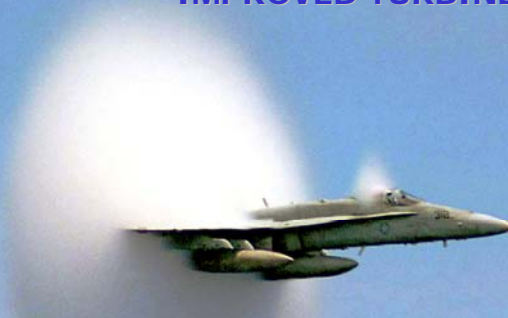


PRESSURE ACTUATED LEAF SEALS FOR IMPROVED TURBINE SHAFT SEALING

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**PRESSURE ACTUATED LEAF SEALS FOR
IMPROVED TURBINE SHAFT SEALING**

Presented by **Clayton Grondahl**

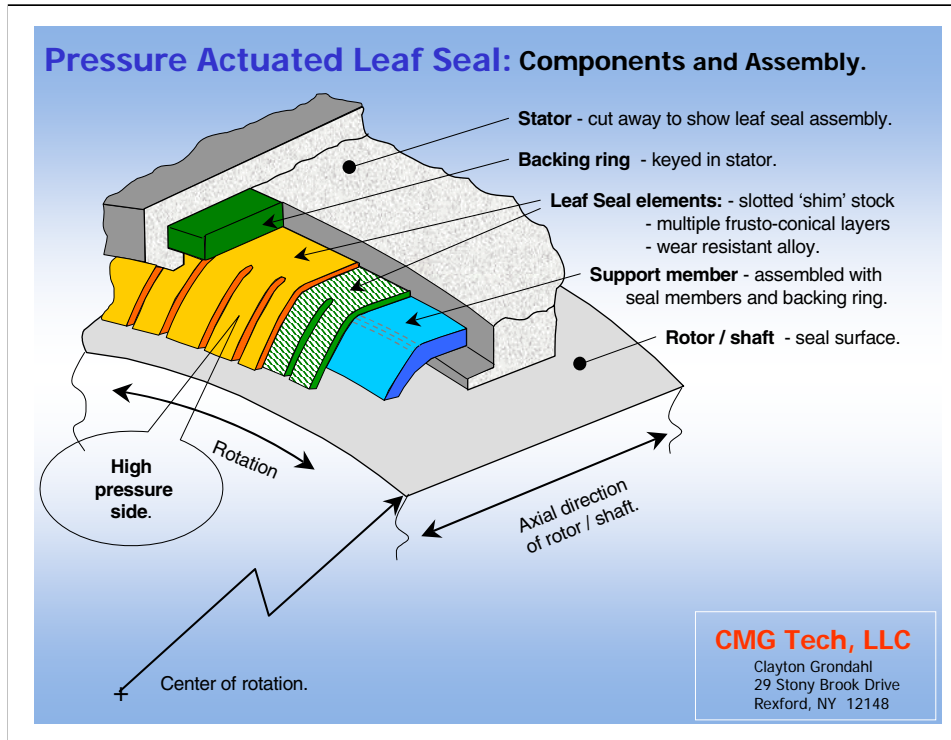
**2005 NASA Seal/Secondary Air System Workshop
November 8-9, 2005**

**AIAA-2005-3985 with update evaluation
of bimetal leaf material to improve rub tolerance.**

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990707-N-6483G-001 ABOARD USS CONSTELLATION (July 7, 1999)– Lieutenant Ron Candiloro, assigned to Fighter Squadron One Five One (VF-151), breaks the sound barrier in an F/A-18 "Hornet". VF-151 is currently deployed with the USS Constellation (CV 64) battlegroup. U.S. Navy photo by Ensign John Gay. [RELEASED]

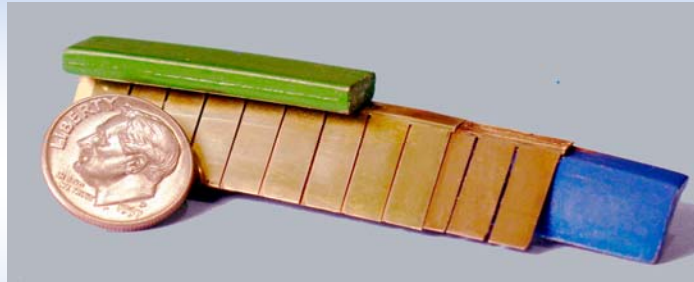
This presentation introduces a shaft seal in which leaf seal elements are constructed from slotted shim material formed and layered into a frusto-conical assembly. Limited elastic deflection of seal leaves with increasing system pressure close large startup clearance to a small, non-contacting, steady state running clearance. At shutdown seal elements resiliently retract as differential seal pressure diminishes. Large seal clearance during startup and shutdown provides a mechanism for rub avoidance. Minimum operating clearance improves performance and non-contacting operation promises long seal life. Design features of this seal, sample calculations at differential pressures up to 2400 psid and benefit comparison with brush and labyrinth seals is documented in paper, AIAA-2005-3985, presented at the Advanced Seal Technology session of the Joint Propulsion Conference in Tucson this past July. In this presentation use of bimetallic leaf material will be discussed. Frictional heating of bimetallic leaf seals during a seal rub can relieve the rub condition to some extent with a change in seal shape. Improved leaf seal rub tolerance is expected with bimetallic material.



Pressure actuated leaf seal features are patented per US 6644667 or Patent Pending per publication US 2004/0150165.

Leaf Seal assembly contains as few as 4 components.

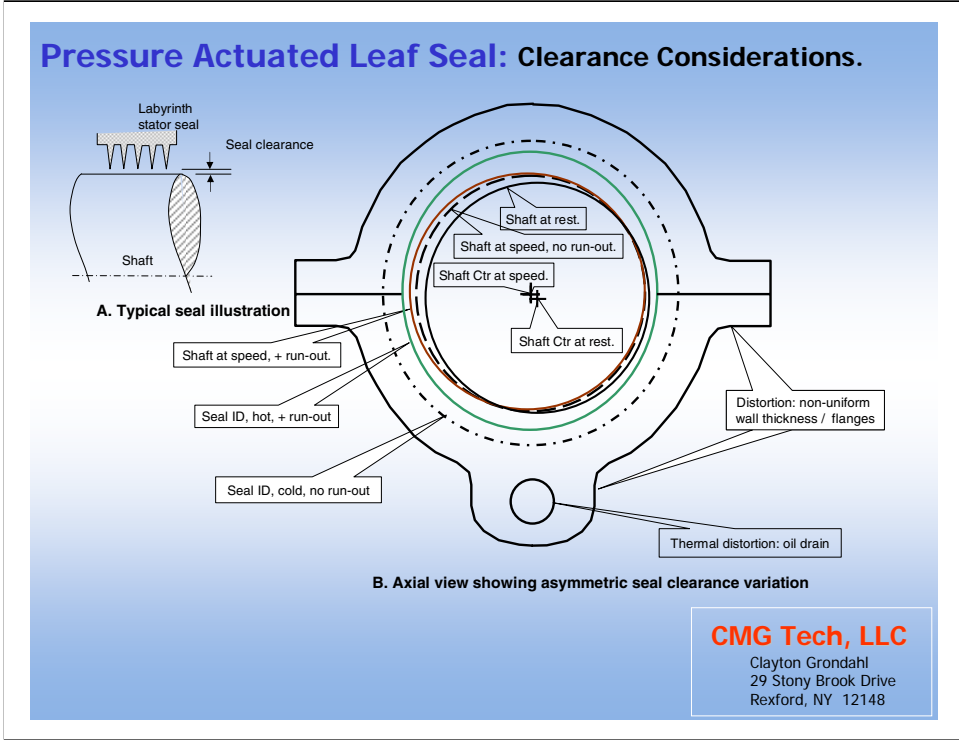
Pressure Actuated Leaf Seal: Full Size Model Photo.



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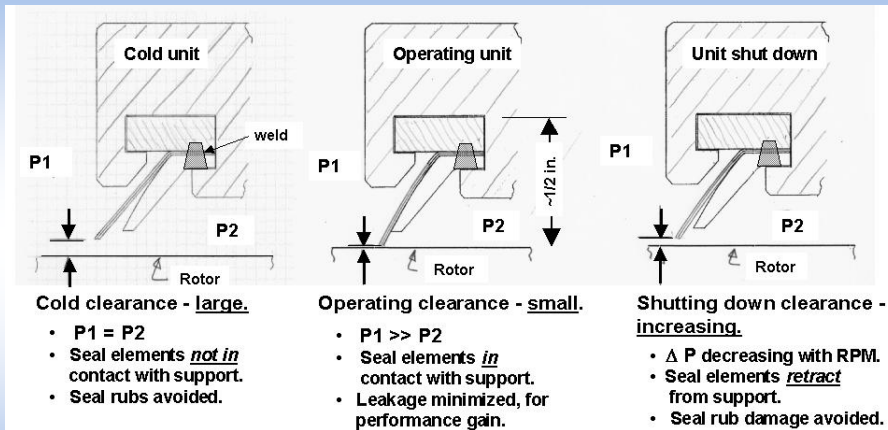
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Leaf seal radial height and axial length is small, of the order of 0.5 inches as shown.



Turbo machinery seal clearances are neither static or uniform. Hence the need for a robust resilient seal.

Pressure Actuated Leaf Seal: Functional Characteristics.



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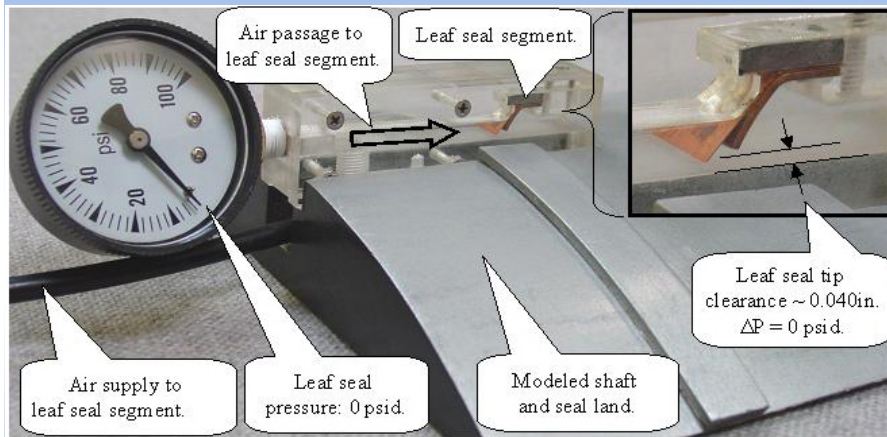
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A radius on the high pressure side of the support member facilitates flexure of the frusto-conical leaf seal members toward the shaft as pressure is applied.

Large seal clearance at startup and shutdown minimizes seal rub hazard during these most vulnerable periods.

Small seal clearance at normal operating conditions provides performance benefits.

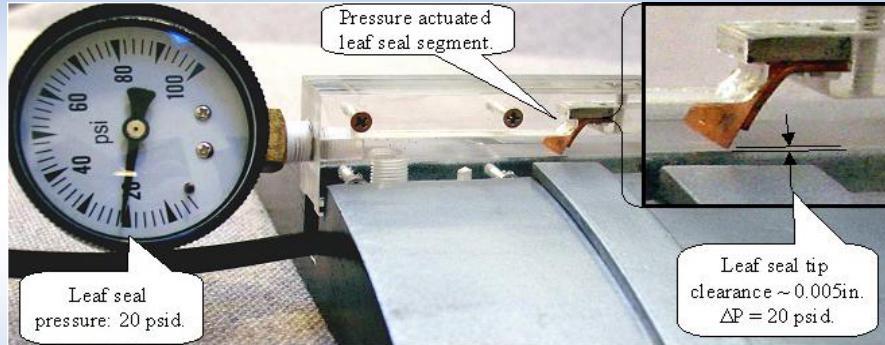
Pressure Actuated Leaf Seal: Functional Model - Static.



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Static model shows large clearance under leaf tip without differential seal pressure.

Pressure Actuated Leaf Seal: Pressure Actuated.



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Pressurized model shows small clearance under leaf tip with differential seal pressure applied.

Pressure Actuated Leaf Seal: Pressure Actuation Demo.

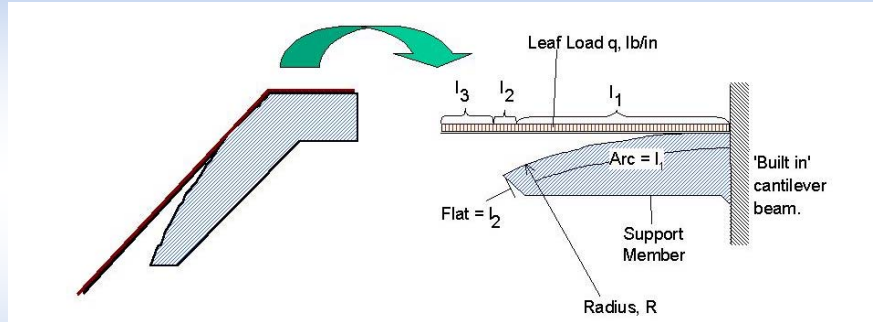


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Video shows action of the previous 2 slides.

Pressure Actuated Leaf Seal: Leaf Seal Analysis Orientation.

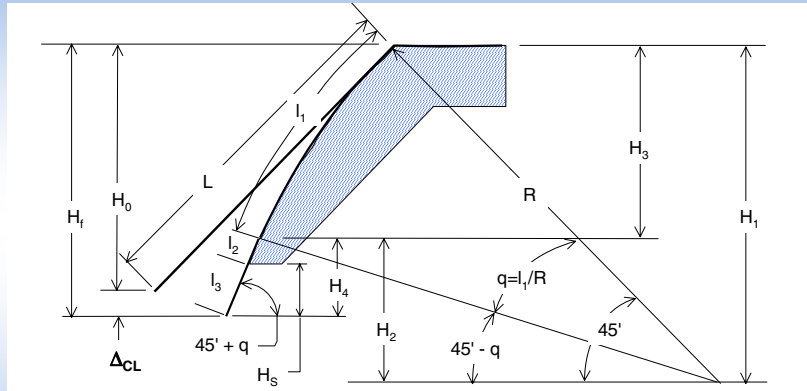


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Preliminary stress analysis and leaf bending has considered leaves as beams in bending.

Pressure Actuated Leaf Seal: Geometry Change Calculations.



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Change in clearance is calculated from geometry shown.

Pressure Actuated Leaf Seal: Preliminary Design Analysis.

Seal Pressure, psid.		Seal Variables, inches.						Δ Seal Clearance and Geometry, inches.				Bending Stress, psi.	
Seal Operating ΔP	Engagement ΔP	Support Radius	Leaf Thickness	Arc Length	Flat Length	Unsupported Leaf Length	# Leaves	Δ Seal Clearance	Seal Angle	Support Height	Unsupported Leaf Deflection	Unsupported Leaves	Leaves Over Radius R.
40	20	2.00	0.010	0.43	0.08	0.12	2	0.056	57.2	0.101	0.000	8640	77747
150	50	2.20	0.014	0.43	0.08	0.12	2	0.051	56.1	0.100	0.000	16531	98951
600	150	2.50	0.016	0.43	0.08	0.12	4	0.045	54.7	0.098	0.001	25313	99516
2400	200	2.50	0.016	0.43	0.08	0.12	6	0.045	54.7	0.098	0.003	67500	99516




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A large range of differential seal pressure capability is tabulated here using various leaf thickness, support radius, and number of leaves. Acceptable leaf stress is shown in applications up to 2400 psi differential seal pressure.

In all cases, substantial seal closure of ~0.05in is shown to be possible.

Pressure Actuated Leaf Seal: Benefit Comparison - Rub Avoidance.

	Rub Avoidance
Labyrinth Seals	
Brush Seals	
Pressure Actuated Leaf Seal	

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Pressure Actuated Leaf Seal: Benefit Comparison - Rub Tolerance.

	Rub Avoidance	Rub Tolerance
Labyrinth Seals	↓	↓
Brush Seals	↓	↑
Pressure Actuated Leaf Seal	↑	TBD

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Pressure Actuated Leaf Seal: Benefit Comparison - Seal Life.

	Rub Avoidance	Rub Tolerance	Seal Life
Labyrinth Seals	↓	↓	↑ w/o rub
Brush Seals	↓	↑	↓ improving
Pressure Actuated Leaf Seal	↑	TBD	↑

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Pressure Actuated Leaf Seal: Benefit Comparison - Low Leakage.

	Rub Avoidance	Rub Tolerance	Seal Life	Low Leakage
Labyrinth Seals	↓	↓	↑ w/o rub	↓
Brush Seals	↓	↑	↓ improving	↑
Pressure Actuated Leaf Seal	↑	TBD	↑	↑

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**Pressure Actuated Leaf Seal: Benefit Comparison -
Hi ΔP , > 300psid.**

	Rub Avoidance	Rub Tolerance	Seal Life	Low Leakage	Hi DP >300psid
Labyrinth Seals	↓	↓	↑ w/o rub	↓	↑
Brush Seals	↓	↑	↓ improving	↑	↓
Pressure Actuated Leaf Seal	↑	TBD	↑	↑	↑

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Pressure Actuated Leaf Seal: Benefit Comparison - Reverse Rotation.

	Rub Avoidance	Rub Tolerance	Seal Life	Low Leakage	Hi DP >300psid	Reverse Rotation
Labyrinth Seals	↓	↓	↑ w/o rub	↓	↑	↑
Brush Seals	↓	↑	↓ improving	↑	↓	↓
Pressure Actuated Leaf Seal	↑	TBD	↑	↑	↑	↑

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Pressure Actuated Leaf Seal: Benefit Comparison - Seal Length.

	Rub Avoidance	Rub Tolerance	Seal Life	Low Leakage	Hi DP >300psid	Reverse Rotation	Seal Length
Labyrinth Seals	↓	↓	↑ w/o rub	↓	↑	↑	↓
Brush Seals	↓	↑	↓ improving	↑	↓	↓	↑
Pressure Actuated Leaf Seal	↑	TBD	↑	↑	↑	↑	↑

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Pressure Actuated Leaf Seal: Benefit Comparison - Summary.

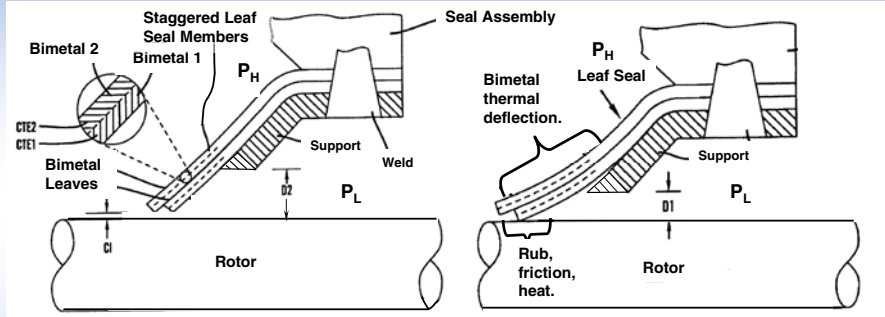
	Rub Avoidance	Rub Tolerance	Seal Life	Low Leakage	Hi DP >300psid	Reverse Rotation	Seal Length	Cost to Manufacture
Labyrinth Seals	↓	↓	↑ w/o rub	↓	↑	↑	↓	↑
Brush Seals	↓	↑	↓ improving	↑	↓	↓	↑	↓
Pressure Actuated Leaf Seal	↑	TBD	↑	↑	↑	↑	↑	↑

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Pressure Actuated Leaf Seal benefits, compared to both labyrinth seals and brush seals, shows a strong basis for development.

Bimetal Leaf Seal Material: Enhanced Rub Tolerance.



Bimetal Leaf Seal - normal operation:

- Seal Pressure delta $P = P_H - P_L$
- Non-contacting seal clearance, C_1
- Bimetal expansion: $CTE1 > CTE2$

Bimetal Leaf Seal - transient rub:

- $D1 < D2$,
- => Frictional heating of bimetal leaves,
- => Thermal response lifts leaves from rotor,
- => Reduced rub force and seal wear.

Bimetal leaf seal material is 'Patent Pending' in
Patent Application Publication US 2004/0150165.

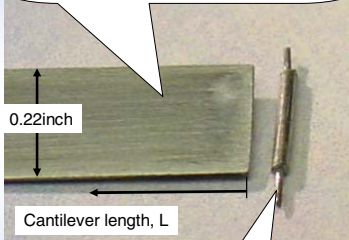
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Leaf seal rub tolerance may be enhanced by use of bimetallic leaf material as illustrated.

Bimetal Leaf Seal Material: Experimental evaluation.

- 0.01in thick 'leaf'
- E5 thermostat material by Engineered Materials Solutions, Inc.

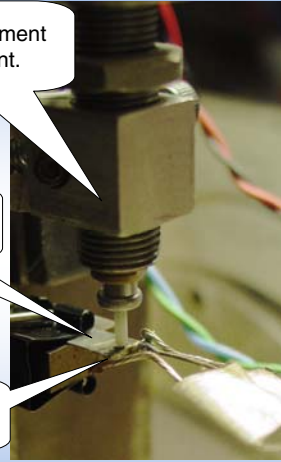


Coaxial ni-chrome heater brazed to leaf for testing.

LVDT displacement measurement.

Cantilever leaf clamped to base .

Heater and TC brazed to leaf tip .



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A selected bimetal leaf material was tested to show concept feasibility.

**PRESSURE ACTUATED LEAF SEALS FOR
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Three good reasons:

Large startup & shut down clearance: → **Rub avoidance.**

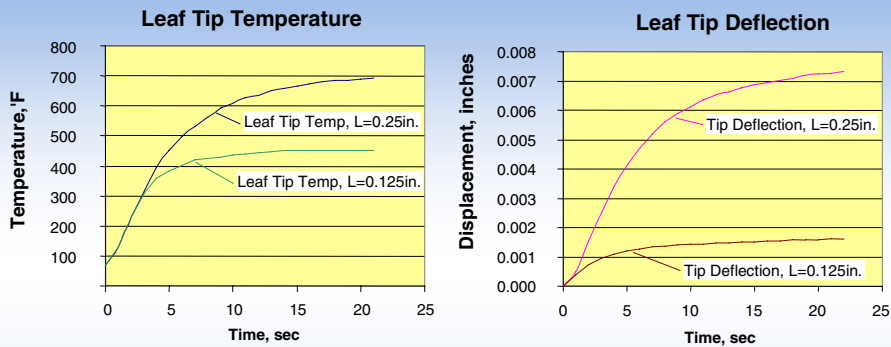
Minimum operating clearance: → **Performance gain.**

Non-contacting operation: → **Long seal life.**

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There appears to be an adequate rationale for the development of the Pressure Actuated Leaf Seal for a wide range of applications.

Bimetal Leaf Seal Material: Thermal Response Results.



Results show bimetal thermal response of :

- sufficient magnitude, at
- reasonable temperature rise,
- and time interval,

to enhance Leaf Seal rub tolerance.

Notes: 1. Tip temperature and deflection shown are transient response to 6 watts heater power; ~ friction heat into 0.01in leaf at a sea delta P of 60psi.
2. Testing is at ambient temperature and no differential seal pressure applied.

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Test results show that a bimetal leaf of proximate seal geometry can respond rapidly to a change in tip temperature and deflect several mils. In a seal application movement away from a moving component could relieve friction heating during a transient rub.