to-BS interface
  - Compression pad
- HS-to-BS Interface Seal System
  - Design has evolved as a result of changes with the CEV TPS
  - Seal system is currently under development / evaluation
    - Coupon level tests
      - Loads
      - Thermal capabilities
      - Leakage resistance
      - Bond strength tests
    - Arc jet tests
    - Validation test development
- Compression Pad
  - Finalizing design options
  - Evaluating material candidates