NASA Lewis Research Center is developing advanced seal concepts and sealing technology for advanced combined cycle ramjet/scramjet engines being designed for the National Aerospace Plane (NASP). Technologies are being developed for both the dynamic seals that seal the sliding interfaces between articulating engine panels and sidewalls, and for the static seals that seal the heat-exchanger to back-up structure interfaces.

This paper will provide an overview of the candidate engine seal concepts, seal material assessments, and unique test facilities used to assess the leakage and thermal performance of the seal concepts.

Outline

1. Introduction
2. Flow Modeling
3. High Temperature Material Friction and Wear Tests
4. High Temperature Durability/Flow Assessments
5. High Heat Flux Facility
6. Summary
HYPERSONIC ENGINE PANEL-EDGE SEAL

HIGH SPEED FLOW

PANEL-EDGE SEAL
Flow Modeling

Ceramic Wafer Seal Flow Modeling

\[ \dot{M}_{TOT} = \dot{M}_1 + \dot{M}_2 + \dot{M}_3 \]

- Seal leakage gap heights
- Seal-to-wall contact dim.
- Seal length
- Inlet & outlet pressures
- Gas viscosity, density, temp.
- Gas constant
Ceramic Wafer Seal Leakage vs Temperature
Comparison of Measured & Predicted

$\Delta P = 20 \text{ psi}$

Leakage rate,
\( \text{lb/s ft} \)
\(5 \times 10^{-3}\)

Tentative leakage limit

- Measured
- Predicted

Temperature, F

$\Delta P = 40 \text{ psi}$

Leakage rate,
\( \text{lb/s ft} \)
\(5 \times 10^{-3}\)

Tentative leakage limit

- Measured
- Predicted

Temperature, F

Leakage Path Flow Resistances

$$\dot{M}_{TOT} = \dot{M}_1 + \dot{M}_2 + \dot{M}_3$$

Rope Seal Flow Paths

<table>
<thead>
<tr>
<th>Flow Path</th>
<th>Flow Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{M}_1$</td>
<td>$R_1 = 9 K \frac{t}{y_o^3}$</td>
</tr>
<tr>
<td>$\dot{M}_2$</td>
<td>$R_2 = 300 K \frac{tL}{A_c} \frac{(1 - e_{avg})^2}{e_{avg}^3 (\phi D_{f,avg})^2}$</td>
</tr>
<tr>
<td>$\dot{M}_3$</td>
<td>$R_3 = 3 K \frac{t}{y_o^3}$</td>
</tr>
</tbody>
</table>

Where:

- $\phi D_{f,avg} = \text{Characteristic length}$

- $e_{avg} = 1 - \frac{A_y N_c + A_y N_s}{t^2} / \cos \theta$
Braided Ceramic Rope Seal Leakage vs Temperature
Comparison of Measured and Predicted

\[ \Delta P = 10 \text{ psi} \]

\[ \Delta P = 35 \text{ psi} \]

Leakage rate, lb/s ft
\[ \begin{array}{c}
\text{Temperature, F} \\
0 & 200 & 400 & 600 & 800 & 1000 & 1200 & 1400
\end{array} \]

\[ \begin{array}{c}
0 & 2 & 4 & 6 & 8 & 10 & 12 & 14 \times 10^3
\end{array} \]

\[ \begin{array}{c}
\text{O Measured} \\
\text{--- Predicted}
\end{array} \]

\[ \varepsilon_{\text{avg}} = 0.43 \]

\[ \varepsilon_{\text{min}} = 0.22 \]

Tentative leakage limit

NORMAL LOAD SENSOR
FLEXURE
PYROMETER PORT
DC MOTOR
PULLEY
SPRING PACK
BEARING SPINDLE
TORQUE TUBE
PIN LOCKING ROD
FURNACE
PYRODENOUS DISK SPECIMENS
PNEUMATIC LOADER

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High Temperature
Solid Seal Durability/Flow Studies

High Temperature Dynamic Seal Rig (U)

Adjustable lateral preload system

Test Seals: Rope or wafer seals

Axial Preload

Simulated wall roughness/waviness
Percent crush (channel depth) or load (bellows) control

High watt density surface heaters

1 ft test zone

Hot, pressurized metered supply gas

Temp. and pressure measurement

Seal Cartridge

Section A-A
SOLID SEAL DURABILITY TEST
Hot Dynamic Seal Rig

Haynes 25 (2 mil wire) Hybrid seal after hot durability cycling

SEAL - HY3 - 1

SEAL - HY3 - 2

CONDITIONS:

SEAL ARCH: HY3(32.8%)-NX312(600/8)-4400/94.8%-H25(172:50)-28x110 S0 (12.00")
SEAL GAP: 0.030 inches
PRELOAD: Active (20 psi contact pressure)

Coolant Panel Braided Ceramic Rope Seal
Potential Alternate to Metal Seal
CONTINUOUS LOOP BRAIDED ROPE SEAL

NASA Lewis Research Center

Transpiration Cooled Seal Concepts Tested for National Aero–Space Plane

Braided Rope Seal

Rocket Nozzle Exit

CRL–22 Hot Gas Facility
Summary

- Hypersonic engines pose unique dynamic seal challenges:
  - Prevent leakage of combustible hydrogen/oxygen mixtures
  - Seal highly distorted sidewalls during sliding
  - Operate hot requiring minimum coolant
  - Resist mechanical abrasion and supersonic-flow erosion

- NASA Lewis has developed unique test capabilities for evaluating the seal/material performance under engine simulated conditions:
  - Materials/Lubricant Friction Apparatus
  - High Temperature Dynamic Seal Rig
  - High Heat Flux Facility

- NASA Lewis developed hybrid seal meets the dynamic engine seal life requirements at temperatures \( \geq 1500 \) F.