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NATIONAL AEROSPACE PLANE ENGINE SEALS
High Temperature Seal Performance Evaluation

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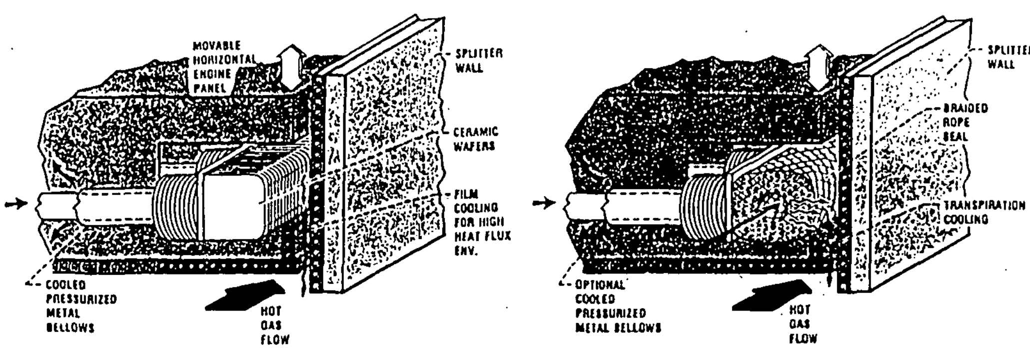
Key to the successful development of the single-stage-to-orbit National Aerospace Plane (NASP) is the successful development of combined cycle ramjet/scramjet engines that can propel the vehicle to 17,000 mph to reach low earth orbit. To achieve engine performance over this speed range, movable engine panels are used to tailor engine flow that require low-leakage high-temperature seals around their perimeter. NASA Lewis is developing a family of new high temperature seals to form effective barriers against leakage of extremely hot (>2000 °F), high pressure (up to 100 psi) flow path gases containing hydrogen and oxygen. Preventing backside leakage of these explosive gas mixtures is paramount in preventing the potential loss of the engines or the entire vehicle.

Described in the subsequent pages of this report are seal technology development accomplishments in the three main areas of concept development, test and evaluation and analytical development. The presentation closes with a brief discussion of future plans.

SEAL CONCEPTS UNDER DEVELOPMENT (U)

CERAMIC WAFER SEAL

BRAIDED CERAMIC ROPE SEAL



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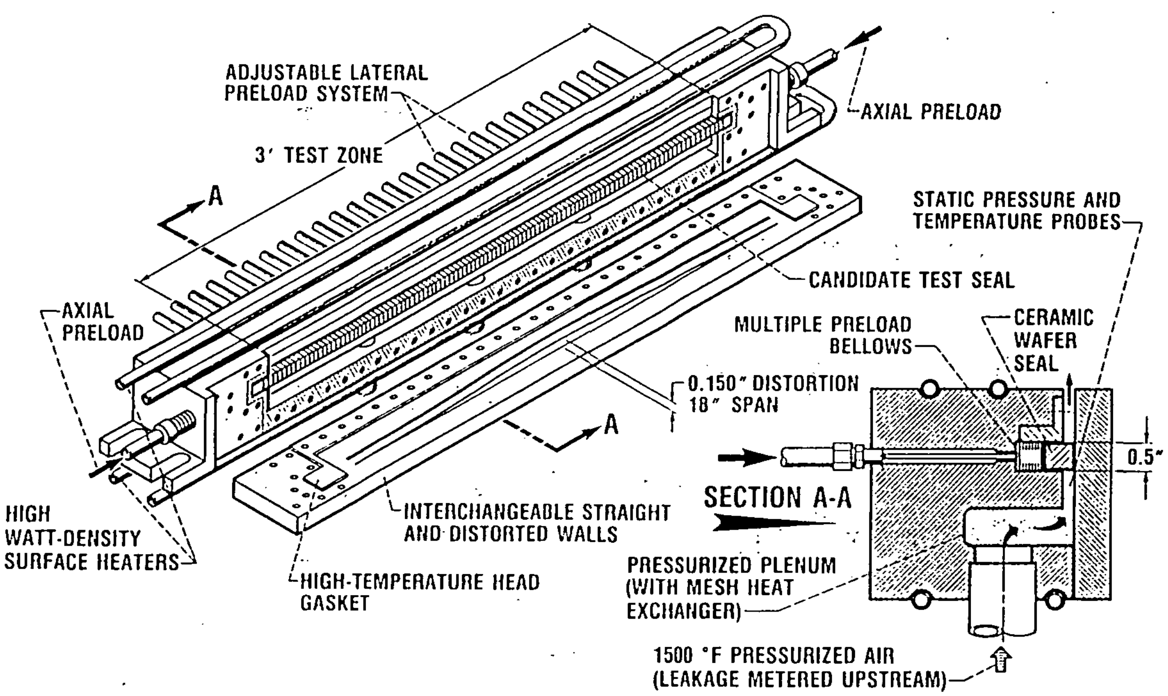
SUMMARY OF TECHNOLOGY DEVELOPMENT

SEAL DEVELOPMENT:
- o ADVANCED CONCEPT DEVELOPMENT
- o FABRICATION TECHNOLOGY

ANALYTICAL DEVELOPMENT:
- o SEAL LEAKAGE FLOW MODELING
- o THERMAL-STRUCTURAL ANALYSES

EXPERIMENTAL DEVELOPMENT AND EVALUATION:
- o HIGH TEMPERATURE LEAKAGE PERFORMANCE EVALUATION
- o HIGH TEMPERATURE FRICTION AND WEAR ASSESSMENTS SOLID FILM LUBRICANT DEVELOPMENT

SCHEMATIC OF HIGH-TEMPERATURE PANEL-EDGE SEAL RIG (U)



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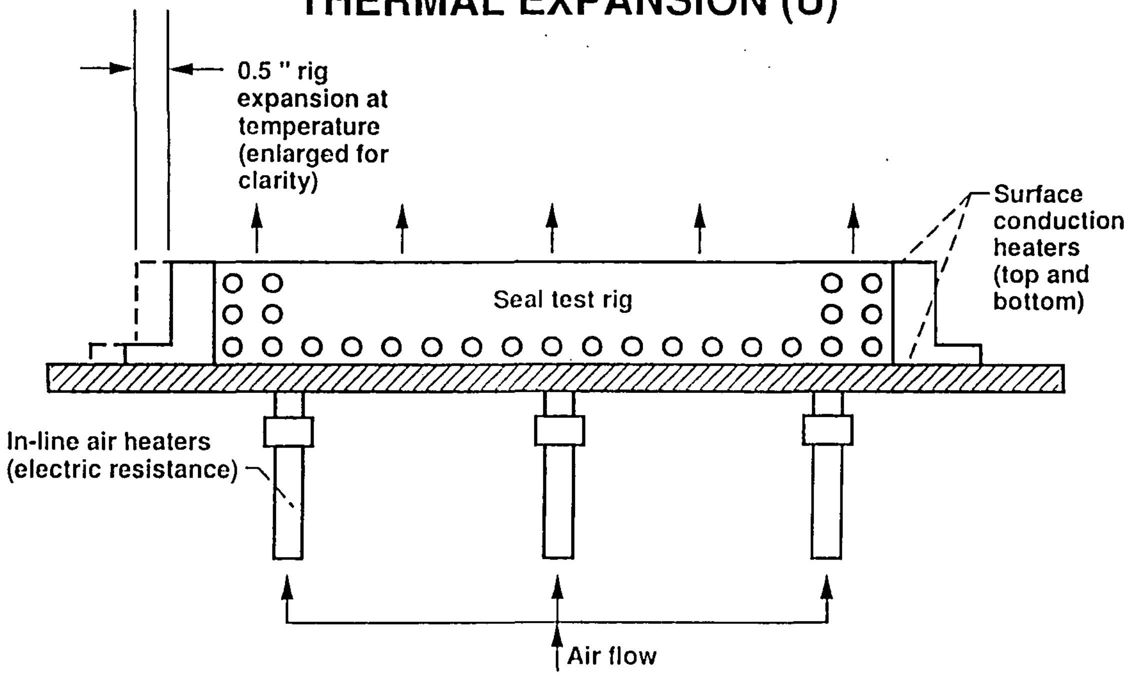
SEAL TEST FIXTURE THERMAL EXPANSION (U)



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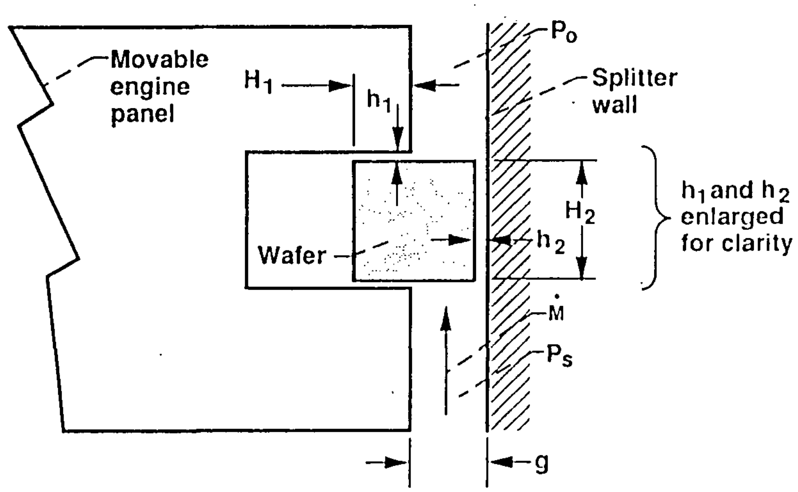
CERAMIC WAFER SEAL LEAKAGE MODEL (U)



$$\dot{M} = \frac{(P_s^2 - P_o^2)}{24\,\mu\, R\ \ T}\left(\underbrace{\frac{Lh_1^3}{H_1} + \frac{Lh_2^3}{H_2}}_{\text{Parasitic leakage around wafers}} + \underbrace{\frac{Ngh_s^3}{H_2}}_{\text{CTE mismatch induced leakage}}\right)$$

Where:

$\dot{M}$ = Seal leakage rate

h_1, h_2 = Eff surface leakage gap

L = Seal length

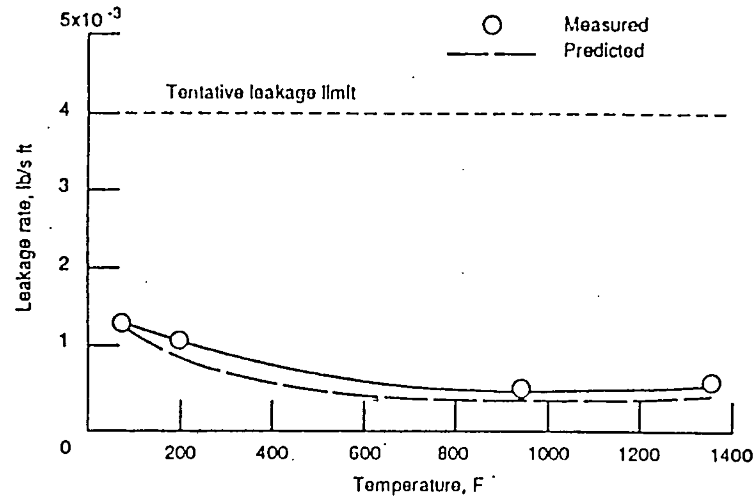
μ (T) = Power law viscosity

$h_s = \frac{\Delta CTE \times L \times \Delta T}{N}$ = small inter-wafer gap

N = No. of interfaces

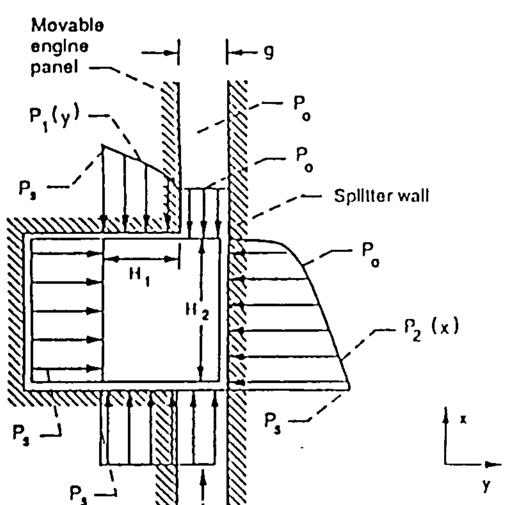
COMPARISON OF MEASURED AND PREDICTED LEAKAGE RATES VS TEMP.

FIXED PRESSURE DIFFERENTIAL: 40 psi



PRESSURE INDUCED WAFER LOADS

PRESSURE DISTRIBUTION:



FORCE BALANCE:

$$\Sigma\frac{F_y}{L} = \frac{F_y}{L} - \int_0^{H_2} (P_s - P_2(x))\,dx$$

$$\Sigma\frac{F_x}{L} = \frac{F_x}{L} - \int_0^{H_1} (P_s - P_1(y))\,dy + \int_{H_1}^{H_1+g} (P_s - P_o)\,dy$$

$$\Sigma\frac{M}{L} = \frac{M}{L} - \int_0^{H_2} (P_s - P_2(x))\,x\,dx + \int_0^{H_1} (P_1(y) - P_s)\,y\,dy + \int_{H_1}^{H_1+g} (P_o - P_s)\,y\,dy$$

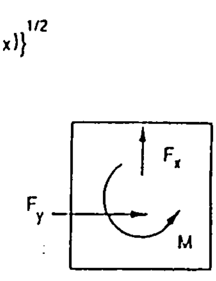
Pressure profiles: $P_1(y) = \left\{P_o^2 + \frac{(P_s^2 - P_o^2)}{H_1}(H_1 - y)\right\}^{1/2}$

$$P_2(x) = \left\{P_o^2 + \frac{(P_s^2 - P_o^2)}{H_2}(H_2 - x)\right\}^{1/2}$$

Resultants:

$$\frac{F_y}{L} = \left(P_s - \frac{2}{3}\frac{(P_s^3 - P_o^3)}{(P_s^2 - P_o^2)}\right)H_2$$

$$\frac{F_x}{L} = \left(P_s - \frac{2}{3}\frac{(P_s^3 - P_o^3)}{(P_s^2 - P_o^2)}\right)H_1 + (P_s - P_o)g$$



Resultant loads

$$\frac{M}{L} = \frac{P_s}{2}(H_2^2 - H_1^2) + \frac{2}{3}\frac{P_o^3}{(P_s^2 - P_o^2)}(H_2^2 - H_1^2) - \frac{4}{15}\frac{(P_s^5 - P_o^5)}{(P_s^2 - P_o^2)^2}(H_2^2 - H_1^2)$$

$$- \frac{(P_s - P_o)}{2}(2H_1 g + g^2)$$

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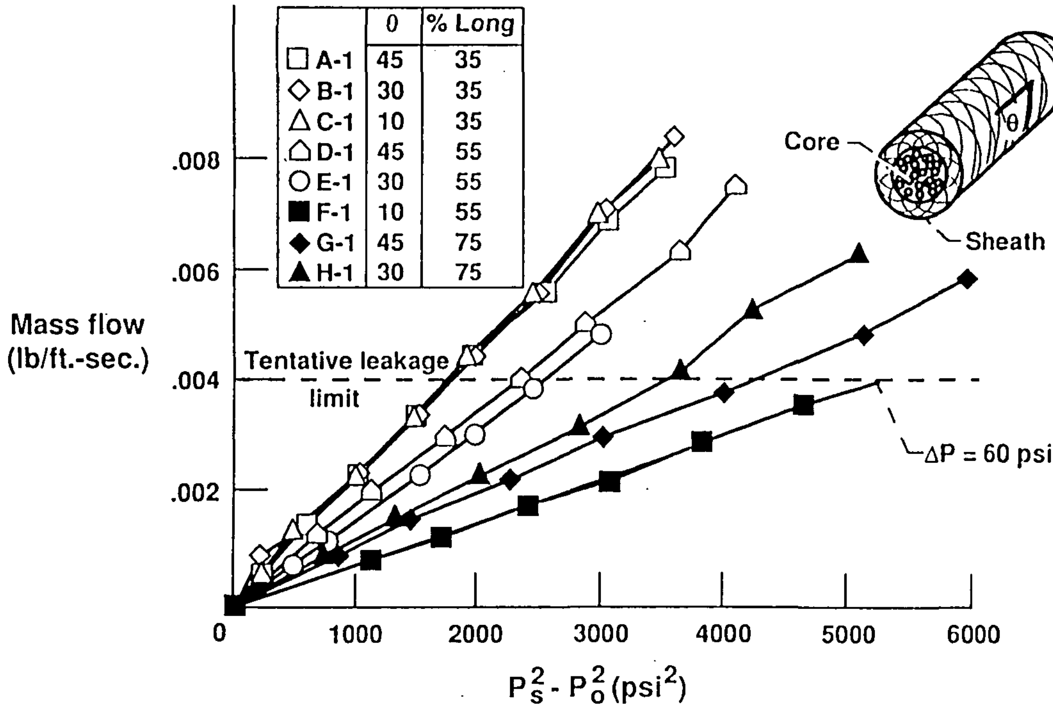
2-D BRAIDED ROPE SEAL LEAKAGE PERFORMANCE (U)

ROOM TEMPERATURE AIR, 80 PSI PRELOAD



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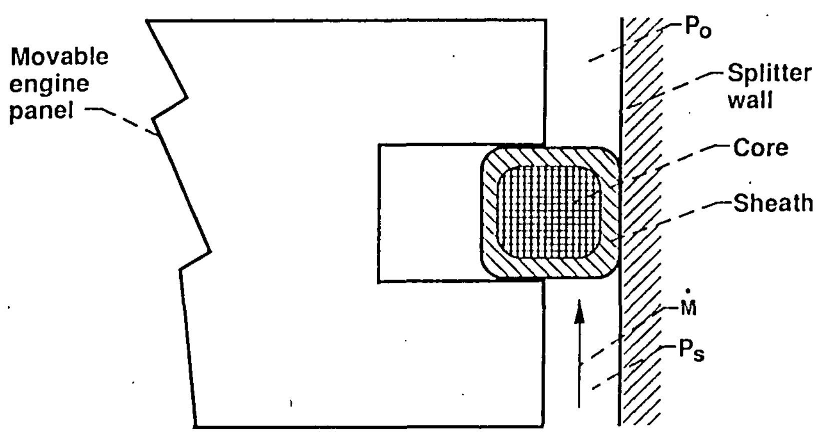
BRAIDED ROPE SEAL LEAKAGE MODEL (U)



$$\frac{\dot{M}}{L} = \frac{P_s^2 - P_o^2}{R}; \quad \frac{1}{R} = \begin{pmatrix}\text{Eff Seal}\\ \text{Resistance}\end{pmatrix}^{-1} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5+R_6+R_7}$$

Where:

$\dot{M}/L$ = Seal leakage per unit length

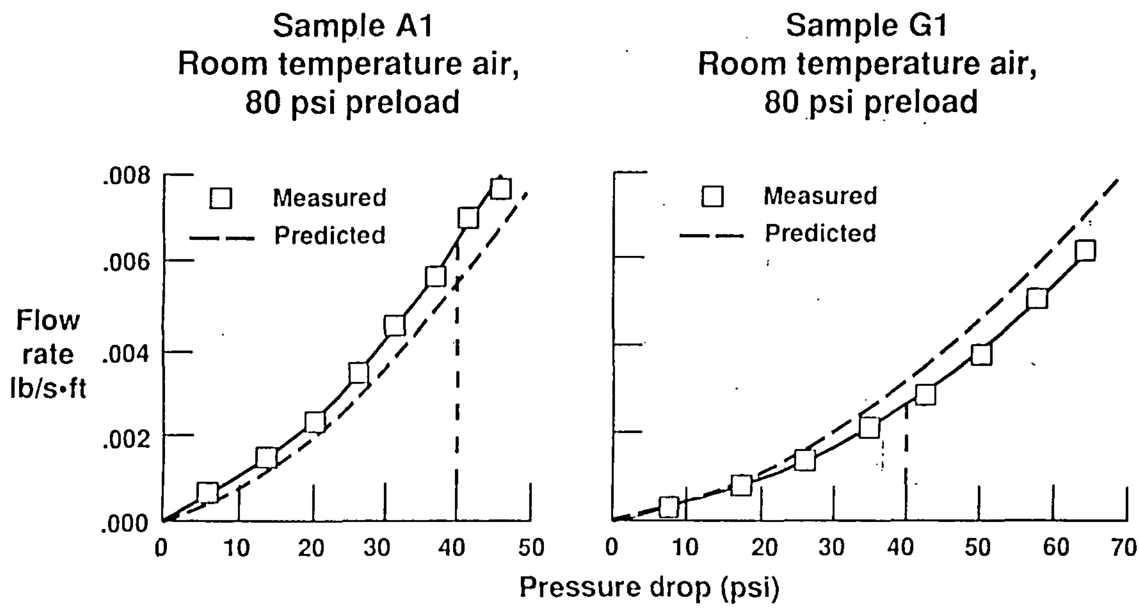
R_1, R_2 = Resistance to flow behind and in-front of seal

R_3, R_4 = Sheath resistance (eg parallel to flow direction)

R_5, R_7 = Sheath resistance (eg perpendicular to flow direction, upstream and downstream)

R_6 = Core resistance

BRAIDED ROPE SEAL LEAKAGE MEASURED AND PREDICTED (U)



SEAL DEVELOPMENT FUTURE PLANS

- EVALUATE ALTERNATE FIBER TOW DURABILITY OVER SIMULATED TEMPERATURES.

- EVALUATE COMBINED DURABILITY/LEAKAGE PERFORMANCE OF ADVANCED BRAID ARCHITECTURES UNDER ENGINE SIMULATED SLIDING CONDITIONS, TEMPERATURES AND PRESSURES.

- EVALUATE SURVIVABILITY OF BRAIDED ROPE SEALS UNDER THE ENGINE SIMULATED EROSIVE SUPERSONIC FLOW FIELD.

- EXPERIMENTALLY ASSESS REQUIRED TRANSPIRATION COOLANT FLOW RATES TO SURVIVE THE HIGH ENGINE-SIMULATED HEAT FLUXES.