Turbine Seal Research at NASA GRC

Presented by

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Turbomachinery Seal Development Objectives

- Evaluate feasibility of advanced seal concepts and materials of meeting next generation engine speed and temperature requirements.

- Develop seal design and analysis methods.

- Provide a state-of-the-art turbomachinery seal test rig capable of testing seals under known and anticipated design conditions.

- Work with industry to assess and demonstrate performance of their seals prior to test in engine.

Overall Goals for Turbomachinery Seals

- What do we want?
  - Long-Life, Low-Leakage, Low-cost Seals
  - Experimentally validated design and analysis tools

- What do we hope to gain?

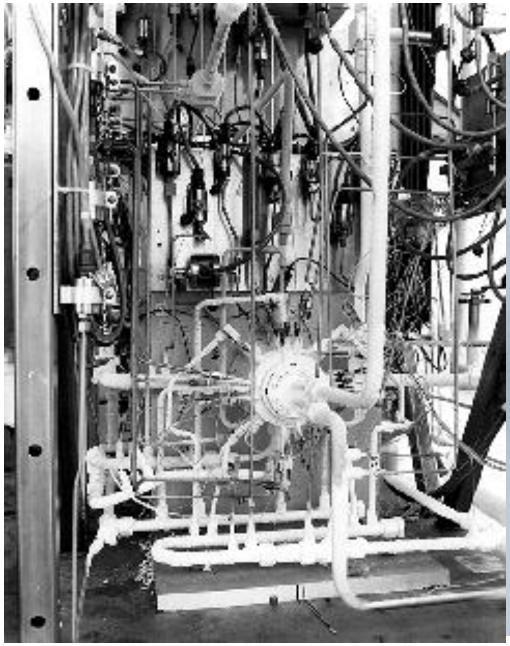
  Aeronautics
  - 2% reduction in specific fuel consumption (SFC) and 0.5 % reduction in direct operating costs (DOC) for gas turbine engines.

  Space
  - Increased payload capability by reduced propellant and interpropellant flows for liquid propellant rocket engines for space applications.

Key Accomplishments: Turbomachinery Seals for Space

NASA GRC Pioneered Using Brush Seals in LH2

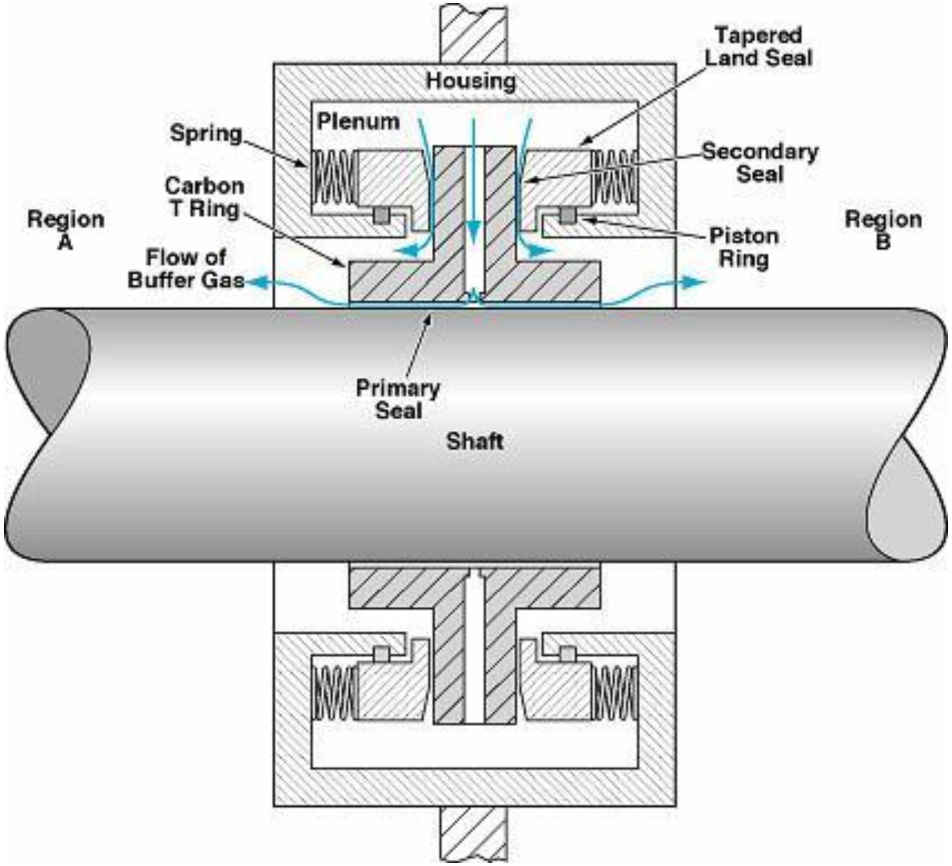
- Demonstrated their low leakage and wear characteristics in LH_2.
- As a result, Rocketdyne is using brush seals in their RS-68 engine for Delta-4.



Delta-4 Rocket flight readiness firing. Photo: Thom Baur/Boeing

Helium Buffer Seal Design Reduces Leakage

- Designed using Space Shuttle Main Engine requirements.
- Experimentally demonstrated leakage performance could increase the Shuttle payload by 1000 lbs.
- Design available, but not incorporated into SSME.



Designed & tested by Wilbur Shapiro Associates, Inc. under NASA SBIR Phase I & II contracts.

Scientific and Design Codes Developed

- SCISEAL
  - A computer program for study of fluid dynamic forces in seals.
  - Solves full Navier-Stokes equations in a generalized coordinate system.

- CFD Seal Analysis Industrial Codes

  A suite of codes to model compressible and incompressible fluids in:
  - Spiral groove face and cylindrical seals
  - Cylindrical and face seals with a variety of tapers, pockets, steps, and orifices (hydrodynamic and hydrostatic features)
  - Labyrinth seals

These codes are used by many in the community to design and evaluate advanced seals.

Codes are available through the GRC Software Repository and Open Channel Software

Key Accomplishments:
Turbomachinery Seals for Aeronautics

Pressure-Balanced, Low Hysteresis Finger Seal

- AlliedSignal developed low-hysteresis finger seal for turbine application under GRC Advance Subsonic Transport project.
- Low cost photo-etching process demonstrated.
- Pressure balanced design demonstrated very low hysteresis in repeated testing in NASA GRC’s seal rig.
- Leakage 20-70% less than typical four-knife labyrinth seal (0.005 inch clearance).

Extensive analytical work and rig testing resulted in decision to test the finger seal in the AS900 engine.

High-Temperature, High-Speed Turbine Seal Rig

Torque-meter housing

Balance piston housing

Turbine

Bypass line

Test section

Seal exhaust line

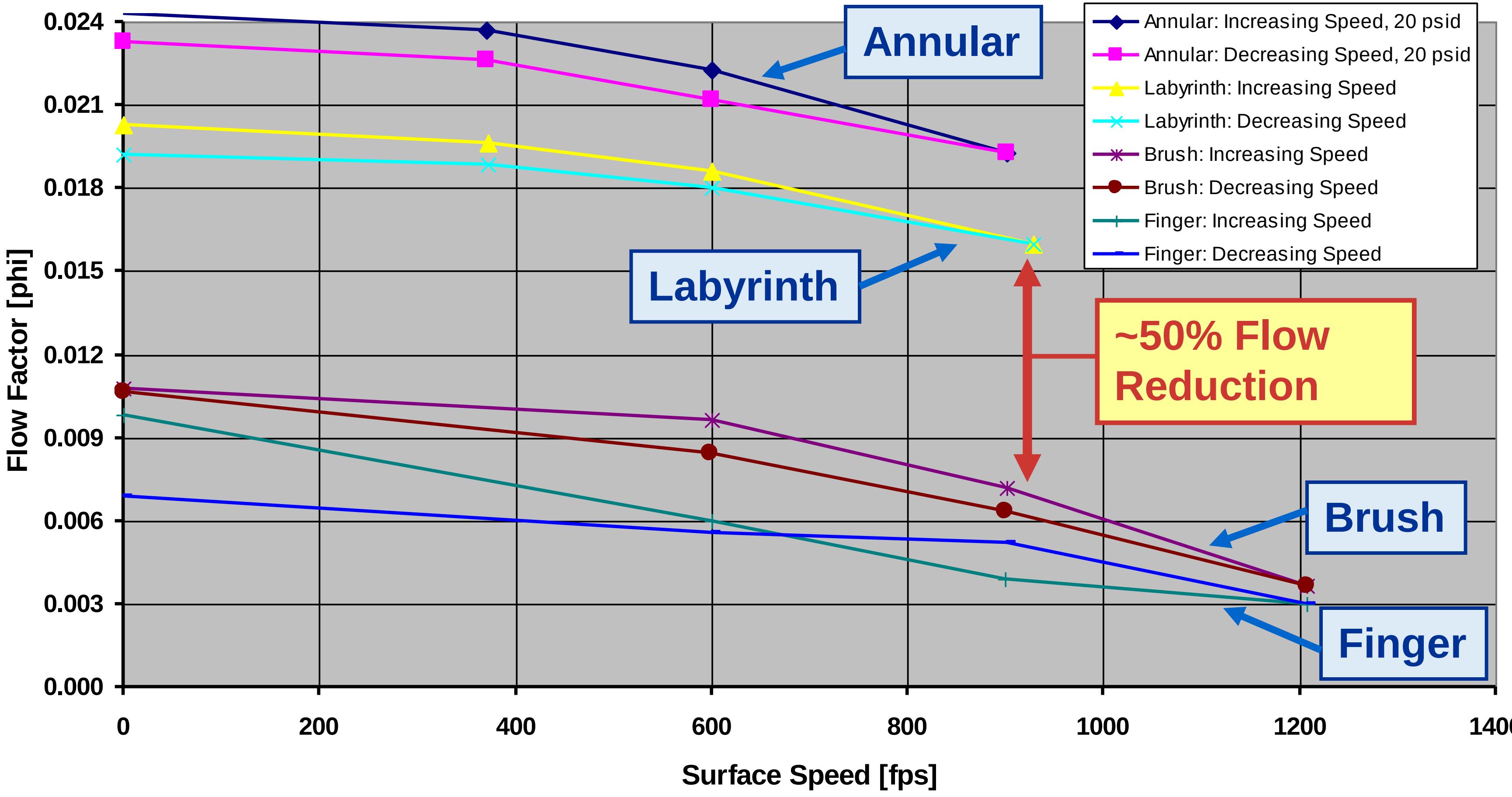
Seal supply line

High Temperature Turbomachinery Seal Test Rig

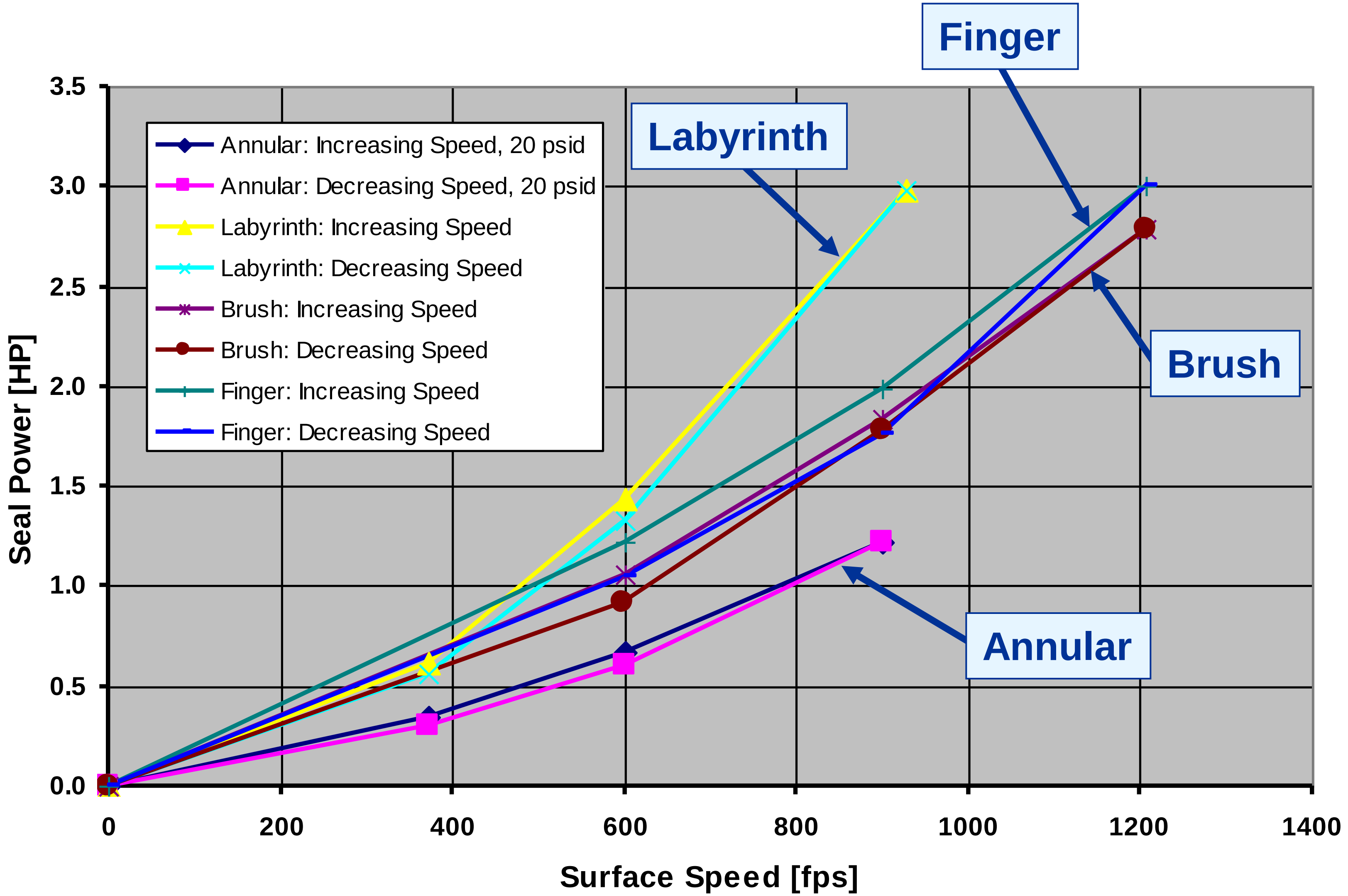
- Test rig is designed to test at speeds and temperatures envisioned for next generation commercial and military turbine engines.
- Test rig is one-of-a-kind. More capable than any known test rig in existence at either engine manufacturers or seal vendors.

• Temperature	Ambient to 1500°F
• Surface speed	0 to 1500 ft/s
• Seal diameter	8.5” design; other near sizes possible
• Seal types	Air seals: brush, finger, labyrinth, film riding rim seals
• Seal pressure	250 psig maximum
	(Temporarily limited to 125 psig.)
• Motor drive	60 hp (60,000 rpm) Barbour Stockwell Air Turbine with advanced digital control for high accuracy/control

Results - Seal Air Leakage at 1200 ºF, 40 psid



Results –Seal Power at 1200 ºF, 40 psid



Current Turbomachinery Seals Research

Turbine Shaft Seals: Challenges and Goals

- Challenges:
  - Minimize leakage to reduce fuel consumption and emissions
  - High temperatures up to 1500°F
  - High speeds up to 1500 ft/s
  - Moderate pressure 250 psid
  - Operate with little or no wear for long life 3-10,000 hrs
  - Minimize heat generation

- GRC Non-Contacting Seal Project Goal:
  - Develop non-contacting seal designs and design methods to enable low-leakage and virtually zero wear:
    - Demonstrate hydrodynamic and/or hydrostatic lift geometries.
    - Demonstrate seals under engine simulated operating conditions
    - Transfer technology to private sector

Low Leakage, Non-Contacting Brush/Finger Turbine Seals

- Fundamental Aeronautics Subsonic Fixed Wing Task

- Key Handoffs targeted:
  1. Low leakage, non-contacting finger or brush seal with
     - Leakage half that of SOA labyrinth seals
     - Durability 2x greater than contacting brush or finger seals at subsonic engine conditions.
  2. Experimentally validated design and analysis tools and methodologies for low leakage non-contacting brush or finger seals.

NASA GRC Non-Contacting Finger Seal Design

Basic Features

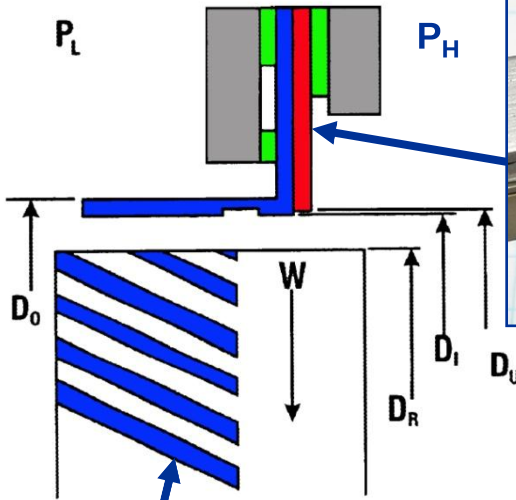
- Downstream: Lift pads on downstream fingers allows tracking of rotor motion.
- Upstream: Fingers block flow between downstream fingers and move with downstream fingers. Clearance between fingers and rotor prevent wear.

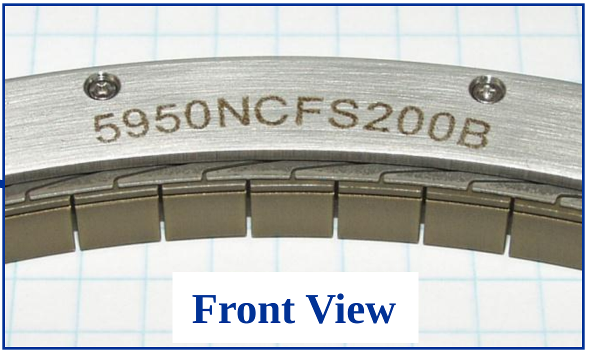
Additional Features

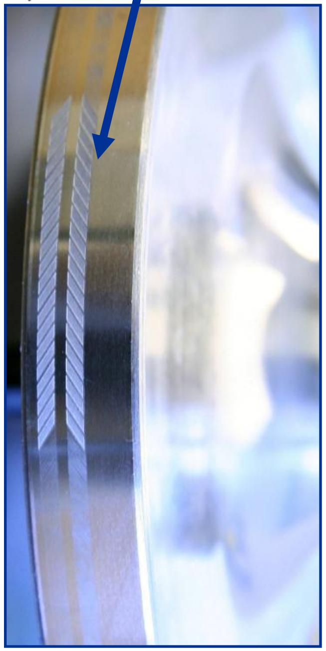
- Herringbone pattern on rotor increases pressure build-up underneath seal pads for additional lift-off during disk rotation – if required.
- EDM processing technique shows feasibility of applying herringbone lift-geometry on test rotor.

Performance

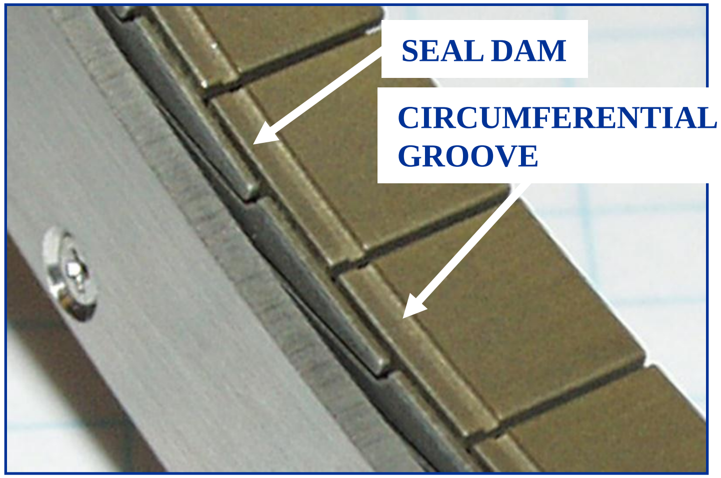
- Small pad-to-shaft clearances promotes low leakage.
- Non-contacting operation promotes long-life.







View of Low Pressure Lift Pad



US Patent No.: 6,811,154

Low Leakage, Non-Contacting Brush/Finger Turbine Seals

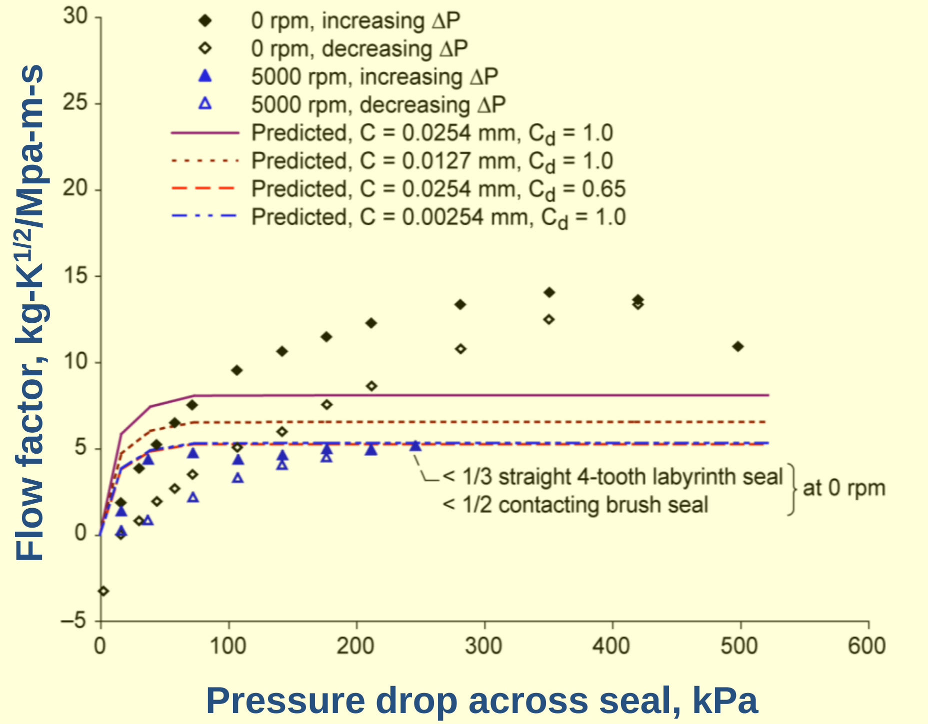
Accomplishments:

•Completed static tests of baseline non-contacting finger seal at 294, 533, and 700 K. Flow factor, Φ, ≤ 15.4 kg-$K^{1/2}$/MPa-m-s at ΔP ≤ 276 MPa.

•Conducted initial performance tests at 5000 rpm and demonstrated seal lift-off.

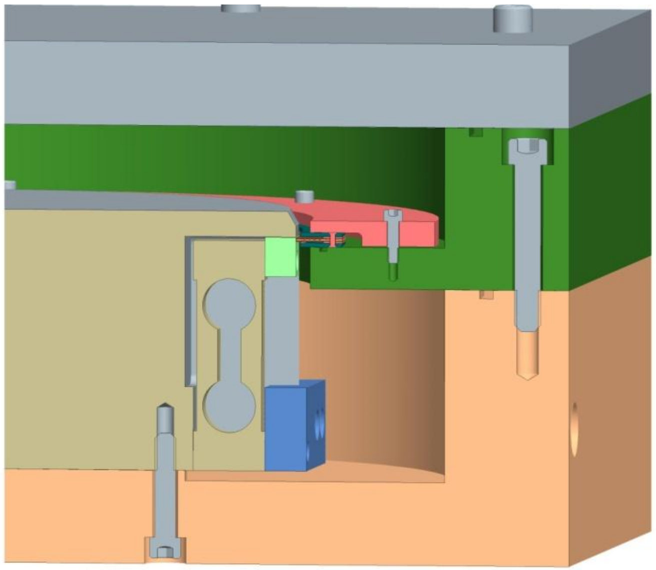
•Version 1 spreadsheet leakage rate predictions are in good agreement with measured leakage when flow is choked.

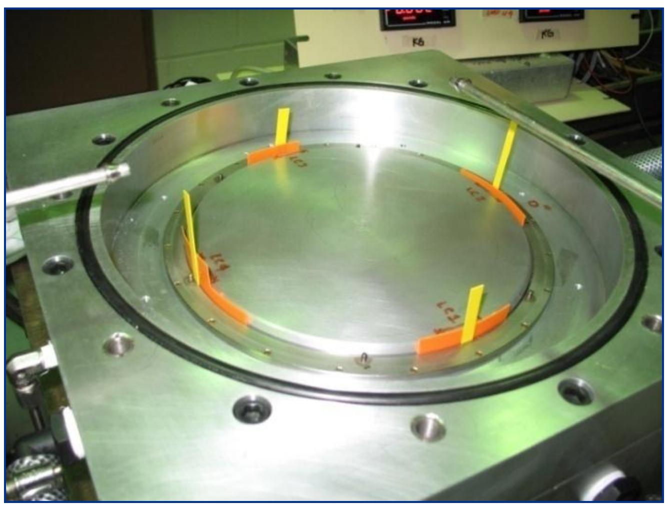
Second Spin Test Leakage Performance at 300 K



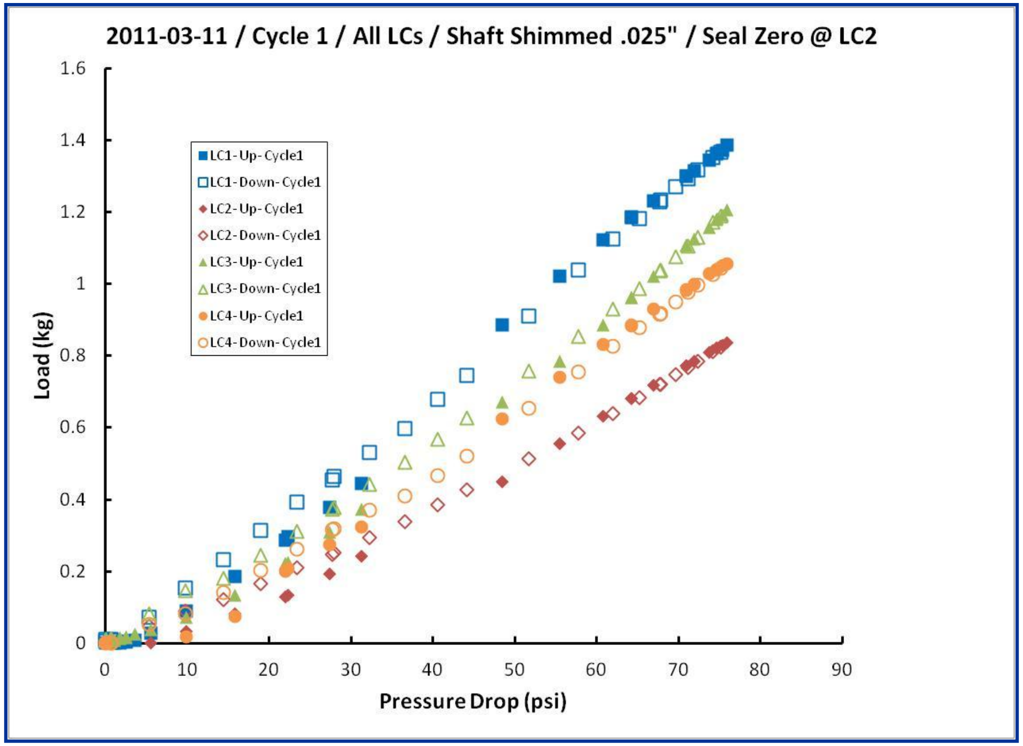
"Preliminary Test Results of a Non-Contacting Finger Seal on a Herringbone-Grooved Rotor," by Margaret P. Proctor and Irebert R. Delgado presented at the 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference in Hartford, CT, July 21-23, 2008 and at the 2008 NASA Seal/Secondary Air Systems Research Symposium Nov. 18, 2008. NASA TM-2008-215475, AIAA-2008-4506.

Pressure Closing Force Measurement





- A finger seal was tested.
- Data from finger seal test will be used to validate portion of design tool for non-contacting finger seals.

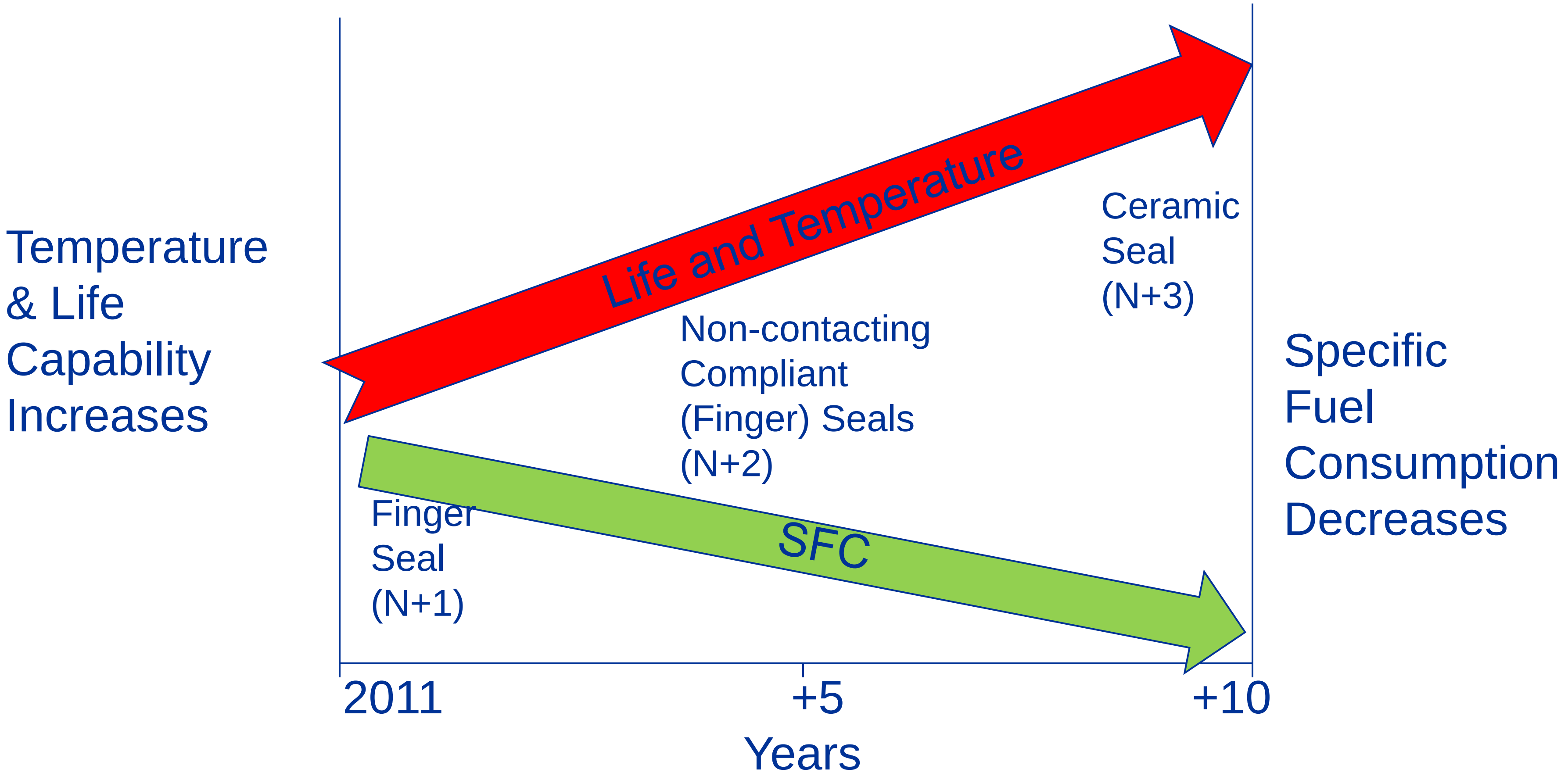


Hybrid Advanced Low Leakage (HALO) Seal Tested For Advanced Technologies Group

- Full-cost reimbursable SAA
- Hybrid Advanced Low Leakage (HALO) Seal tested in the High Temperature Turbine Seal Test rig at NASA GRC Dec. 2008.
- Ambient & Hot performance tests at operating conditions of the T-700 compressor discharge seal.
- Non-contacting operation achieved.
- 10 hours of hot rotational testing accumulated without contact or wear.

HALO Seal's compliant hydrostatic design prevents contact with the rotor. Design intent is to achieve the low leakage of a brush seal without degradation and wear.

NASA GRC Turbine Seals Research Roadmap



- Dynamic modeling and computing life-cycle fatigue
- Design guides & tools & CFD and structural modeling

Past and Potential Collaborations with Industry & Academia

- Past Collaborations:
  - AlliedSignal: Brush, Finger, Non-contacting Finger seal testing
  - Honeywell: Finger seal testing
  - Mohawk Innovative Technologies, Inc: Foil Seal SBIRs and testing
  - R&D Dynamics Corporation: Foil Face Seal Phase I SBIR
  - Arora Consulting: Hydrostatic Floating Pad & Finger Seal designs & tests
  - University of Akron: Non-contacting Finger Seals

- Current Collaborations:
  - Advanced Technologies Group: Testing of Hybrid Brush Seal (Reimbursable SAA)

Future Collaborations with industry & academia for mutual benefit are desired.

Summary

- Low-leakage, long-life turbomachinery seals are important to both Space and Aeronautics Missions.
    - **Increased payload capability**
    - **Decreased specific fuel consumption and emissions**
    - **Decreased direct operating costs**

- NASA GRC has a history of significant accomplishments and collaboration with industry and academia in seals research.

- NASA's unique, state-of-the-art High Temperature, High Speed Turbine Seal Test Facility is an asset to the U.S. Engine / Seal Community.

- Current focus is on developing experimentally validated compliant, non-contacting, high temperature seal designs, analysis, and design methodologies to enable commercialization.