EFFECTS OF COMPRESSION, STAGING, AND BRAID ANGLE ON BRAIDED ROPE SEAL PERFORMANCE

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Background

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

Rope Seal Benefits

- High temperature operation (1500-2000+ °F)
  → 500-1000 °F hotter than graphite seals
- Low leakage
- Flexible: Seals & conforms to complex geometries
  → O-ring-like flexibility
- Resilient
- Allows relative thermal growth between primary/support structures
- Field joint capability
- Hybrid design resists abrasion
High Temperature (1500 °F)

Rope Seal Test Fixture
Comparison of Hybrid Seal Braid Architecture

46° Braid Angle Hybrid

Core: Nextel 550
Sheath: Haynes 188
10 wires/bundle

58° Braid Angle Hybrid

Core: Nextel 550
Sheath: Haynes 188
4 wires/bundle
Residual Interference After Compression Cycling

All ceramic seals exhibit more residual interference
Effect of Compression, Braid, and Staging on Seal Flow
(Δp = 10 psid; T = 1300 °F; After Scrubbing)

Hybrid Seals (1/16")

- High braid angle hybrid seal exhibited 1/2 - 1/3 the leakage of low braid angle hybrid for same linear crush, but had 6x unit pressure
- Two stage seals leaked less than single stage seals
  High braid angle/high stiffness hybrid: 30+% less
Effect of Compression, Braid, and Staging on Seal Flow
(Δp = 10 psid; T = 1300 °F; After Scrubbing)

All Ceramic Seals (1/16")

- Multiple stage seals leaked less than single stage seals
  Two stage seals: 60% less
  Three stage seals: 70% less
Effect of Staging on Seal Pressure Drop

Multiple Stage Seals, After Scrubbing

All Ceramic: 3 Seals

.018" Linear Crush

100 psi, 70°F
100 psi, 1100°F
100 psi, 1300°F

Supply
Exhaust

Station 1

Pressure, psi
Three Stage Seal Durability

After Hot Scrubbing

10 cycles x 0.13" Stroke at 1300°F

Static Pressure Taps 3 Places

Seals survived accelerated seal durability cycle at temperature
P&W Turbine Vane Seal Requirements

- Operate hot
  Seal/metal temperature: 1200 °F
  Gas stream temperature: last stage vane

- Exhibit low leakage – minimize cooling requirements

- Permit relative vane-to-shroud thermal growths

- Seal complex turbine airfoil geometries

- Resist abrasion in high acoustic environment

- Maintain structural integrity
Next Generation Fighter F-22
P&W F119 Engines
Summary and Conclusions

- Increasing hybrid seal braid angle and core coverage reduced leakage 1/2 - 1/3rd that of conventional hybrid for same compression but increased stiffness and unit preload

- Using multiple seals, the last stage seal always resists the largest percentage of the inlet pressure
  - Two stage seals: 1st stage resists 25%
    2nd stage resists 75%
  - Three stage seals: 1st stage resists 20%
    2nd stage resists 30%
    3rd stage resists 50%

- Multiple stage seals reduced leakage considerably
  - Hybrid seals 2 stage: 30+% reduction
  - Ceramic seals 2 stage: 60+% reduction
    3 stage: 70+% reduction

Braided Rope Seals are meeting an important need arising from increased engine cycle temperature, performance, and efficiency requirements