OVERVIEW OF CEV THERMAL PROTECTION SYSTEM SEAL DEVELOPMENT

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Overview of CEV Thermal Protection System Seal Development

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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
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

<table>
<thead>
<tr>
<th></th>
<th>Apollo</th>
<th>Orion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew</td>
<td>3</td>
<td>3-6 LEO/ISS</td>
</tr>
<tr>
<td>Max. Diam.</td>
<td>12.8 ft</td>
<td>16.5 ft</td>
</tr>
<tr>
<td>Height</td>
<td>11.4 ft</td>
<td>10.8 ft</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>12,800 lbs</td>
<td>19,250 lbs</td>
</tr>
<tr>
<td>Volume</td>
<td>218 ft³</td>
<td>692 ft³</td>
</tr>
<tr>
<td>Seals</td>
<td>Silicone RTV, elastomers*</td>
<td>Ceramic fiber thermal barriers, elastomer seals, gaskets, foams/sponge</td>
</tr>
</tbody>
</table>

Heat Shield-to-Back Shell Interface Seal System
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
Seal design has evolved continuously since project inception.
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: 5.8x10⁻⁵ – 1.1x10⁻⁷ 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

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
Phase II Results:
Hybrid Thermal Barrier Flow Results

Flow per inch of seal (SCFMin.)

Delta P (psid)

Notes:
1) $R_h$ (roughness) values for each heat shield candidate shown in parentheses
2) $R_h$ for AETB-8 = 155 μin. (all trials)

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**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