HIGH TEMPERATURE BRAIDED ROPE SEALS FOR STATIC SEALING APPLICATIONS: CURRENT PROGRESS

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Presentation slide review:

1. Background:
Current program has origins in Space Shuttle and National Aerospace Plane programs. Seals are currently being optimized for three applications: Industrial Tube Seal; Turning Vane Seal; and JTAGG Turbine Vane Seal (these applications will be described in more detail below). Unique characteristics of these seals include: high temperature capability; flexibility; resilience; field joint capability; and low leakage. Goals for this project are to develop unique seal approaches for >1500°F temperature applications, and to improve current seal resiliency and leakage performance.

2. Case Study: Aerospace Customer:
Advanced Nickel-Aluminide (NiAl) turbine stator vanes were originally brazed to both platforms. In this configuration (left frame in slide), the vanes failed in flame tunnel tests due to high thermal stresses. GE and NASA co-developed an improved design (right frame) which employs a braided rope seal serving as both a seal and a compliant mount at the shroud platform. The NiAl vanes survived the flame tunnel tests using this technique. Hybrid seals (ceramic fiber core with an overbraided superalloy wire sheath) were used in this application.

3. GE Uses NASA Seals to Meet JTAGG Engine Goals:
Having successfully completed the flame tunnel tests, the seal/compliant mount configuration was qualified for installation into a JTAGG engine. The NiAl vane and seal were implemented into the JTAGG engine and run successfully for multiple cycles meeting the following seal performance criteria: operate at temperatures up to 1500°F and pressures up to 100 psid; allow the vane to slide 0.06 in. relative to the mount without vane fracture; and exhibit low seal wear. The seal enabled the vane to operate at IHPTET Phase I rotor-inlet temperatures (classified), and this technology combined with others contributed to meeting JTAGG Phase I program goals which included a 20% reduction in specific fuel consumption and a 40% increase in power-to-weight ratio in a 4000-6000 shaft horsepower-class turboprop/turboshaft engine.

4. **Case Study: Industrial Customer:**
An industrial application required high temperature, flexible tube seals. The seals must also serve as a compliant mount in order to prevent excessive structural loads caused by thermal growth differential between the tubes and their support platforms. Additional operating parameters are listed to the left on the slide. All-ceramic braided rope seals (ceramic fiber core with a ceramic overbraided sheath) were applied to this application, and they demonstrated the ability to seal and support structural loads while allowing for relative thermal growth between components.

5. **Case Study: Turning Vane Seal:**
This slide shows a turbine stator vane application similar to the first application discussed (above in slides 2 and 3), except that geometrical constraints of the system require that the seals be mounted on the vane end-surfaces. The seals were mounted in grooves in the platforms and fully support the vane while allowing for thermal growth differentials between the vane and the platforms. This configuration is to be flame tunnel tested under the conditions noted at left in the slide.

6. **Schematics of Test Fixtures:**
At left is a schematic of the NASA High Temperature Flow and Durability Test Facility. Seals are flow and durability tested at temperatures up to 1500°F and pressures up to 100 psid with scrubbing strokes up to 0.3 inches. At right is a schematic of the compression fixture used to determine seal preload and resilience characteristics. Contact load and seal crush are measured using standard instrumentation (as noted in the slide), and contact area is measured using a two-part, pressure sensitive film.

7. **Percent Crush, Working Deflection, and Preload:**
This slide shows preliminary compression test results of four all-ceramic seal types: 1/16" round cross section; 1/16" square cross section; 1/8" round cross section; and 1/8" square cross section. Round cross section seals are the baseline in this case, having previously been the subject of report and presentation (Joint Propulsion Conference, July 1996). Square cross section seals show a small improvement in working deflection over round cross section seals of similar size. Working deflection is defined as the amount a seal can spring back and still maintain at least 50% of the seal load. Preloads are similar for round and square cross section seals of similar size.

8. **High Temperature (1500°F) Rope Seal Test Fixture:**
Photo of the NASA High Temperature Flow and Durability Test Facility at operating temperature. The piston and cylinder are at center (piston reciprocates within the cylinder). The bright, serpentine coils are radiant heater elements.

9. **Flow Comparison:**
Preliminary flow results for 1/16" and 1/8" round- and square- cross section seals at 1300°F and 2 psid are shown in this slide. The 1/8" square cross section seal shows significant flow performance improvement over the 1/8" round cross section seal. 1/16" round- and square- seal flow results are more similar. All seals satisfied a customer defined flow goal of 0.0064 SCFM per inch of seal (set by the industrial customer, description on slide #4).

10. Summary and Conclusions:
As operating temperatures of advanced gas turbine and industrial systems continue to rise designers face more difficult challenges of implementing high temperature structural materials and seals to meet system performance goals. To maximize efficiency, coolant flows are being reduced to their practical minimum requiring low-leakage seals made of temperature-resistant superalloy and ceramic materials. Seals are required to both seal and serve as compliant mounts allowing for relative thermal growths between high temperature but brittle primary structures and the surrounding support structures. NASA is developing high temperature braided rope seals in a variety of configurations to help solve these problems. This presentation described some of the types of seals being developed, unique test techniques used to assess seal performance, and presented leakage flow data under representative pressure, temperature and scrubbing conditions. Seal feasibility for specific applications was also explored.

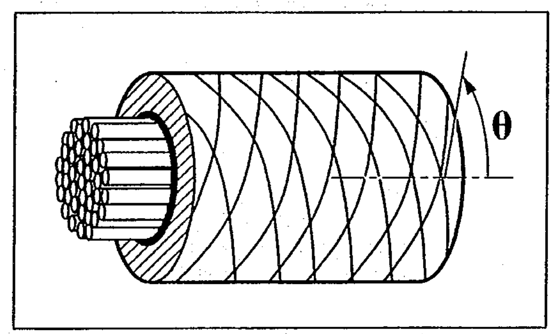
11. Future Plans:
See text on slide.

12. Resilient Braided Seal:
Schematic of a new seal design for future testing. The canted coil spring will significantly increase seal resiliency and working deflection. Samples have already been manufactured and will soon be tested.

Background

- High temperature flexible packings have origins in several programs
  - Space Shuttle Thermal Protection System (TPS)
  - National Aerospace Plane (NASP) engine seals

- Current effort builds on these programs to optimize seals for three applications:
  - Industrial Tube Seal
  - Turning Vane Seal
  - JTAGG Turbine Vane Seal



- Braided Rope Seal Features
  - High temperature
  - Flexibility
  - Resilience
  - Field Joint Capability
  - Low Leakage

NASA Long Term Goals

- Develop unique seal approaches for extreme (1500 - 2000 °F) temperature applications (aerospace/industrial)

- Improve seal resiliency through novel seal enhancements for long term cyclic use

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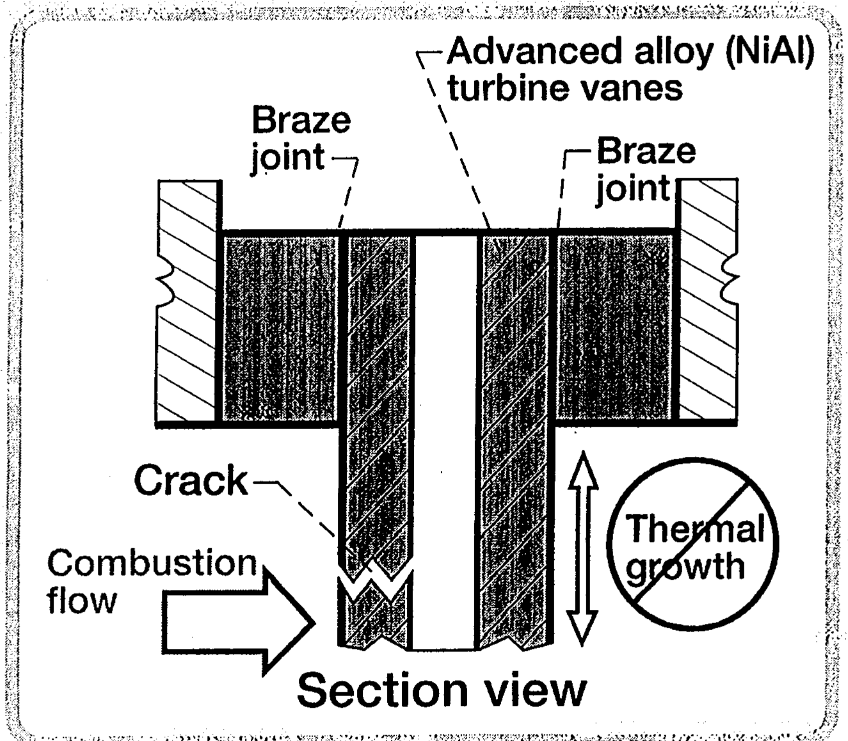
Case Study: Aerospace Customer

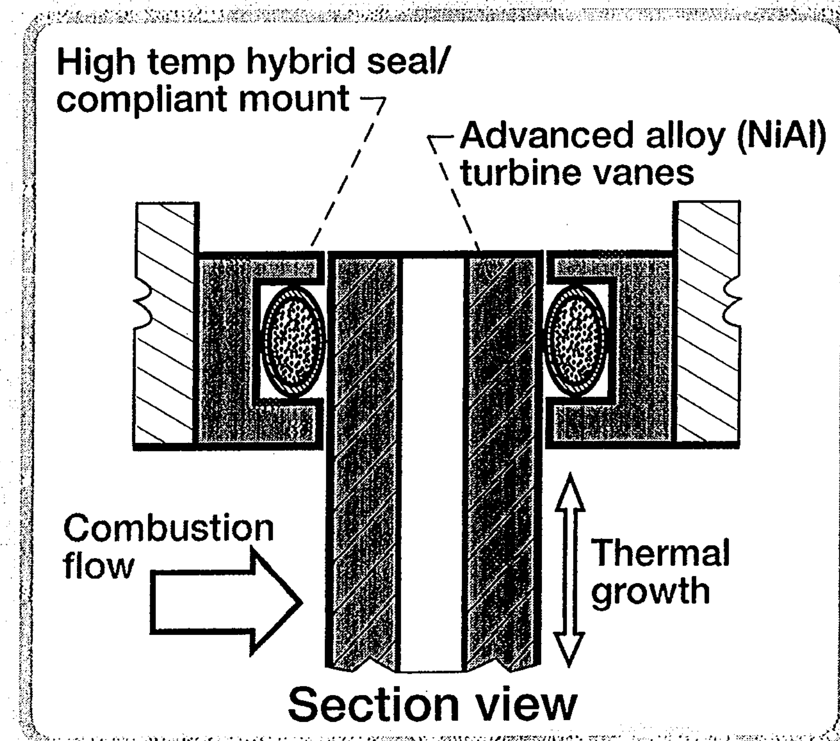
Problem:

Advanced alloy turbine vane rigidly brazed into shrouds failed during thermal shock tests due to high thermal stresses preventing program goals to be met.

Conventional Brazed Design



Improved Design



Solution:

Compliant mount/seal arrangement co-developed by GE and NASA

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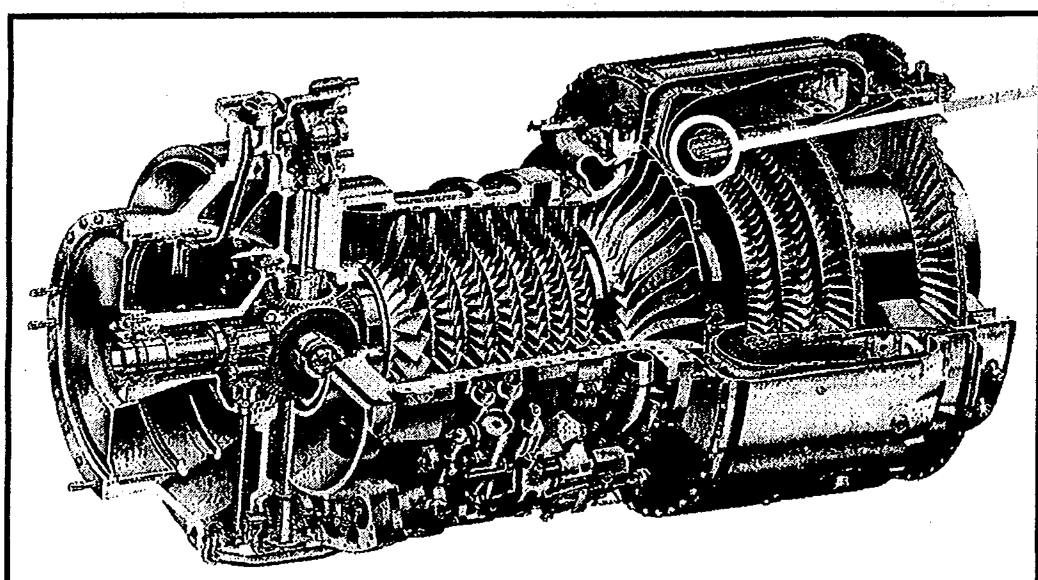
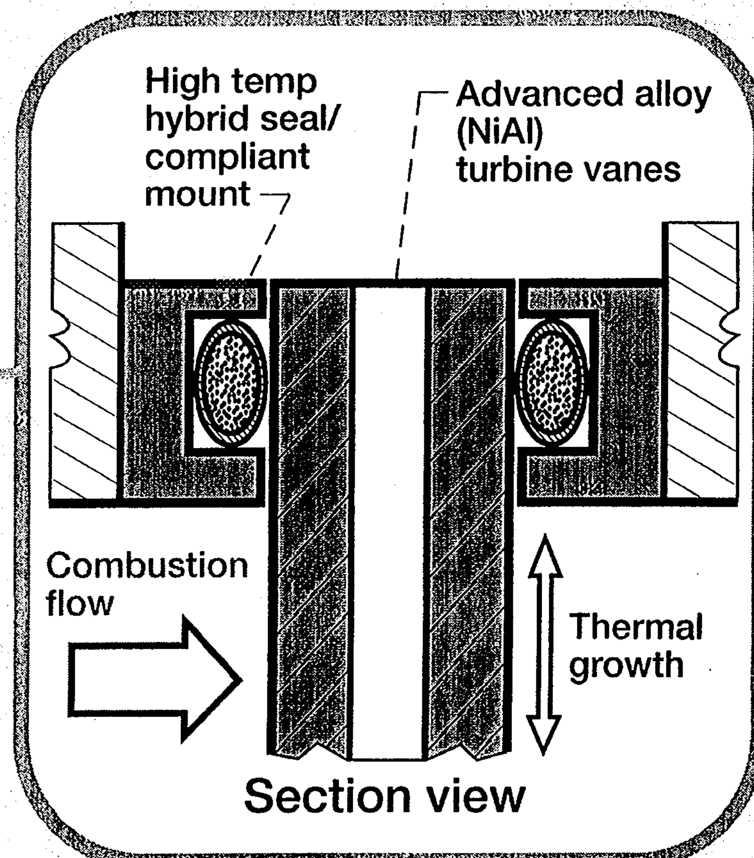
GE Uses NASA Seals to Meet JTAGG Engine Goals

- GE application of NASA 1500 °F rope seals overcomes thermal shock failure of advanced NiAl blades in engine test
- Contributed to meeting JTAGG Phase 1 goals:
  + Reducing specific fuel consumption by 20%
  + Increasing power-to-weight by 40%
- Engine Team awarded 1995 Aviation Week & Space Technology Laureate Award



Schematic of vane seal hardware



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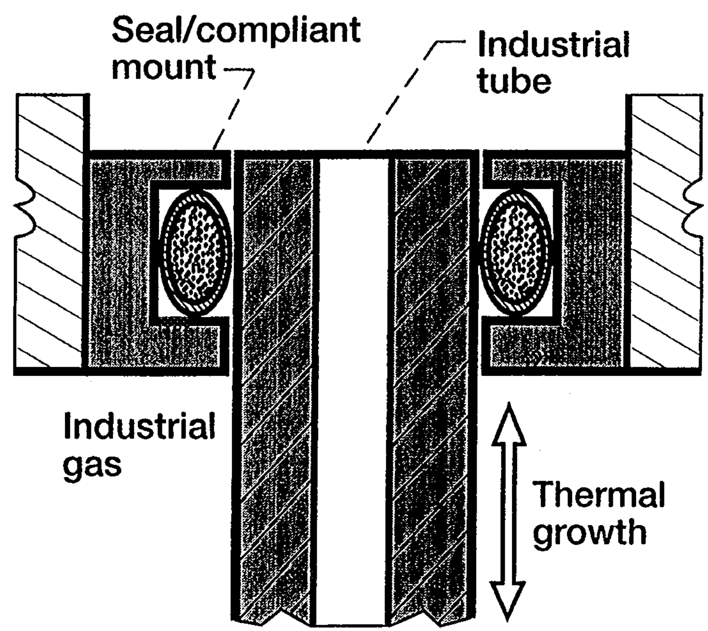
Case Study: Industrial Customer

Problem:

Industrial application requires high temperature, flexible seal/compliant mount to seal apparatus and prevent excessive structural loads.

Demonstrated features:
- **Operates hot (1500+°F)**
- **Exhibits low leakage**
- **Allows 0.3" relative thermal growth without binding or abrasion**
- **Chemically inert**



Section view

Solution:

NASA demonstrates feasibility of compliant mount/seal arrangement for industrial customer that meets customer flow and durability goal.

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Case Study: Turning Vane Seal

Goal:

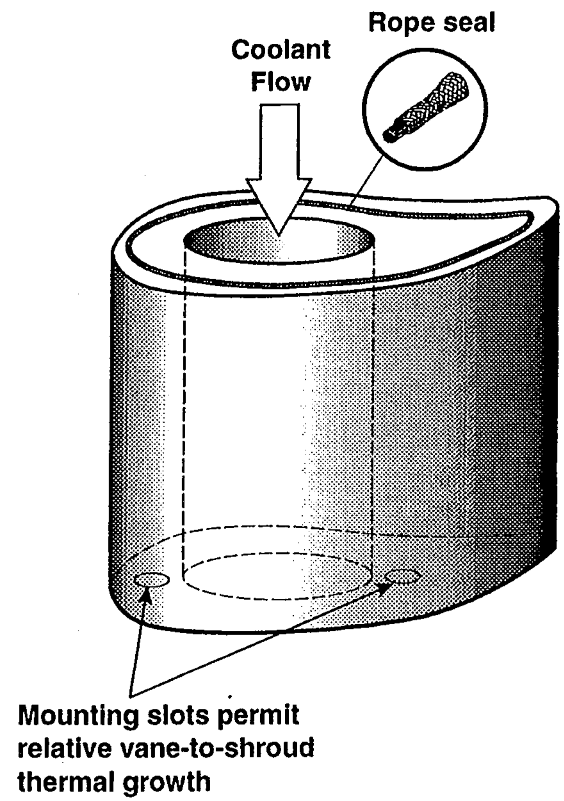
Apply compliant rope seals to hot turbine vane to accomodate relative thermal growth and minimize vane prêssure-to-suction side leakage

Conditions:
Flow path (2500 °F)

Max Δp = 40-50 psi (trailing edge)

Vane Materials:
- **Skin: Carbon/SiC**
- **Core: SiC Foam**

Rope Seal
1/16" diam. Nextel 550



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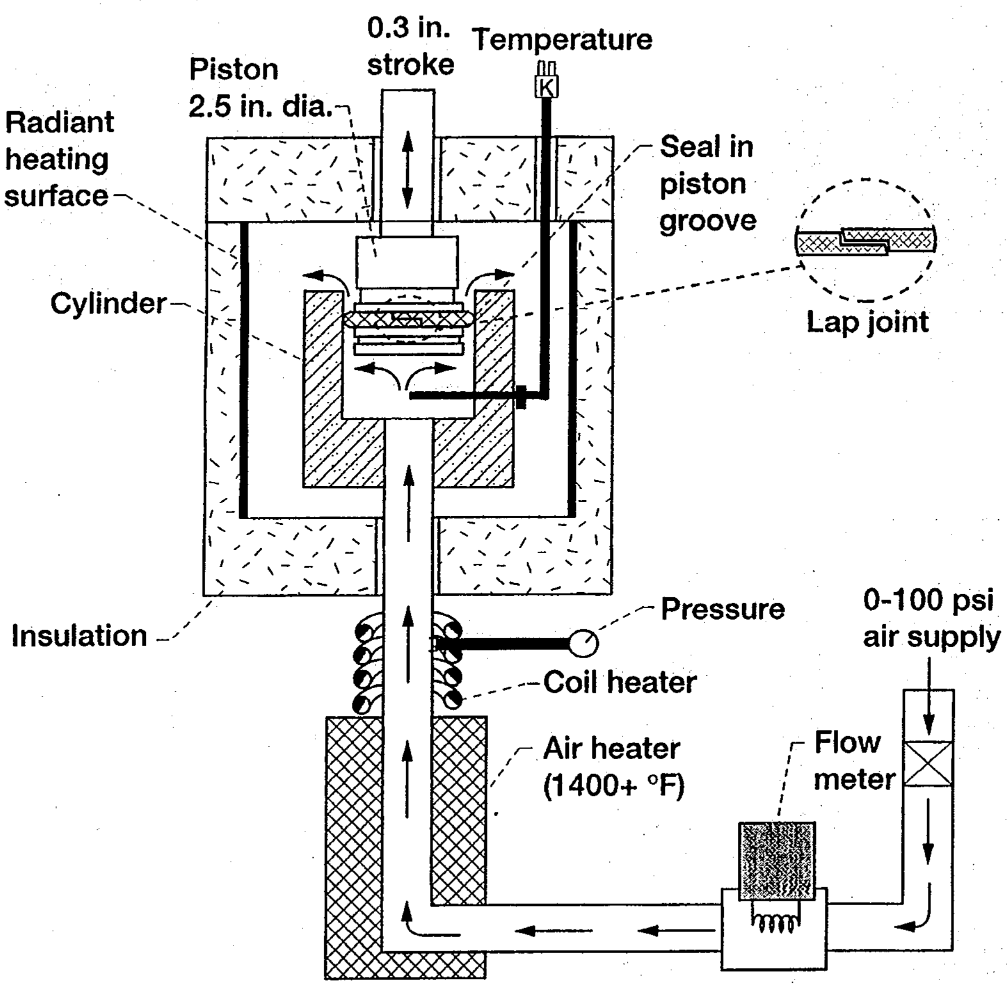
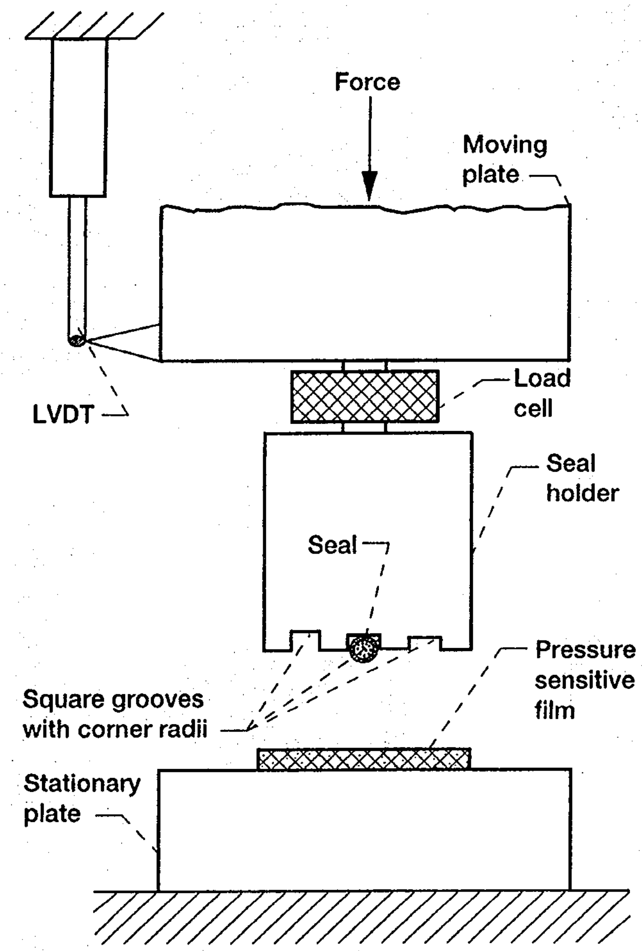
Schematic of Flow Fixture



Schematic of Compression Fixture



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Percent Crush, Working Deflection, and Preload

Seal	% Crush	Working deflection (in)	Preload (psi)
1/16" All-Ceramic Round	28%	0.003	235
1/16" All-Ceramic Square	28%	0.004	175
1/8" All-Ceramic Round	17%	0.005	110
1/8" All-Ceramic Square	17%	0.006	135

Working Deflection = Amount of seal spring back retaining half or more of seal load (lb/in seal)

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High Temperature (1500 °F) Rope Seal Test Fixture

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Summary and Conclusions

Industrial tube seal

- The 1/16" diameter all-ceramic rope seal exhibited acceptable flow and durability for the design preloads, pressures, and temperatures (1300+ °F)

Turbine vane seal

- The hybrid rope seal flow and durability tests combined with GE flame tunnel, combustor, and engine tests demonstrated seal feasibility for select engine applications
- The all-ceramic seal will be used in turning vane combustor tests in order to structurally support the vane, allow for thermal growth differential between metal and ceramic components, and minimize coolant leakage.

Square cross section seals

- Exhibit increased working deflection and lower leakage than round cross section seals

Rope seals are effective in serving both as a compliant mount and seal for advanced aerospace and industrial applications;
Allow differential thermal expansion without failure at high temperatures

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Future Plans

- Improve seal resiliency and working deflection through advanced concepts and braid technologies
- Investigate high temperature performance of new ceramic fibers (e.g. Nextel 720)
- Apply seals to other aerospace and industrial applications

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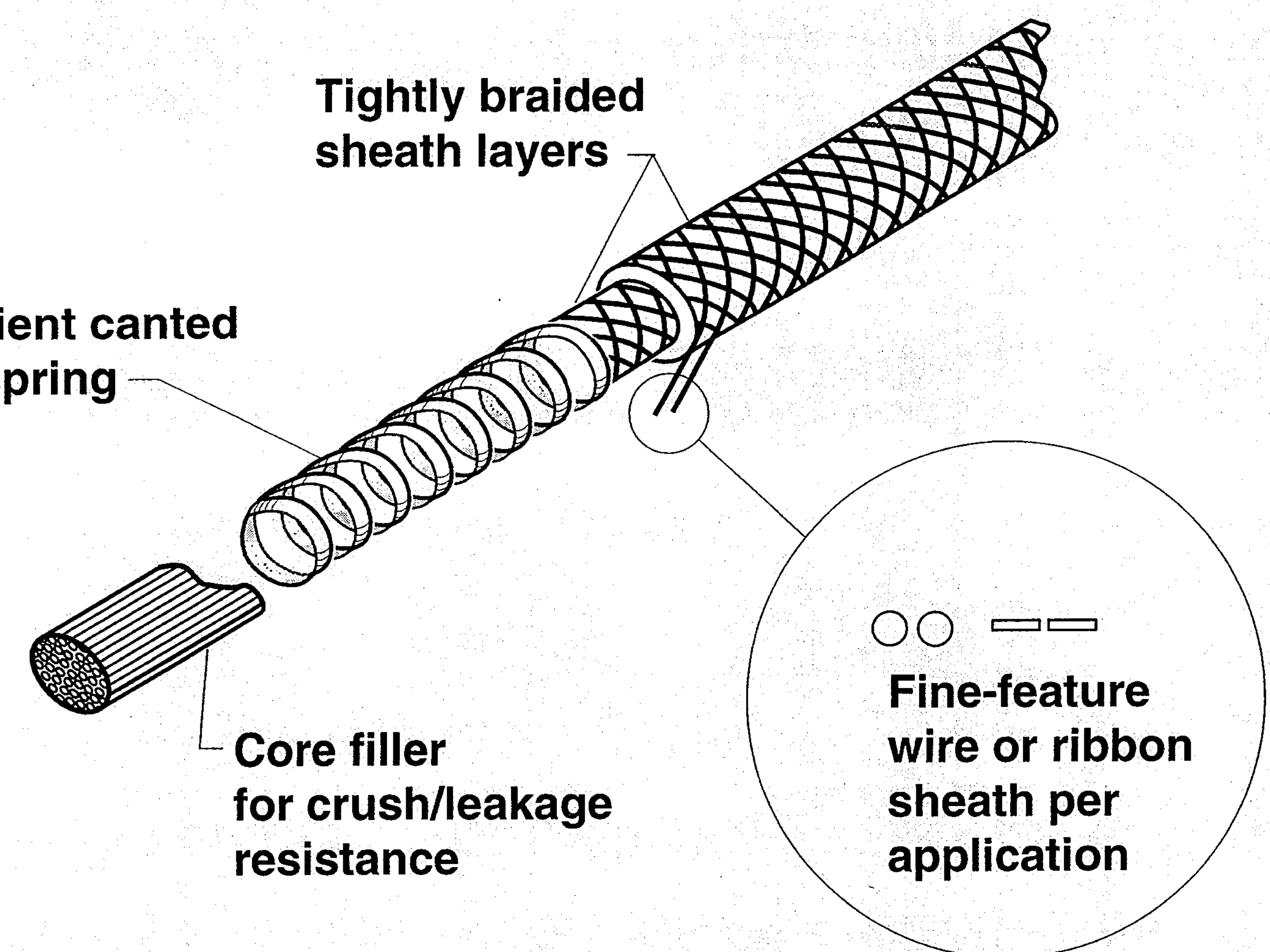
Resilient Braided Seal



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