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?

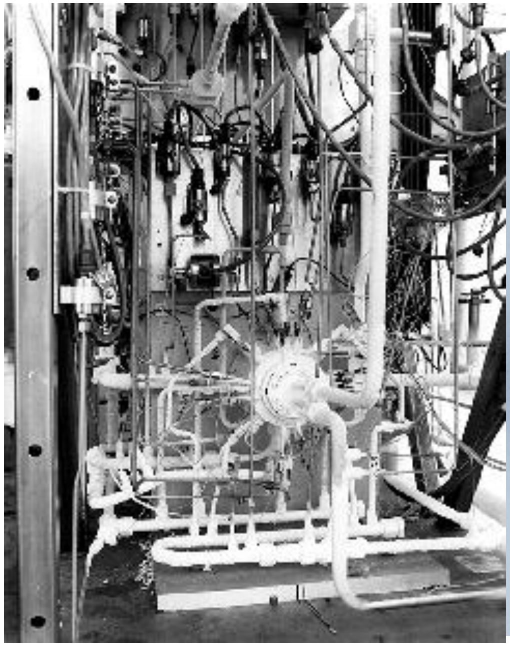
  Aeronautics
  - 2% reduction in specific fuel consumption (SFC) and 0.5 % reduction in direct operating costs (DOC) for gas turbine engines.

  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

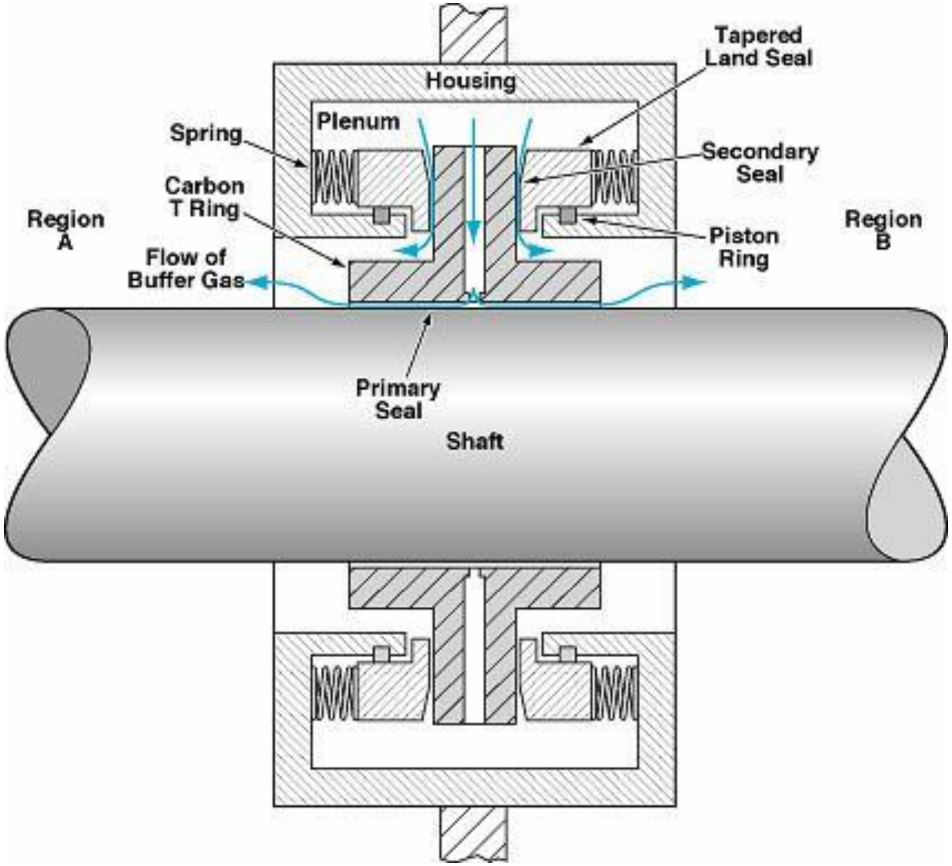
- Demonstrated their low leakage and wear characteristics in LH_2.
- As a result, Rocketdyne is using brush seals in their RS-68 engine for Delta-4.



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

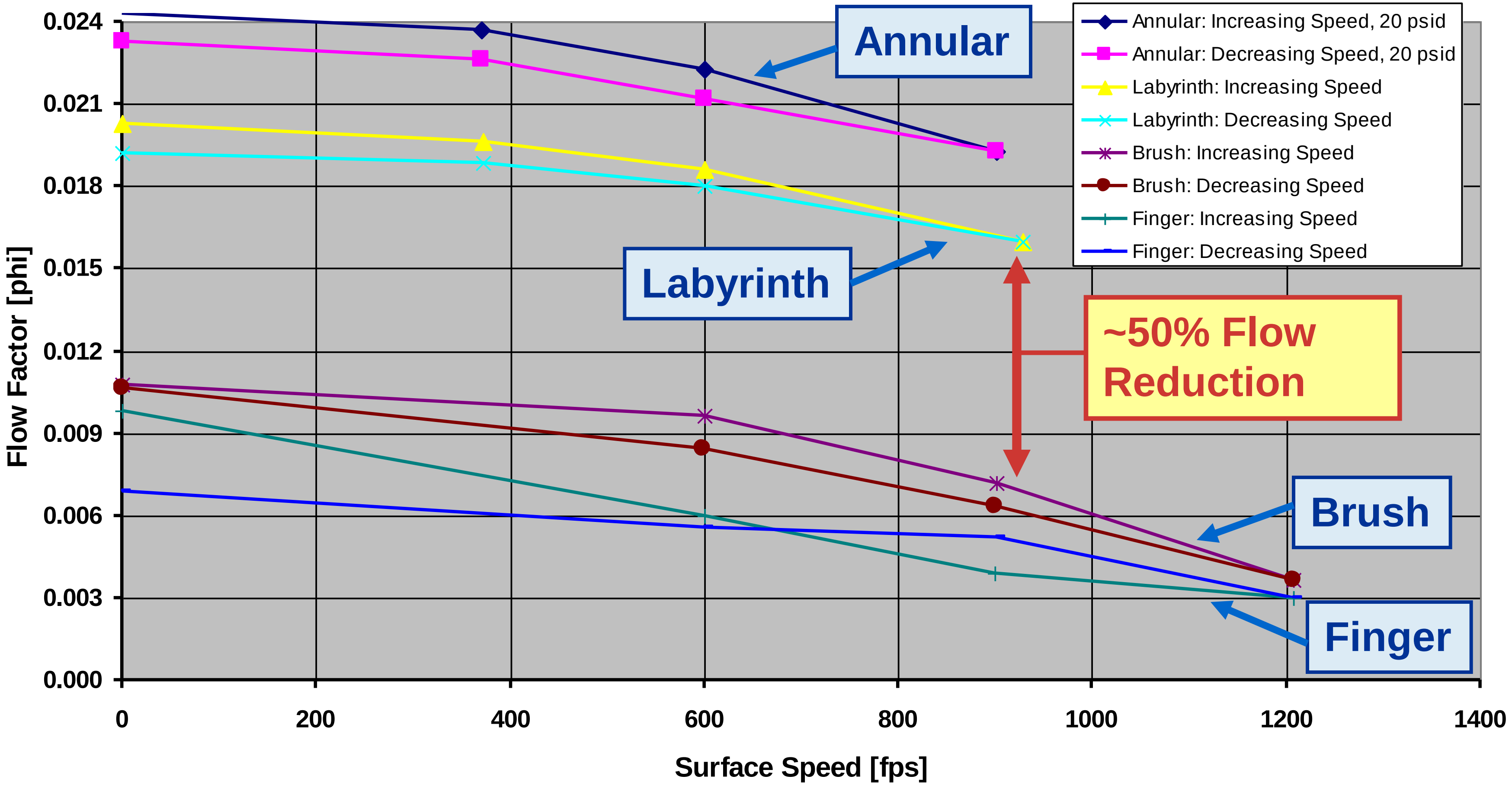
Seal supply line

High Temperature Turbomachinery Seal Test Rig

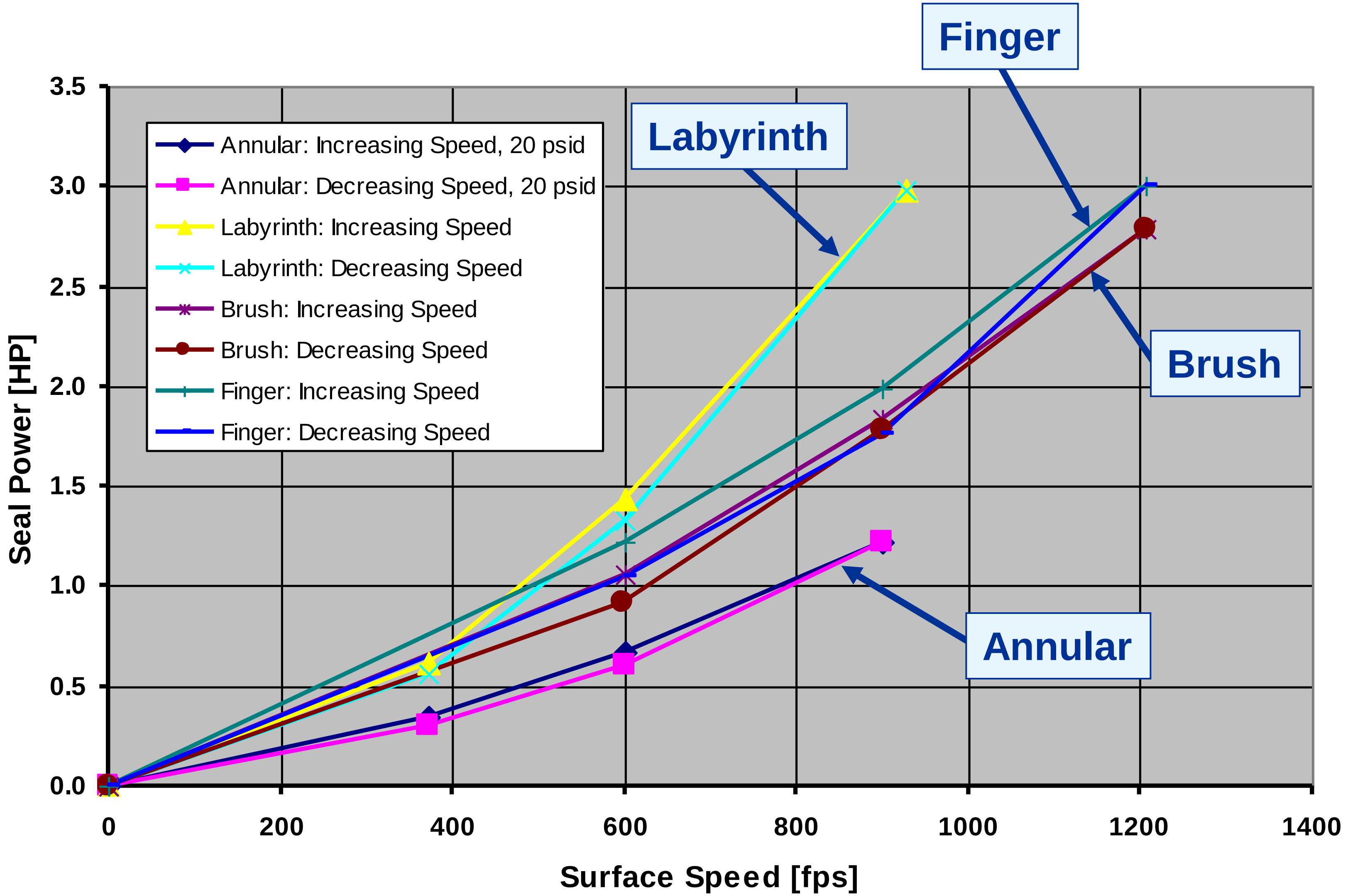
- Test rig is designed to test at speeds and temperatures envisioned for next generation commercial and military turbine engines.
- Test rig is one-of-a-kind. More capable than any known test rig in existence at either engine manufacturers or seal vendors.

• 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

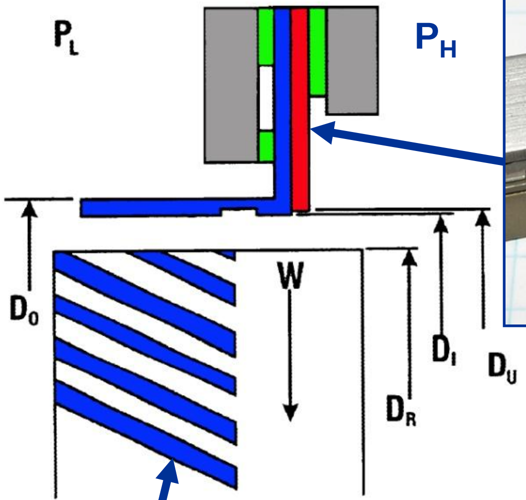
- **Downstream: Lift pads on downstream fingers allows tracking of rotor motion.**
- **Upstream: Fingers block flow between downstream fingers and move with downstream fingers. Clearance between fingers and rotor prevent wear.**

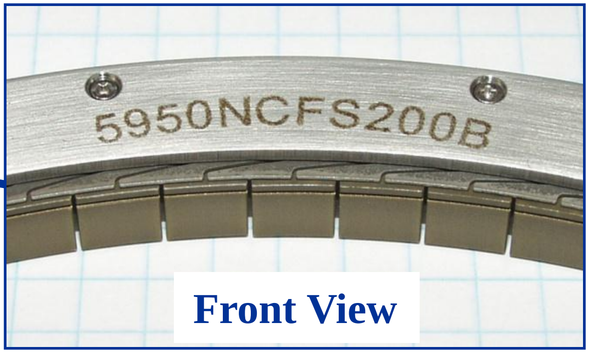
Additional Features

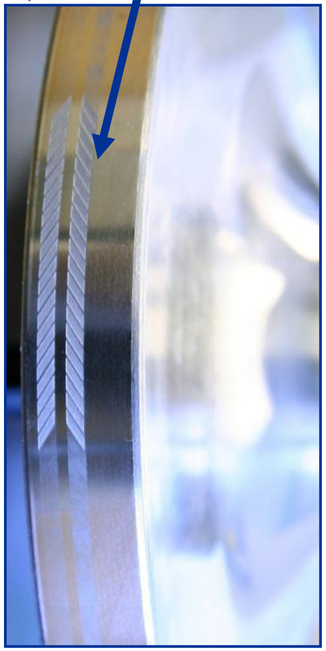
- **Herringbone pattern on rotor increases pressure build-up underneath seal pads for additional lift-off during disk rotation – if required.**
- **EDM processing technique shows feasibility of applying herringbone lift-geometry on test rotor.**

Performance

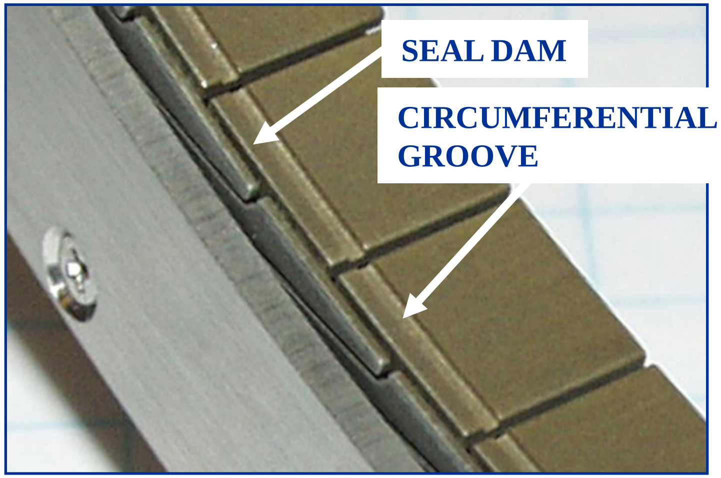
- **Small pad-to-shaft clearances promotes low leakage.**
- **Non-contacting operation promotes long-life.**







View of Low Pressure Lift Pad



US Patent No.: 6,811,154

Low Leakage, Non-Contacting Brush/Finger Turbine Seals

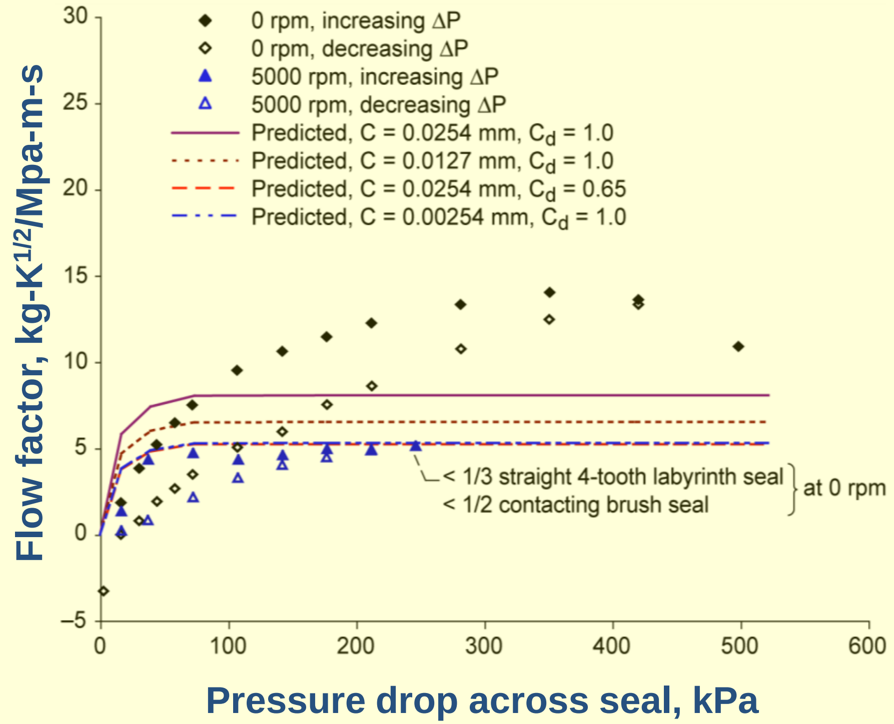
Accomplishments:

•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.

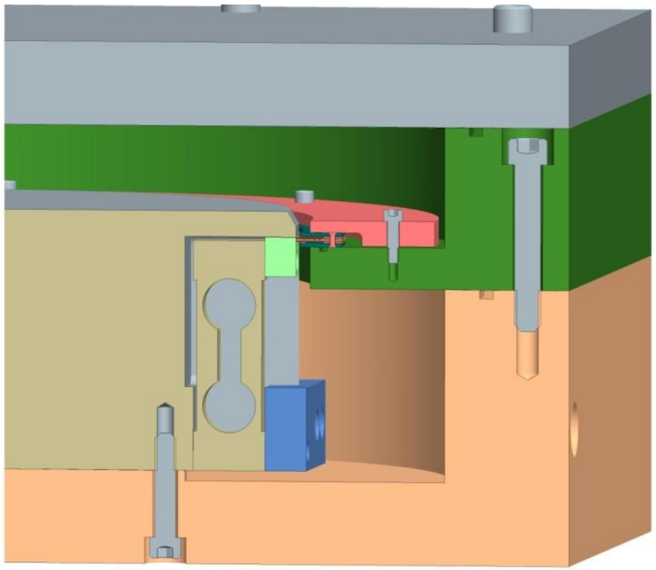
Second Spin Test Leakage Performance at 300 K

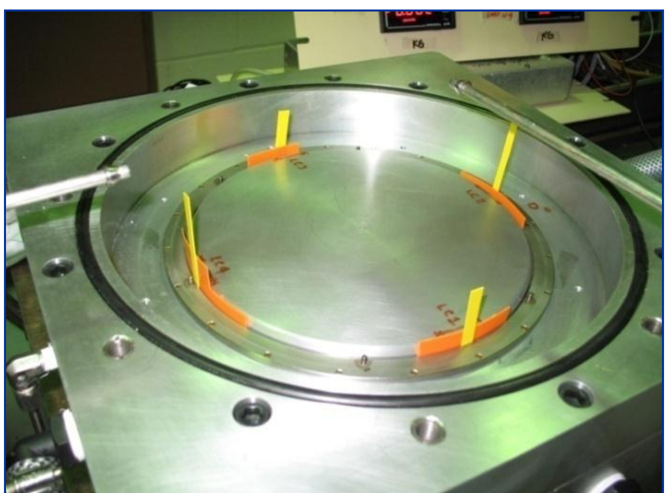


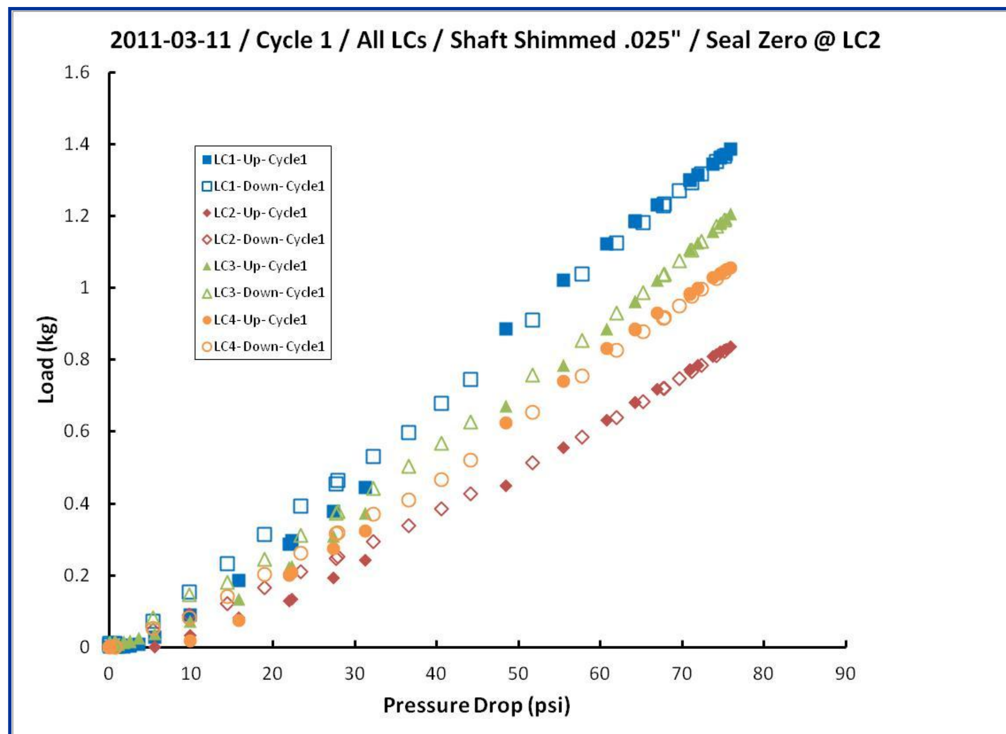
"Preliminary Test Results of a Non-Contacting Finger Seal on a Herringbone-Grooved Rotor," by Margaret P. Proctor and Irebert R. Delgado presented at the 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference in Hartford, CT, July 21-23, 2008 and at the 2008 NASA Seal/Secondary Air Systems Research Symposium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

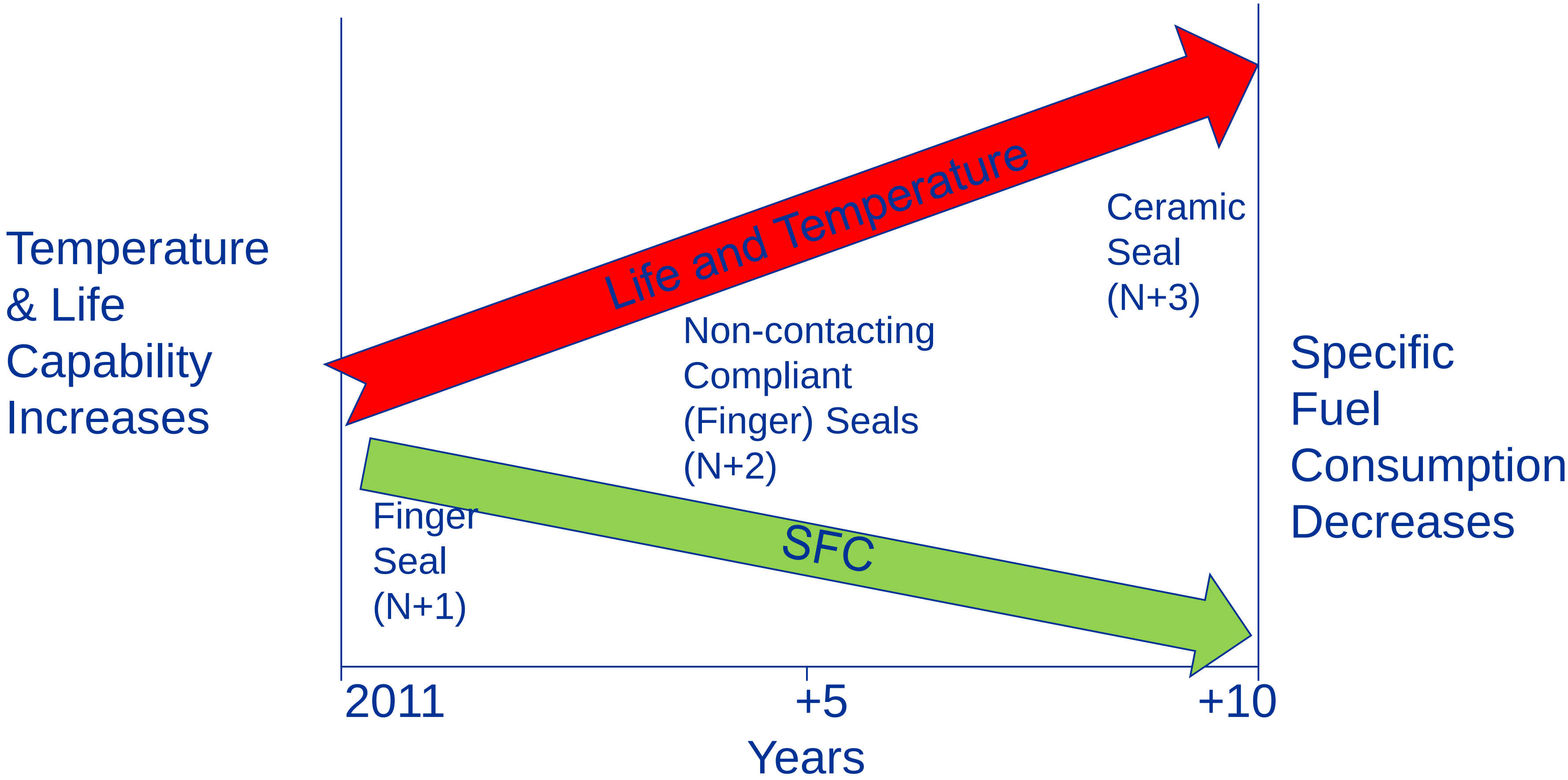
- Ambient & Hot performance tests at operating conditions of the T-700 compressor discharge seal.

- 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, <u>high temperature</u> seal designs, analysis, and design methodologies to enable commercialization.