THE UNIVERSITY OF TOLEDO 1872

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

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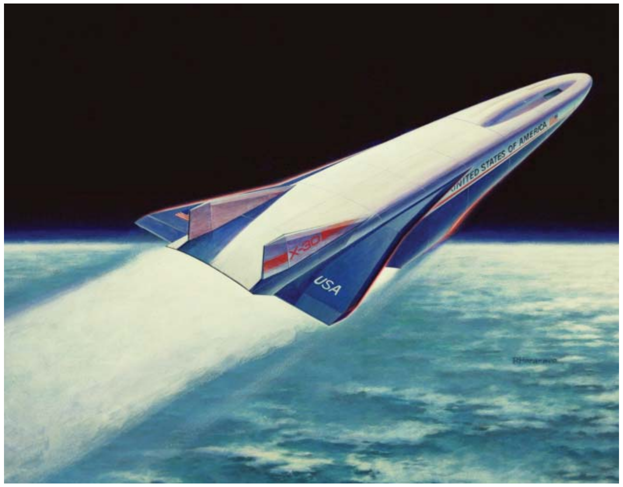
Content of Discussion

- 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:

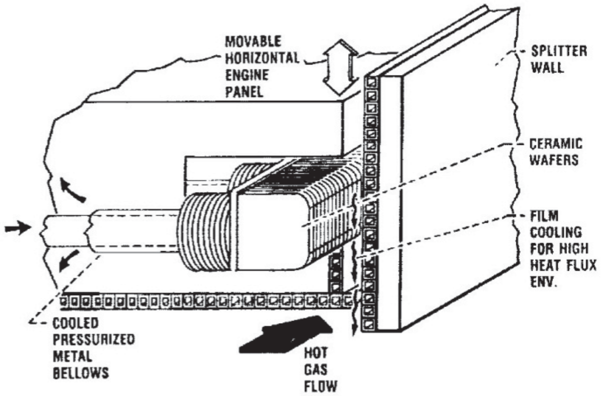
HISTORY OF THERMAL SEALS DEVELOPMENT AT NASA GRC

The Beginnings at GRC

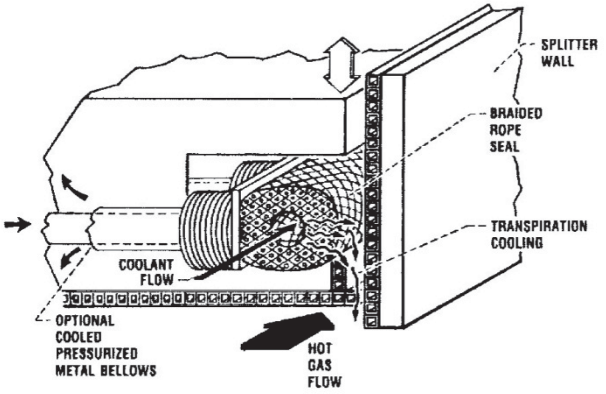


NASP

- 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



Wafer Seals

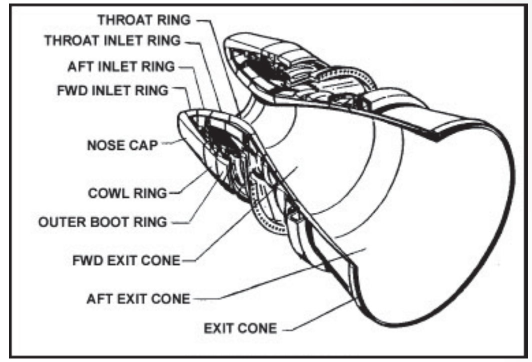


Braided Rope Seal

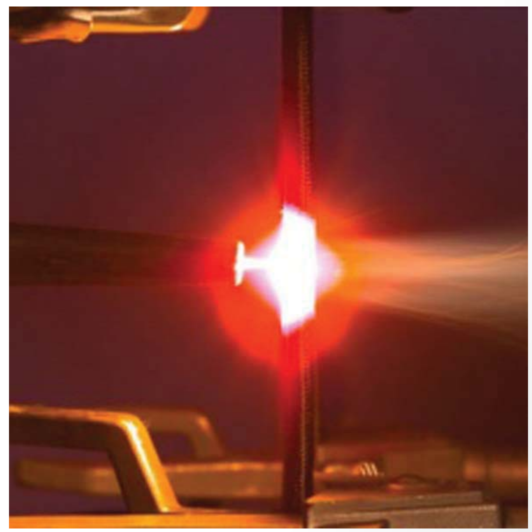
Amidst the Tragedy

Space Shuttle Challenger

- 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



Shuttle SRB Nozzle



Carbon Fiber Rope Seal

The Hypersonics Age

FALCON

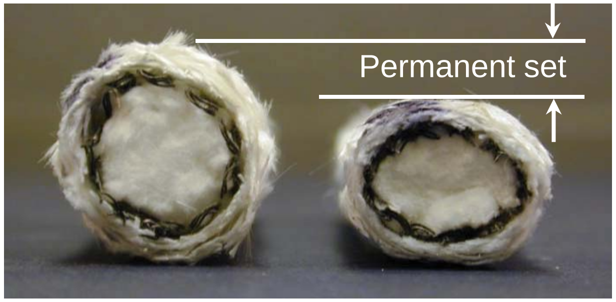
- Time: 2000 - Current
- Vehicles
  - X-38 CRV
  - X-37 OTV
  - Falcon
  - Orion MPCV
- Control surface and acreage TPS thermal seals
- Significant testing of thermal seals against hot structure materials
  - C/C and C/SiC CMC's
  - Acreage tile

X-37

X-38

Orion MPCV

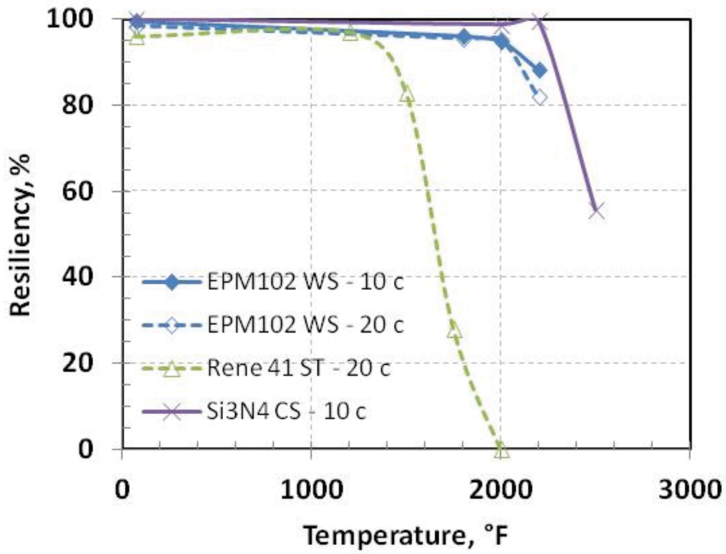
The Push for Better Performance



Thermal Barrier Permanent Set

- 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

Spring Tube Thermal Barrier



Preloader Performance

Single Crystal CCS

(Patent Pending)

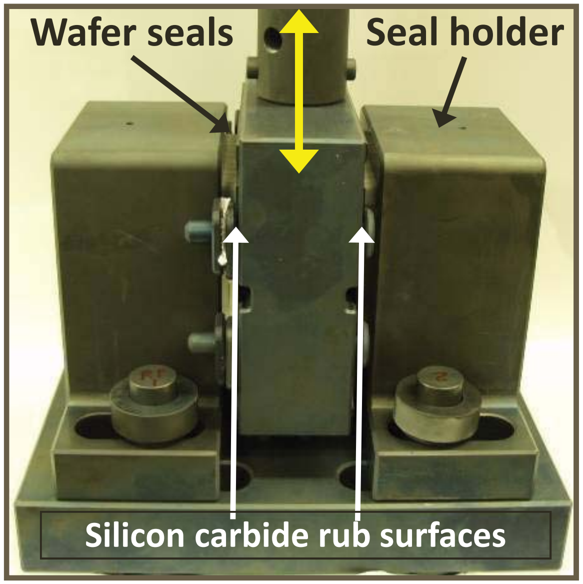
OUR TOOLS:

TEST CAPABILITIES AT NASA GRC

Thermal Seals Testing Methodology

Advancing the Technology Readiness Level (TRL)

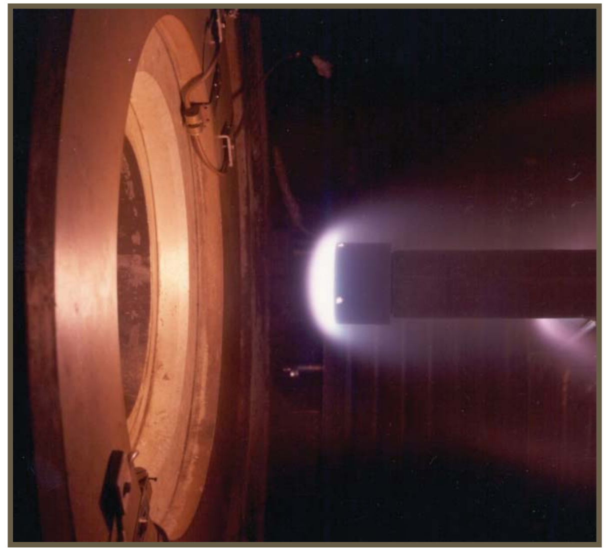
Coupon level tests at GRC



TRL 3-5 → TRL 5-6

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

TRL 5-6 → TRL 7-9

Flight level tests/operations

Features:
Final verification

Coupon Level Mechanical Testing

High Temperature Compression / Scrub Rig

Capabilities:

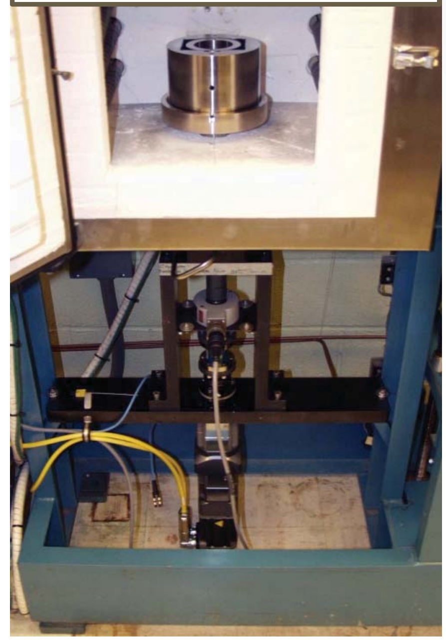
- Purpose: Assess loads, resiliency, wear at temp.
- Temp.: RT to 3000°F
- Environment: Air
- Max. loads: ±3300 lbf
- Max. stroke range: ±3 in.
- Stroke rate: 0.001 to 6 in./s
- Furnace working size: 9 x 14 x 18 in.

Multi Temperature Compression Rig

Capabilities:

- 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

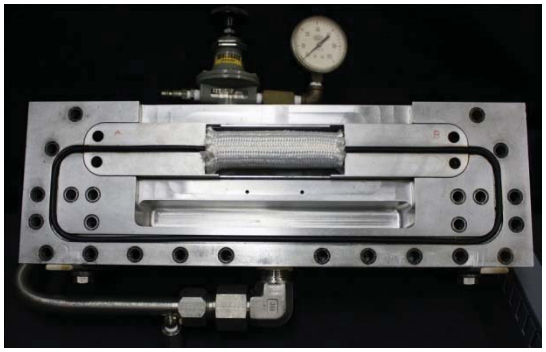


Capabilities:

- 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

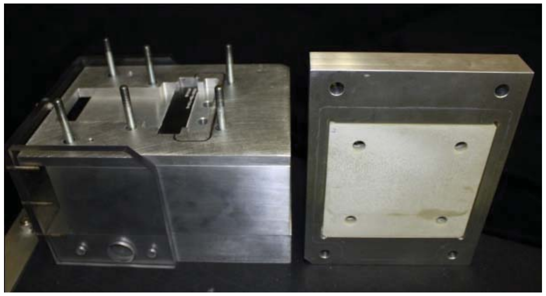
Ambient Linear Flow Rig #1



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

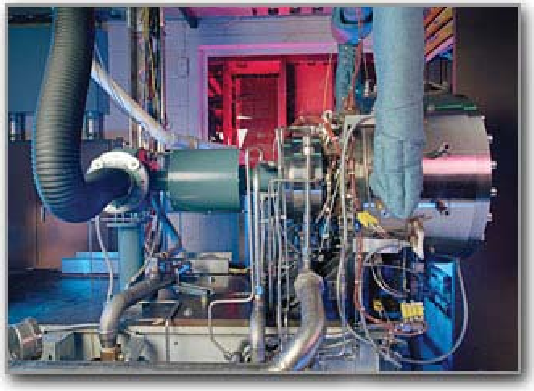
Coupon Level High Temp. Leakage Testing

High Temperature Flow Rig

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

Turbine Seal Test Rig



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.

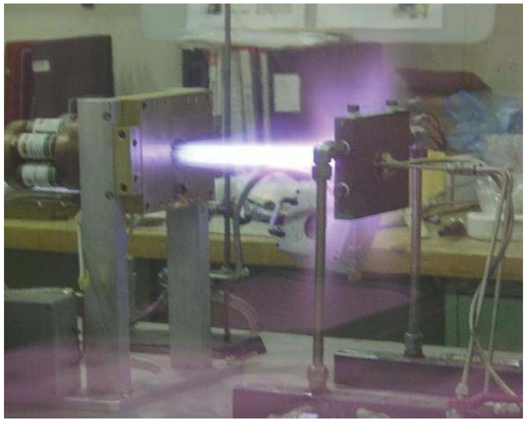
Thermal Testing

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/cm^2
Fuel: Jet + Air

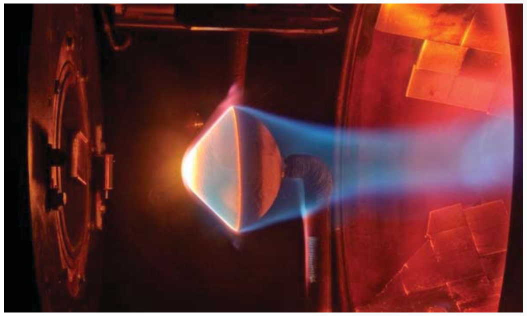
QARE Testing



Capabilities:

Purpose: Assess performance under high heat flux conditions, evaluate environmental durability
Location: GRC
Temp.: 2500°F+
Heat Flux: Up to 400 W/cm^2
Fuel: $H_2 + O_2$

Arc Jet Testing



Capabilities:

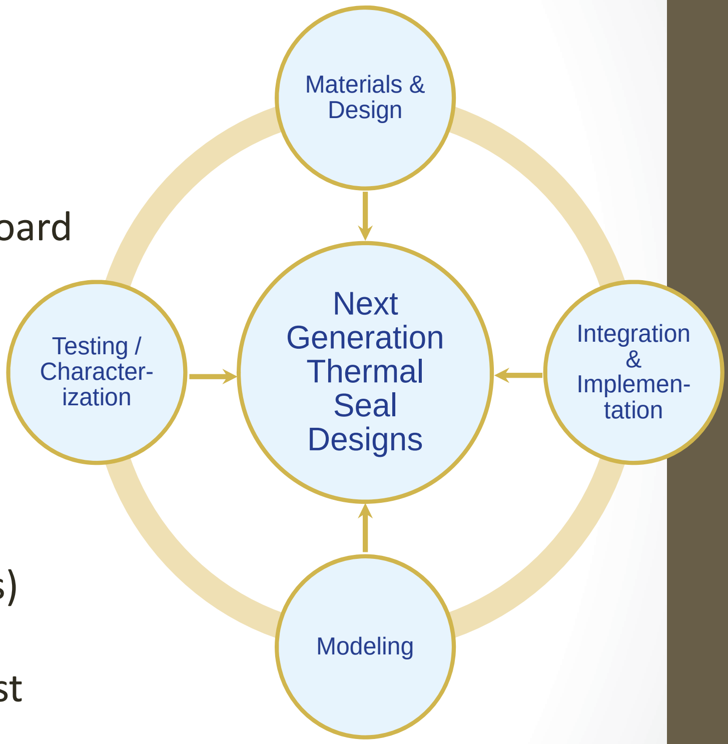
Purpose: Assess performance under reentry-like conditions
Location: ARC
Facility: PTF, IHF
Temp.: 2500°F+
Mach No: 5.5 – 7.5
Heat Flux: Up to 750 W/cm^2
Gas: Air
Hardware config.: Static

OUR [DESIRED] PATH:

Where We Hope to Go

Key Approaches: Thermal Seals

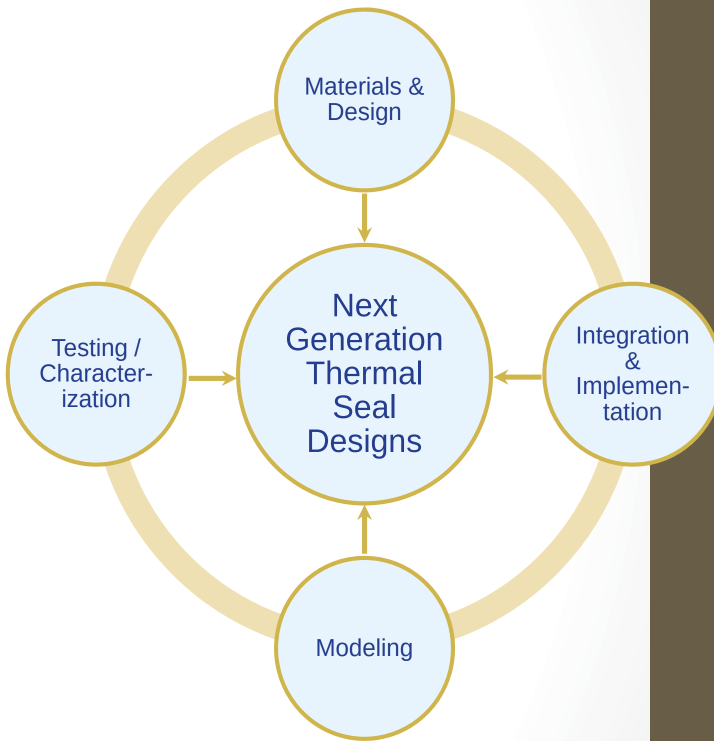
- **Materials & Design** – Develop/identify/test materials and unique configurations to meet requirements
  - ➢ Improved material systems/configurations
    - High temp (3000ºF), oxidation resistant, flexible fibers and batting
    - Aerogels
    - OFI (opacified fibrous insulation)
    - MLI (multi-layer 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 O_2 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

Points of Contact

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