OVERVIEW OF CEV THERMAL PROTECTION SYSTEM SEAL DEVELOPMENT

Jeff DeMange and Shawn Taylor
University of Toledo
Toledo, Ohio

Patrick Dunlap, Bruce Steinetz, Irebert Delgado, and Josh Finkbeiner
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

John Mayer
Analex Corp.
Cleveland, Ohio

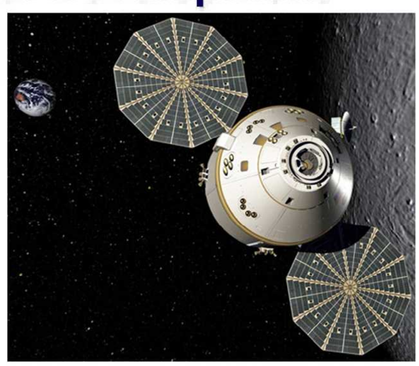
National Aeronautics and Space Administration

Overview of CEV Thermal Protection System Seal Development

University of Toledo
Toledo, OH
Jeff DeMange
Shawn Taylor

NASA GRC
Cleveland, OH
Pat Dunlap
Bruce Steinetz
Irebert Delgado
Josh Finkbeiner

Analex Corp.
Cleveland, OH
John Mayer



NASA Seal/Secondary Air System Workshop
November 18, 2008
Cleveland, OH

www.nasa.gov 1

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

National Aeronautics and Space Administration

Orion CEV Compared to Apollo CM

	Apollo	Orion
		
Crew	3	3-6 LEO/ISS 4 Lunar 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

www.nasa.gov 3

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

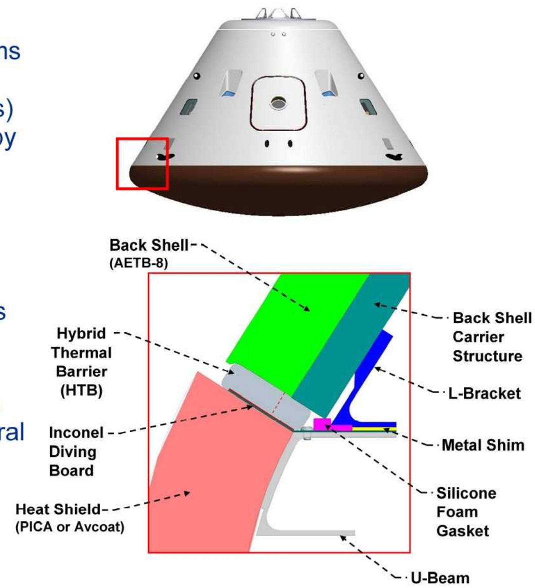
Requirement and Attributes

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



Highlight seal design is recent

Seal is attached to Inconel diving board for easy of installation

Objective & Approach

Objective:

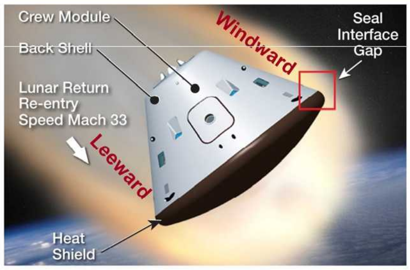
Develop required databases to support successful design and implementation of the CEV heat shield-to-back shell interface seal

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

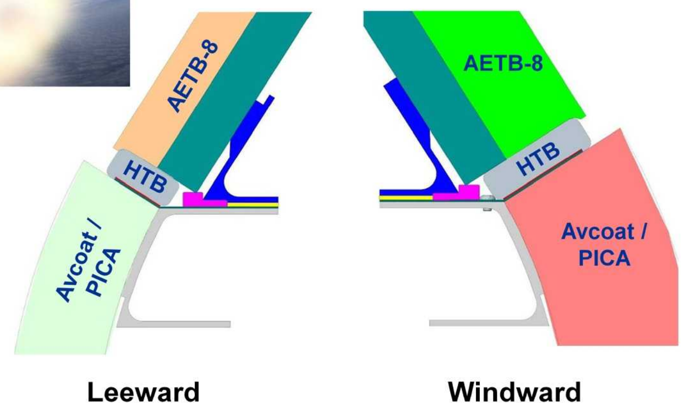
National Aeronautics and Space Administration

HS-to-BS Interface Design



In order to reduce overall weight, thickness of heat shield varies around circumference of CEV

- Thickest areas where greatest need for thermal protection
- Affects width of hybrid thermal barrier (HTB)
- Necessitates design of HTB transition segments



www.nasa.gov 7

During reentry, heat distribution is non-uniform

National Aeronautics and Space Administration

Phase I: Early Design Evaluations

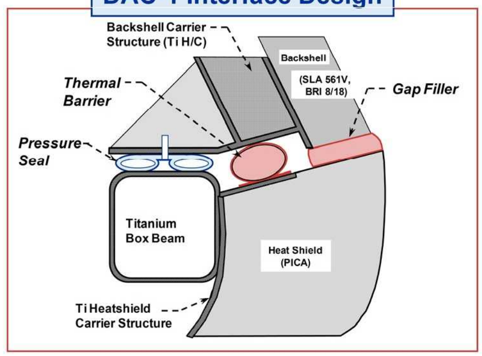
Purpose: Initial screening of seal design in simulated mission profile across different gap scenarios
- Small gap opening (+0.05 in.)
- Large gap opening (+0.10 in.)
- Large gap closing (-0.19 in.)

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

RT Flow Test → RT Compression (Assembly & disassembly of heat shield) → RT Flow Test → Multi-temperature Relaxation Tests (Thermal cycling of seal during mission) → Hot/Warm Compression Test (Simulates reentry) → RT Flow Tests

www.nasa.gov 8

Seal design has evolved continuously since project inception

National Aeronautics and Space Administration

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: 5.8×10^{-5} – 1.1×10^{-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

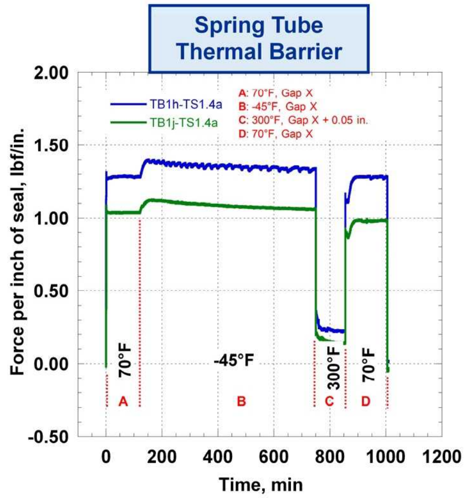
Elastomer Pressure Seal

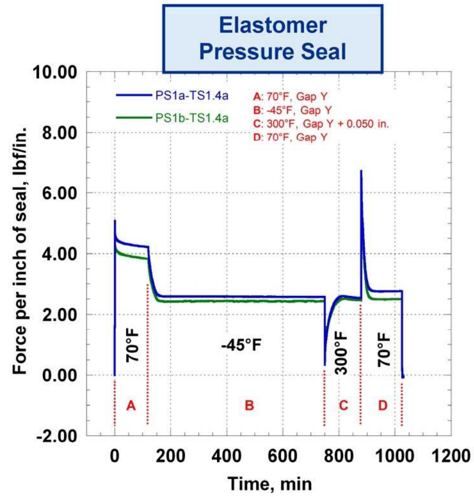
www.nasa.gov 9

Results are applicable to next generation (HTB) seals

National Aeronautics and Space Administration

Phase I Example Results: Load vs. Mission Profile





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

www.nasa.gov 10

Phase II: Evaluations

Purpose: Testing of evolved seal design in representative interface configuration

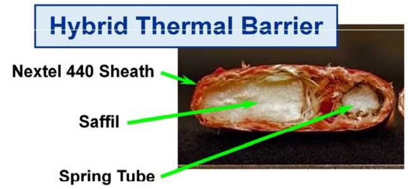
Seal Configuration: Integrated hybrid thermal barrier, silicone foam gasket

Tests and Analyses:

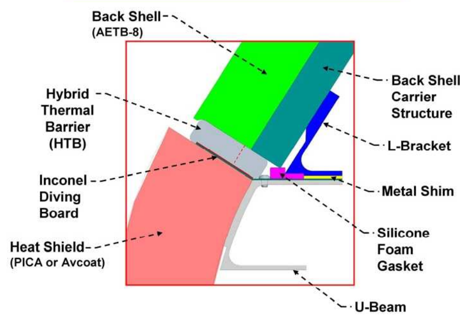
- Exploratory compression tests
- Alt. TPS material flow tests
- Alt. TPS material seal compression tests
- QARE rig tests
- Seal attachment evaluations
- Installation verification tests
- Ongoing thermal analyses

Status: In process

Hybrid Thermal Barrier

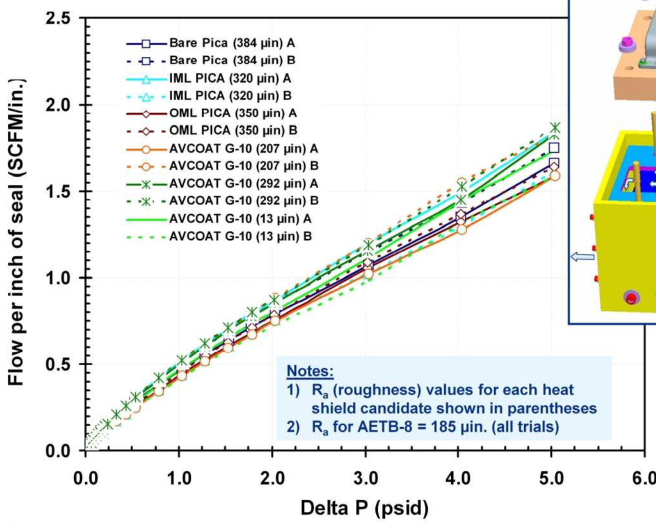


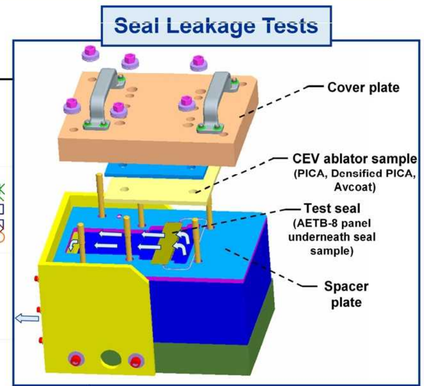
DAC-2 Interface Design



National Aeronautics and Space Administration

Phase II Results:
Hybrid Thermal Barrier Flow Results





National Aeronautics and Space Administration

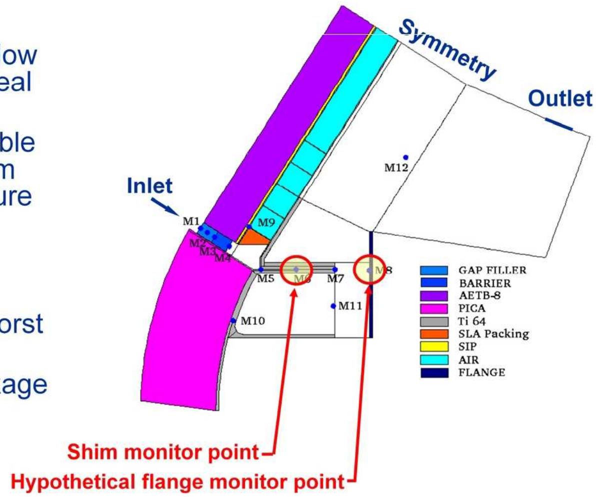
Thermal Modeling: Background

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

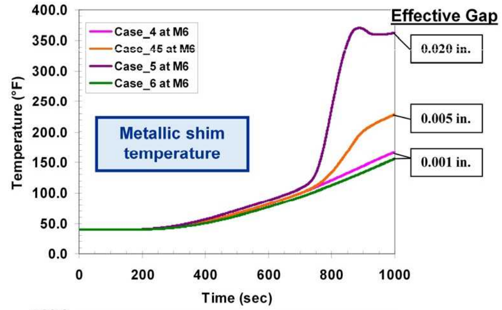


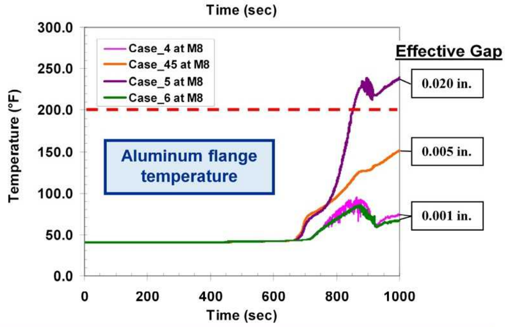
Orion seal thermal model geometry (PICA version)

www.nasa.gov 13

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

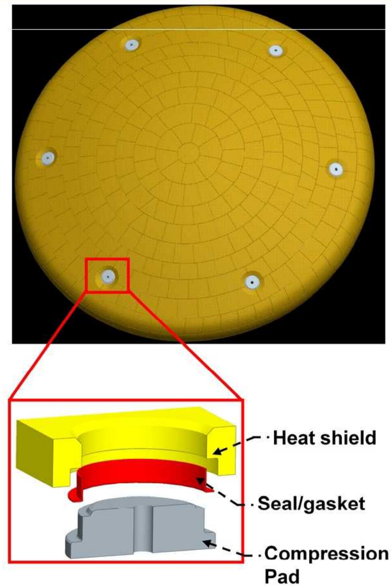
Compression Pad Seal Development

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