An Overview of High Temperature Seal Development and Testing Capabilities at the NASA Glenn Research Center

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Content of Discussion

• Our Story: History of Thermal Seals Work at NASA GRC
  - Vehicles/Programs
  - Technologies
• Our Tools: Current Test Capabilities
  - Leakage/flow
  - Load/resiliency
  - Durability
• Our [ Desired] Path - Technology Thrusts
• Conclusions
OUR STORY:

HISTORY OF THERMAL SEALS DEVELOPMENT AT NASA GRC
The Beginnings at GRC

- Time: Mid 1980’s - Early 1990’s
- Vehicle: NASP (National Aerospace Plane)
  - Passenger space plane
  - M25 (New York to Tokyo in 2 hrs)
- Advanced hypersonic propulsion system with variable flow path geometry
  - Need to minimize core flow leakage around variable geometry
  - Developed specialized/unique seals
    - Wafer seals
    - Braided rope seal
Amidst the Tragedy

- Time: 1990’s – 2000’s
- Vehicle: Challenger (1986)
- Loss of crew and vehicle due to o-ring field joint failure in starboard SRB during STS-51-L
- Redesign effort to improve reliability of SRB joints
- C-fiber rope seal developed at GRC (nozzle joint)
  - Survived 5500°F for 3X mission life
  - Successful motor testing
  - Implementation in SRB in 2003
  - Used on Atlas V SRB since 2003
The Hypersonics Age

- Time: 2000 - Current
- Vehicles
  - X-38 CRV
  - X-37 OTV
  - Falcon
  - Orion MPCV
- Control surface and acreage TPS thermal seals
- Significant testing of thermal seals against hot structure materials
  - C/C and C/SiC CMC’s
  - Acreage tile
The Push for Better Performance

- Time: 2002 - Present
- Permanent set noted in Shuttle thermal barriers → open gap
- Development of high temperature preloaders
  - Rene 41 spring tubes
  - Refractory alloy preloaders
  - Single crystal preloaders
- Thermal seals with improved durability
OUR TOOLS:

TEST CAPABILITIES AT NASA GRC
Thermal Seals Testing Methodology
Advancing the Technology Readiness Level (TRL)

**Coupon level tests at GRC**
- **Features:**
  - Extreme temperature
  - Scrubbing or compression
  - Load cycling
  - Leakage

**System/component level tests in Arc Jet, DCR, GRC Cell 22, etc.**
- **Features:**
  - Combined high temp. heat flux, flow/pressure, scrubbing in realistic environment

**Flight level tests/operations**
- **Features:**
  - Final verification

**Pictorial Diagram:**
- **Left Side:**
  - **Wafer seals**
  - **Seal holder**
  - **Silicon carbide rub surfaces**

**Right Side:**
- **System:**
  - **Features:**
    - TRL 3-5 → TRL 5-6

- **Flight Level:**
  - **Features:**
    - TRL 5-6 → TRL 7-9
**Coupon Level Mechanical Testing**

### Capabilities:

**High Temperature Compression / Scrub Rig**
- **Purpose:** Assess loads, resiliency, wear at temp.
- **Temp.:** RT to 3000°F
- **Environment:** Air
- **Max. loads:** ±3300 lbf
- **Max. stroke range:** ±3 in.
- **Stroke rate:** 0.001 to 6 in./s
- **Furnace working size:** 9 x 14 x 18 in.

**Multi Temperature Compression Rig**
- **Purpose:** Assess loads, resiliency at temp.
- **Temp.:** -238 to 1100°F
- **Environment:** Air
- **Max. loads:** ±33.7 kip
- **Max. stroke:** 49.6 in.
- **Stroke rate:** 0 to 0.5 in./s
- **Chamber working size:** 15 x 15 x 22 in.

**High Temperature Rotary Wear Rig**
- **Purpose:** Assess wear, loads at temp.
- **Temp.:** RT to 1500°F
- **Environment:** Air
- **Max. torque:** ±885 in.-lbf
- **Rotation range:** ±30°
- **Rot. speed:** 0.1 to 370 deg/s
- **Furnace working size:** 12 x 12 x 13 in.
Coupon Level Room Temp. Leakage Testing

Ambient Linear Flow Rig #1

Capabilities:
Purpose: Assess leakage against smooth substrates
Temp.: RT
Environment: Air
Flow rates: 0 to 88 SCFM
Gap range: 0 to 0.4 in.
Compression range: 0 to 55%
Pressure range: 0 to 100 psid
Max sample size: φ1.5 in. dia. x 12 in. long

Ambient Linear Flow Rig #2

Capabilities:
Purpose: Assess leakage against variable substrates
Temp.: RT
Environment: Air
Flow rates: 0 to 88 SCFM
Gap range: Variable
Compression range: 0 to 70%
Pressure range: 0 to 100 psid
Max sample size: φ2.5 in. dia. x 5 in. long
Coupon Level High Temp. Leakage Testing

**Capabilities:**
- **Purpose:** Assess seal leakage at temp.
- **Temp.:** RT to 1200°F
- **Environment:** Air/Nitrogen
- **Flow rates:** 0 to 3.5 SCFM
- **Pressure range:** 0 to 25 psid
- **Furnace working size:** φ9.5 in. ID x 11 in. tall

**Capabilities:**
- **Purpose:** Assess turbine seal leakage/torque loss at temp.
- **Temp.:** RT to 1200°F
- **Environment:** Air
- **Speeds:** Up to 1200 ft/s
- **Pressure range:** 0 to 250 psid
- **Max sample size:** φ8.5 in. dia.
Thermal Testing

Mach 0.3 Torch Testing

Capabilities:
- Purpose: Assess performance under moderate heat flux conditions, evaluate thermal cycling performance
- Location: GRC
- Temp.: 700 to 2500°F
- Heat Flux: 10 to 20 W/cm²
- Fuel: Jet + Air

QARE Testing

Capabilities:
- Purpose: Assess performance under high heat flux conditions, evaluate environmental durability
- Location: GRC
- Temp.: 2500°F+
- Heat Flux: Up to 400 W/cm²
- Fuel: H₂ + O₂

Arc Jet Testing

Capabilities:
- Purpose: Assess performance under reentry-like conditions
- Location: ARC
- Facility: PTF, IHF
- Temp.: 2500°F+
- Mach No: 5.5 – 7.5
- Heat Flux: Up to 750 W/cm²
- Gas: Air
- Hardware config.: Static
OUR [DESIRED] PATH:
WHERE WE HOPE TO GO
Key Approaches: Thermal Seals

- **Materials & Design** – Develop/identify/test materials and unique configurations to meet requirements
  - Improved material systems/configurations
    - High temp (3000°F), oxidation resistant, flexible fibers and batting
    - Aerogels
    - OFI (opacified fibrous insulation)
    - MLI (multi-layer insulation)
    - Functionally graded thermal seal systems (e.g., inboard preloaders, thermal + environ. barriers)
    - Coatings (thermal, wear-resistant, etc.)
  - Design tools (e.g., preliminary sizing calculator, config. design guide, etc.)
  - Game-changing designs
    - Smart seals (e.g., SMA)
    - Seal-less interfaces (e.g., physics-based approaches)

- **Testing/Characterization Capabilities** – Develop/identify test methods/facilities to better characterize performance
  - Mechanical testing under realistic temp., temp. gradient, and partial pressure O₂ conditions
  - Testing under simultaneous conditions (temperature, pressure, vibrations, etc.)
  - Quantifying thermal transfer mechanisms under different conditions for optimized thermal seal design
Key Approaches: Thermal Seals (cont’d)

- **Modeling** – Develop/identify/incorporate methodologies/modeling approaches to help predict/optimize thermal seal system performance
  - Thermal modeling (heat transfer mechanisms, design effects)
  - Mechanical modeling (design, environ. effects)

- **Integration & Implementation** – Provide aerospace vehicle developers with tools to confidently implement thermal seals in various subsystems
  - Design for implementation
  - Accurate documentation/databases of previous testing and implementations in heritage vehicles
  - Improved methods for verifying proper thermal seal installation/operation
  - Health and condition monitoring for multiple missions: retire for cause
Conclusions

• NASA GRC has had a long history in high temperature thermal seal development and testing
  ➢ NASP
  ➢ Shuttle
  ➢ X-vehicles
  ➢ MPCV

• NASA GRC has extensive thermal seal testing capabilities/experience
  ➢ Temps: Near-cryogenic to 3000°F
  ➢ Types of tests: Mechanical, physical, thermal
  ➢ Both static and dynamic (durability) testing capabilities

• NASA GRC is looking to advance the technologies across many facets of thermal seal development
  ➢ Materials and Design
  ➢ Testing/characterization Capabilities
  ➢ Modelling
  ➢ Integration & Implementation
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