

OVERVIEW OF NASA GLENN SEAL PROJECT

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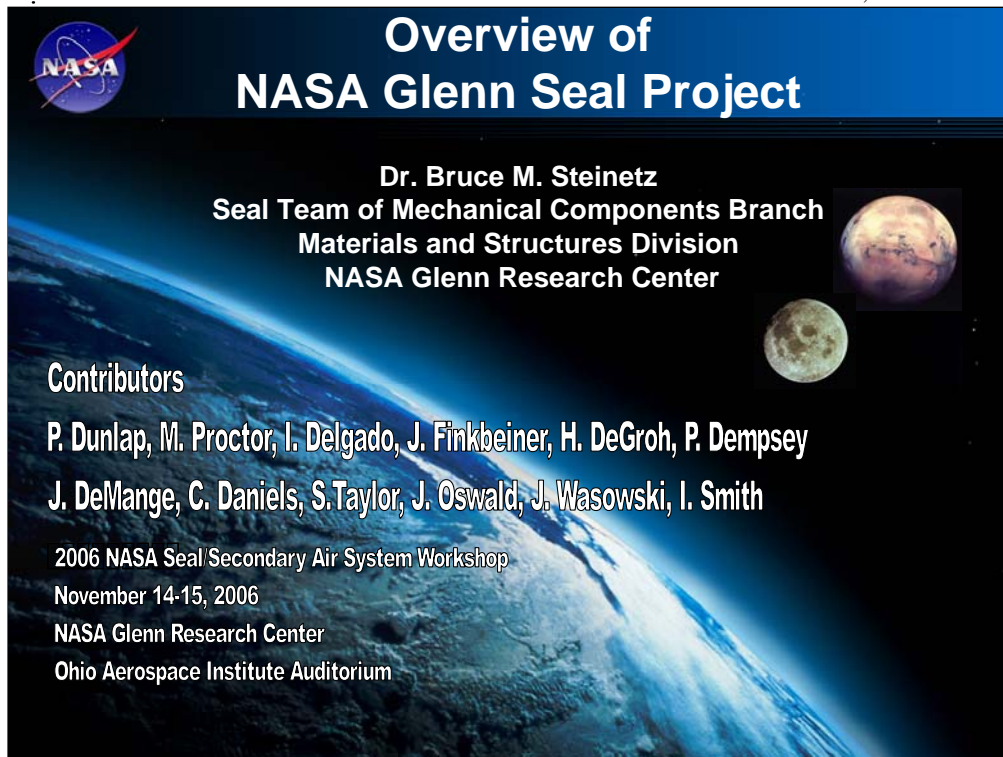
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The slide features a blue header with the NASA logo and the title "Overview of NASA Glenn Seal Project". Below the header, the text identifies Dr. Bruce M. Steinetz as the lead of the Seal Team of Mechanical Components Branch in the Materials and Structures Division at NASA Glenn Research Center. A list of contributors is provided, including P. Dunlap, M. Proctor, I. Delgado, J. Finkbeiner, H. DeGroh, P. Dempsey, J. DeMange, C. Daniels, S. Taylor, J. Oswald, J. Wasowski, and I. Smith. The event details are listed as the 2006 NASA Seal/Secondary Air System Workshop, held from November 14-15, 2006, at the NASA Glenn Research Center, Ohio Aerospace Institute Auditorium. The background of the slide is a composite image showing the Earth's horizon from space, with the Moon and Mars visible in the dark sky.

NASA Glenn hosted the Seals/Secondary Air System Workshop on November 14-15, 2006. At this workshop NASA and our industry and university partners shared their respective seal technology developments. We use these workshops as a technical forum to exchange recent advancements and “lessons-learned” in advancing seal technology and solving problems of common interest. As in the past we are publishing the presentations from this workshop in two volumes. Volume I will be publicly available and individual papers will be made available on-line through the web page address listed at the end of this presentation. Volume II will be restricted as Sensitive But Unclassified (SBU) under International Traffic and Arms Regulations (ITAR).

Workshop Agenda

Tuesday, Nov. 14, Morning

Registration

8:00 a.m.–8:30 a.m.

Introductions

Introduction
Welcome

8:30-8:50

Dr. Bruce Steinetz, R. Hendricks/NASA GRC
Dr. Tony Strazisar, Chief Scientist/NASA GRC

Program Overviews and Requirements

Vision for Space Exploration
Overview of the NASA Aeronautics Program
Overview of NASA Glenn Seal Project
Perspective on Alternative Energy Sources

8:50-10:40

Mr. Bryan Smith, H. Cikanek/NASA GRC
Ms. Anita Liang/NASA GRC
Dr. Bruce Steinetz/NASA GRC
Mr. Robert Hendricks/NASA GRC

Break

10:40 -10:55

Turbine Seal Development Session I

Benefits of Improved HP Turbine Active Clearance Control

High Temperature Investigations into an
Active Turbine Blade Tip Clearance Control Concept

Microwave Blade Tip Sensor Development: An Update

10:55-12:00

Mr. Ken Seitzer, W. Sak, R. Ruiz,
B. Albers/GE Aviation
Mr. Shawn Taylor/Univ of Toledo,
B. Steinetz/NASA GRC
J. Oswald/J&J Technical Solutions
Mr. Jon Geisheimer/Radatech Inc.

Lunch: OAI Sun Room

12:15-1:15



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The first day of presentations included overviews of current NASA programs. Mr. Smith reviewed the goals and objectives of NASA's new Exploration Initiative targeting both robotic and manned missions to the Moon, Mars and beyond. Ms. Anita Liang reviewed project plans and objectives of the Fundamental Aeronautics Project aimed at developing technologies for rotorcraft, sub-sonic fixed wing, supersonic and hypersonic systems.

Dr. Steinetz presented an overview of NASA seal developments for both NASA's aeronautic and space projects. Mr. Hendricks presented a call-to-action for the community to address the sobering fact that the world is consuming greater oil resources than it is discovering. Though improved sealing technology can play a role in reducing fuel burn by improving engine efficiency, there is a need to start addressing alternate energy sources to help ward-off a future energy crisis.

Turbine engine studies have shown that reducing high pressure turbine (HPT) blade tip clearances will reduce fuel burn, lower emissions, retain exhaust gas temperature margin and increase range. Mr. Seitzer presented an overview of GE's current work in developing improved turbine active clearance control concepts. Mr. Taylor presented an overview of the new Active Clearance Control Test rig aimed at demonstrating advanced ACC kinematic systems, actuators, control methods, and sensors. Mr. Taylor presented recent leakage and clearance control data collected using the test rig at temperatures up to ~1200°F. Mr. Geisheimer of Radatech presented an overview of their microwave blade tip sensor development efforts. Microwave tip sensors show promise of operation in the extreme gas temperatures present in the HPT location.

Workshop Agenda

Tuesday, Nov. 14, Afternoon

Turbine Seal Development Session II

Application of Non-metallic Fiber Brush Seals to Barrier Sealing Applications (*Withdrawn*)
Comparison of Labyrinth, Annular, Brush, and Finger Seal Power Loss and Leakage Characteristics
Large Diameter Non-Contacting Face Seal Development
Brush Seal Design Option Evaluation Results
Forming a Turbomachinery Seals Working Group
An Overview and Discussion

1:15-2:55

Dr. Eric Ruggiero and Mr. Mark Lusted/GE Global Research Center
Mr. Irebert Delgado/U.S. Army Res. Lab, M. Proctor/NASA GRC
Dr. Xiaoqing Zheng, G. Berard /Eaton-Centurion Mechanical Seals
Mr. Chuck Trabert, X. Zheng, J. Duquette
Eaton-Centurion Mechanical Seals
Ms. Margaret Proctor/NASA GRC

Break

2:55-3:10

Turbine Seal Development Session III

Experimental Implementation & Results of Four Types of Non-Contacting Finger Seals.
Force Balance Determination of a Film Riding Seal Using CFD
Robustness of Modeling of Out of Service Gas Mechanical Face Seal
A Rapid Survey of the Compatibility of Selected Seal Materials with Conventional and Semi-Synthetic Jet Fuel

3:10-5:00

Mr. Ian Smith/Analex Corp. and Dr. Minel J. Braun/Univ of Akron
Mr. John Justak/Advanced Technologies Group, Inc
Dr. Itzhak Green/Georgia Institute of Technology
Mr. John Graham, R. Striebich, Univ. of Dayton Research Inst.,
D. Minus, W. Harrison/Propulsion Directorate AFRL

Adjourn

Group Dinner: 100th Bomb Group

6:00-?



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Mr. Delgado provided an update on comparisons he and Ms. Proctor are making for labyrinth, annular, brush, and finger seal power loss and leakage characteristics. Representatives from Eaton presented leakage data of brush seals and early performance assessments of large diameter non-contacting face seal under development. Ms. Proctor presented a status update on an a turbomachinery working group formation. She is evaluating whether such a working group would be beneficial to the community.

Dr. Braun and Ian Smith presented investigations into a non-contacting finger seal under development by NASA GRC and University of Akron. Mr Justak presented CFD work being used to understand the force balance in a film-riding H-seal assessing fluid dynamic effects on gap sizes. Dr. Green presented modeling work of seals that have seen actual service conditions where worn face conditions exist. Mr. Graham presented results assessing compatibility of seal materials currently in operation within the Air Force with semi-synthetic jet fuels blended from JP-8 and Fisher-Tropsch fuels, with an aim to reduce dependence on foreign oil supplies.

Workshop Agenda Wednesday, Nov. 15 Morning

Registration at OAI	8:00-8:30
Space Systems Development Future Space Vehicle Docking/Berthing Mechanism and Seal Needs: An Update CEV Project Overview and Seals Challenges Falcon Vehicle Program Objectives and Seal Challenges: An Update Development, Evaluation, and Qualification of Low-Temperature Seal Materials for RSRM Use	8:30-10:00 Mr. Brandon Burns, Mr. J. Lewis, /NASA Johnson Space Center Mr. Matt Parke, Mr. Warren "Hunts" Kretsch/Lockheed-Martin Mr. Brian Zuchowski, V. Bodepudi/Lockheed-Martin Mr. Neal Carter/ATK Thiokol
Break	10:00-10:15
Structural Seal Development Session I Overview of LIDS Docking and Berthing System Seals Space Environments Effects on Candidate LIDS Seal Materials FEA Modeling of Elastomeric Seals for LIDS Overview of CEV Heatshield Interface Seals Development Apollo Seals: Basis for CEV Seal Development	10:15-12:30 Dr. Christopher Daniels/Univ. of Akron, P. Dunlap, H. DeGroh, B. Steinetz/NASA GRC, J. Oswald/J&J Technical Solutions, I. Smith/Analex Corp. Mr. Henry deGroh,/NASA GRC, C. Daniels/Univ. of Akron, P. Dunlap, J. Dever, S. Miller/NASA GRC, D. Waters/ASRC Aerospace Corp, B. Steinetz/NASA GRC Mr. Jay Oswald/J&J Tech. Solutions, C. Daniels/Univ. of Akron Mr. Pat Dunlap, B. Steinetz, J. Finkbeiner/NASA GRC, J. DeMange, S. Taylor/Univ. of Toledo Mr. Josh Finkbeiner, Patrick Dunlap, et al/NASA GRC
Lunch OAI Sun Room	12:30-1:30



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NASA is developing a standardized system for docking and berthing for future exploration system vehicles, including as the Crew Exploration Vehicle (CEV). Mr. Brandon Burns presented the goals and objectives of this Low Impact Docking Systems (LIDS) project, headed by NASA JSC. Dr. Daniels presented an overview of the extensive seal and seal test fixture development underway at NASA Glenn to support the LIDS development project. Mr. DeGroh presented GRC's efforts to characterize the effects of space environments (atomic oxygen, ultraviolet and particle radiation) on LIDS seal performance (compression set, leakage, and adhesion). Mr. Oswald presented GRC's approach of performing structural analyses of elastomer seal loads in a seal-on-seal configuration. He also presented experimentally measured data supporting the hyperelastic constitutive models used to perform the finite element modeling.

DARPA and the Air Force (with support from NASA) are developing a hypersonic payload delivery system that can reach Mach 10 conditions. Mr. Zuchowski presented an overview of project goals and identified extensive vehicle seal challenges. Mr. Neal Carter presented work ATK Thiokol is doing with the seal vendors to reduce the operating temperature capability of Viton O-ring seals to help with cold launch conditions for the Space Shuttle.

Mr. Dunlap presented an overview of the structural seal development activities underway for the Crew Exploration Vehicle heat shield. GRC has been tasked to develop a seal for the heat-shield to command module interface, evaluate its performance under simulated conditions and make a recommendation to the prime contractor, Lockheed-Martin. Mr. Finkbeiner presented an summary of the seal technologies used for the Apollo capsule that serve as good reference points for the CEV seal designs.

Workshop Agenda

Wednesday, Nov. 15, Afternoon

Structural Seal Development Session II

An Update on High Temperature Structural Seal Development at NASA GRC
Development and Evaluation of High Temperature Gaskets for Hypersonic and Reentry Applications
High Temperature Metallic Seal Development: An Update
Survey of Dust Issues for Lunar Seals and the RESOLVE Project

1:30-3:00

Mr. Jeff DeMange/Univ. of Toledo, P. Dunlap, B. Steinetz, F. Ritzert/NASA GRC,
Dr. Jay Singh/OAI, T. Shpargel/ASRC Aerospace/NASA GRC
Dr. Amit Datta/Advanced Components and Materials G. More/Parker Co.
Ms. Margaret Proctor, P. Dempsey/NASA GRC

Tour of NASA Seal Test Facilities

3:15-4:15

Must have NASA/Seal Workshop badge for tour

Adjourn



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Mr. DeMange presented high temperature structural seal development efforts underway at GRC for future hypersonic and re-entry vehicles. Dr. Singh reviewed materials developments for high temperature 1800+F gasket materials. Mr. More and Dr. Datta presented recent progress in developing higher temperature metal seals that incorporate single-crystal blade alloy finger preloaders capable of 1600+°F operation. Ms. Proctor reviewed the key issues seal designers face for lunar seals that must operate in a dusty environment – including a reaction chamber seal for the RESOLVE project.

Outline

- Seal Team Organization and Members
- Turbine Seals
 - Challenges
 - Ongoing GRC Projects
 - » Shaft Seals
 - » Clearance Management
- Space Exploration Seals
 - Ongoing GRC Projects
 - » Docking and Berthing Seals
 - » CEV Heat Shield Interface Seals (see Volume 2)
 - » Surface Operation Seals
- Hypersonic Vehicle Seals
 - Development Goals
 - Challenges



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Seal Team

The presentation is divided into these major discussion areas.

NASA Glenn Seal Team: Turbomachinery Seals

Seal Team Leader: Bruce Steinetz (RX)
Mechanical Components Branch/RXM

Turbomachinery Seals

Shaft Seals

❖ Develop high-speed, high-temperature, non-contacting, low-leakage turbomachinery seals.

P.I./P.O.C.: Margaret Proctor

– Irebert Delgado, Dave Fleming, Joe Flowers

Clearance Management

❖ Develop novel approaches for blade-tip clearance control

Co-P.I.s: Shawn Taylor, Bruce Steinetz

– Jim Smialek, Analex

Analex Engineering Design Staff:

M. Robbie, G. Drlik, A. Erker,
J. Assion, M. Hoychick, T. Mintz

Technician Support:

R. Tashjian, C. Horn, G. Schade, E. Patino,
P. Adams



NASA Glenn Research Center
Seal Team

November 11, 2006

The Turbomachinery Seal Team is divided into two primary areas. The principal investigators and supporting researchers for each of the areas are shown in the Table.

As NASA pursues research in Fundamental Aeronautics, advanced seal development is important. Two key areas that NASA Glenn is contributing to include the following:

- + Non-contacting shaft seals are being developed to reduce leakage enabling lower specific fuel consumption and emissions and increase engine service lives.
- + Novel approaches for clearance management are being pursued to reduce specific fuel consumption and emissions and increase engine service lives. Both active clearance control system and passive “smart” material approaches are being pursued.

NASA Glenn Seal Team: Structural Seals

Seal Team Leader: Bruce Steinetz (RX)
Mechanical Components Branch/RXM

Structural Seals

Docking & Berthing Seals

- ❖ Develop space-rated, low-leakage, long-life docking system seals
- Co-P.I.s: Pat Dunlap, Chris Daniels**
 - Henry DeGroh, Mike Tong, Jay Oswald, Janice Wasowski, Ian Smith, Analex, Other

Re-Entry Vehicle Seals

- ❖ Develop heat-resistant thermal barriers/seals for future re-entry vehicles
- Co-P.I.s: Pat Dunlap, Jeff DeMange**
 - Shawn Taylor, Josh Finkbeiner, Analex, Other

Hypersonic Vehicle Seals

- ❖ Develop heat-resistant thermal barriers/seals for future hypersonic vehicles & propulsion systems.
- Co-P.I.s: Pat Dunlap, Jeff DeMange**
 - Josh Finkbeiner, Frank Ritzert, Shawn Taylor, Analex, Other

Lunar Surface Operation Seals

- ❖ Develop dust-resistant, low-leakage, long-life seal technology for dusty environments.
- Co-P.I.s: Margaret Proctor, Paula Dempsey**

Analex Engineering Design Staff:

M. Robbie, G. Drlik, A. Erker,
J. Assion, M. Hoychick, T. Mintz

Technician

Support:
R. Tashjian, G. Schade,
E. Patino, C. Horn

Other Support:

B. Banks, S. Miller, J. Dever, D. Waters,
J. Singh, T. Shpargel



NASA Glenn Research Center
Seal Team

November 11, 2006

The Structural Seal Team is divided into four primary areas. The principal investigators and supporting researchers for each of the areas are shown in the slide.

As NASA pursues the Vision for Space Exploration, advanced seal development is critical. Four key areas that NASA Glenn is contributing to include the following:

- + Docking and berthing seals are being developed to ensure that vehicles can dock and prevent leakage of limited astronaut cabin pressure air.
- + Re-entry vehicle heat shield and penetration thermal barriers/seals are being pursued to ensure hot plasma re-entry gases do not compromise the function of the thermal protection system.
- + Technology for dust resistant, surface operation seals is being investigated for space suits, airlocks, quick disconnects, robotic experimental payloads and the like. Dust resistant seals exhibiting low-leakage, and long life are essential to ensure long-term mission success.
- + Hypersonic vehicle and propulsion system thermal barriers/seals are being developed to enable future single-stage and two-stage access-to-space options.

**Turbine Engines:
Seal Challenges and Projects Supported**

Turbine Shaft Seals: Challenges and Goals

- Challenges:
 - Minimize leakage to enable: reduced fuel consumption and emissions
 - High temperatures: up to 1500°F
 - High speeds up to 1500 fps
 - Moderate pressure 250 psi
 - 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 under engine simulated operating conditions
 - » Transfer technology to private sector



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Seal Team

Designers of future turbine engine seals face ever increasing challenges (Steinetz and Hendricks, 1998) including high temperature, high speed operation, the need to operate for long lives with little or no wear while minimizing heat generation. One of NASA GRC's turbine engine seal goals is to develop non-contacting seal designs that incorporate hydrostatic and/or hydrodynamic lift geometries. Seals under development will be fabricated and tested in NASA GRC's high temperature, high speed seal rig to assess their performance under engine simulated conditions.

NASA GRC Non-Contacting Finger Seal Design

Basic Features

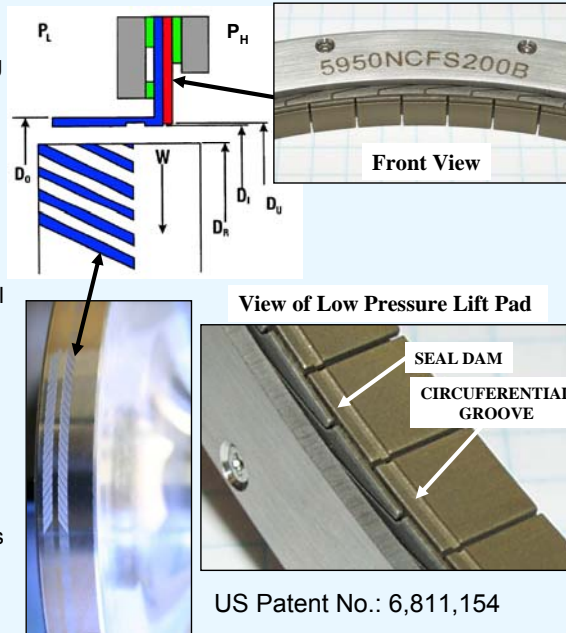
- Downstream: Lift pads on downstream fingers allows tracking of rotor motion
- Upstream: Fingers block flow between downstream fingers and move with downstream fingers. Clearance between fingers and rotor prevent wear.

Additional Features

- Herringbone pattern on rotor enables 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



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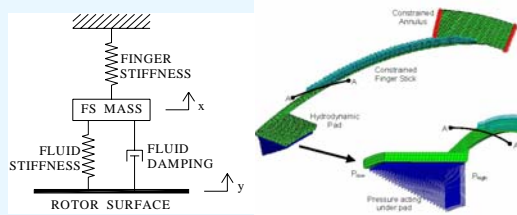
Conventional finger seals like brush seals attain low leakage by operating in running contact with the rotor (Proctor, et al, 2002). The drawbacks of contacting seals include wear over time, heat generation, and power loss.

NASA Glenn has developed several concepts for a non-contacting finger seal. In one of these concepts the rear (low-pressure, downstream) fingers have lift pads (see lower right figure) and the upstream (high pressure side) fingers are pad-less, and are designed to block the flow through the slots of the downstream fingers. The pressure-balance on the downstream-finger lift-pads cause them to lift. The front fingers are designed to ride slightly above the rotor preventing wear. Pressure acts to hold the upstream fingers against the downstream fingers. It is anticipated that the upstream/downstream fingers will move radially as a system in response to shaft transients. Though a small pin-hole leakage path exists between the inner diameter of the upstream fingers, the rotor, and the downstream fingers, this small pin-hole doesn't cause a large flow penalty especially considering the anticipated non-contacting benefits of the overall approach.

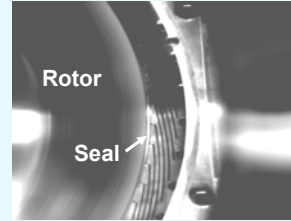
A non-contacting finger seal based on the GRC patent (US Patent No.: 6,811,154) has been fabricated (see upper right figure) and will be tested in GRC's turbine seal test rig. The seal will be tested against a rotor that has a herringbone lift geometry that is fashioned onto the rotor surface using a Electro Discharge Machining process.

Non-Contacting Finger Seal Investigations: University of Akron

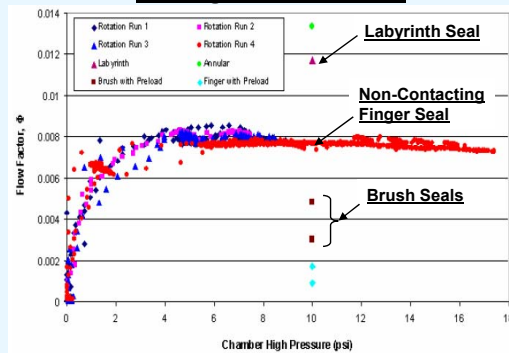
Seal Dynamics & 2-D Solid Modeling



Visualization



Leakage Measurement



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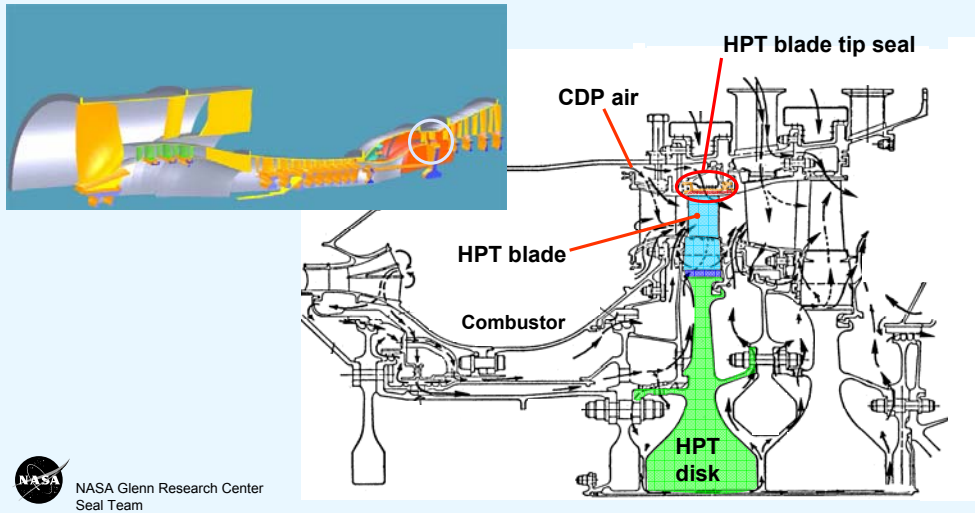
Dr. J. Braun and his team at the University of Akron is performing analyses and tests of this GRC concept through a cooperative agreement (Braun et al, 2003). University researchers developed an equivalent spring-mass-damper system to assess lift characteristics under dynamic excitation. Fluid stiffness and damping properties were obtained utilizing CFD-ACE+ (3-D Navier-Stokes code) and a perturbation approach. These stiffness and damping properties were input into the dynamic model expediting the solution for design purposes. Dr. Braun an expert in advanced visualization techniques has investigated the finger seal lift-off using unique lighting and measurement techniques during seal operation at ambient temperature using the Univ of Akron's test rig. These measurements are providing useful insights into seal operation for design evolution.

More details can be found in Braun et al, 2006 in this Seal Workshop Proceedings. After feasibility tests are complete at the University, seals will be tested under high speed and high temperature conditions at NASA GRC.

Turbine Clearance Management

Turbine Clearance Management Goal

Develop and demonstrate clearance management technologies to improve turbine engine performance, reduce emissions, and increase service life



System studies have shown the benefits of reducing blade tip clearances in modern turbine engines. Minimizing blade tip clearances throughout the engine will contribute materially to meeting NASA's engine efficiency goals. Large SFC and emissions improvements are achievable by improving blade tip clearances in the high pressure turbine.

Motivation for Tip Clearance Control + Challenges

The Problem:

Clearances between the shroud and blade tips vary over the operation and life of an engine. Wear and thermal erosion increases blade tip clearance.

Benefits of Clearance Control:

- Increased engine efficiency & reduced SFC (0.8-1% SFC)
- Reduced NOx & CO emissions
- Delayed rise in exhaust gas temperature (EGT)

ACC System Challenges:

Temperature: Gas path - >2500°F
Cooling air - >1200°F
Case - 600°F (w/ soak back)

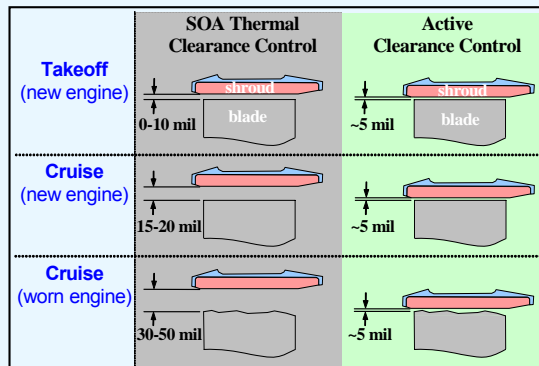
Load/Response: Actuators must react ~2000 lbf
move ~0.05" in 10 sec

Accuracy: Current Systems - 0.015-0.020-in
Goal - <0.005-in

Size/Weight: Small, lightweight ACC systems required
Goal ≤ current thermal systems (<100 lbs).



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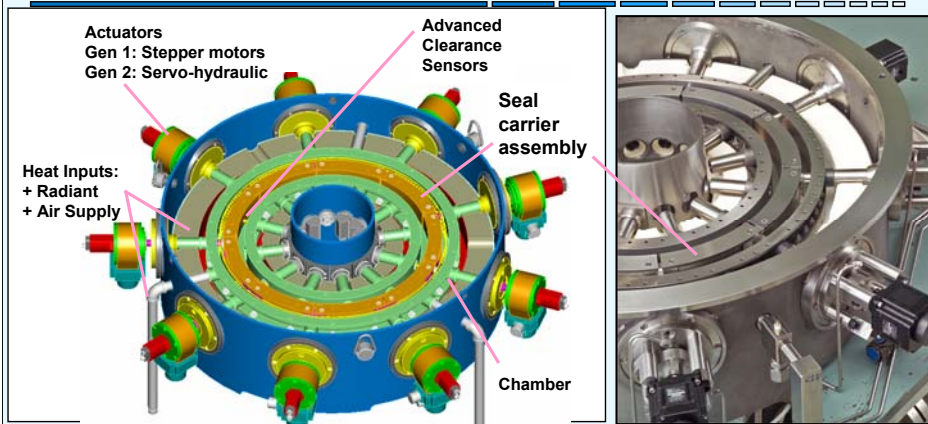


Blade tip clearance directly influences gas turbine performance, efficiency, and life (Lattime and Steinetz, 2002). Reducing air leakage over the blade tips increases turbine efficiency and permits the engine to meet performance and thrust goals with less fuel burn and lower rotor inlet temperatures. Running the turbine at lower temperatures increases the cycle life of hot section components, which in turn, increases engine service life by increasing the time between overhauls.

Lattime and Steinetz [2003], GE [2004], and Wiseman and Guo [2001] provide overviews of the many benefits of advanced active clearance control systems. Some of the more noteworthy benefits of implementing fast mechanical ACC systems in the HPT of a modern high bypass engine are provided herein for completeness. In terms of fuel savings, a tip clearance reduction of 0.010-in. results in ~0.8 to 1 percent decrease in specific fuel consumption. By reducing fuel burn significant reductions in NOx, CO, and CO2 emissions are also possible. Reducing tip clearances by 0.010-in. decreases exhaust gas temperature (EGT) ~10 °C. Deterioration of EGT margin is the primary reason for aircraft engine removal from service. Running the engine at lower operating temperatures can result in increased life of hot section components and extend engine time-on-wing (up to 1000 cycles). Additional benefits include increased payload and mission range capabilities.

There are a number of technical challenges that need to be addressed to fielding an effective active clearance control system, as shown in the chart. Two primary challenges include the high temperature environment and the need for accurate control.

Active Clearance Control Concept & Evaluation Test Rig



Purpose:

- Evaluate ACC kinematic system + actuator response and accuracy under engine simulated thermal (to 1200°F) and pressure (to 120 psi) conditions.
- Evaluate clearance sensor response and accuracy
 - Capacitance & Microwave
- Measure ACC system seal performance (leakage and wear) and identify mitigation strategies.

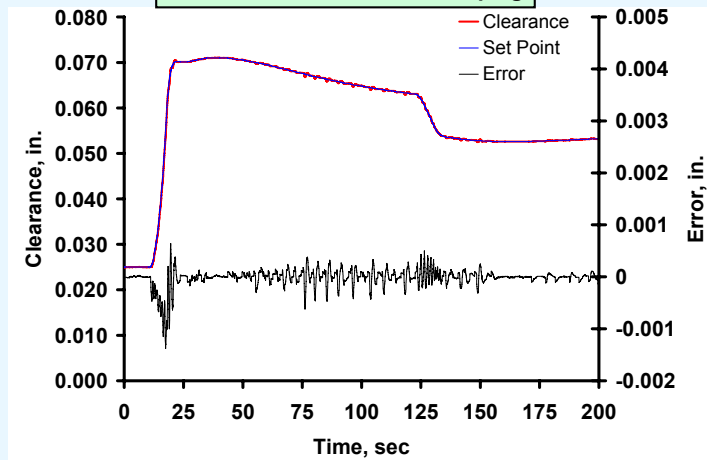
NASA GRC is developing a unique Active Clearance Control (ACC) concept and evaluation test rig. The primary purpose of the test rig is to evaluate ACC kinematic systems, actuator concept response and accuracy under appropriate thermal (to 1200°F) and pressure (up to 120 psig) conditions. Other factors that will be investigated include:

- Actuator stroke, rate, accuracy, and repeatability
- System concentricity and synchronicity
- Component wear
- Secondary seal leakage
- Clearance sensor response and accuracy

The results of this testing will be used to further develop/refine the current system design as well as other advanced actuator concepts. More details regarding this test rig can be found in Taylor, et al 2006 (in this Seal Workshop Proceedings), Taylor et al, 2006, Steinetz et al, 2005, and Lattime et al, 2003.

Simulated Take-off Engine Clearance Transient

Test Conditions: 1180°F, 120 psig



- Hydraulic actuators tracked the set point well at 1180F and full ΔP .
- Maximum lag (~1 mil) occurred during 0.010 in./sec clearance increase.



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The installation of the new servo-hydraulic actuation package onto the ACC test rig enabled the system to easily track a simulated engine clearance profile at the full design pressure differential of 120 psig while at 1180°F. The maximum error observed between the commanded setpoint clearance and the measured control clearance was only 0.0012 in. noted at the start of the profile's 0.010 in./s clearance transient. Error was calculated by subtracting the commanded setpoint clearance from the measured control clearance. This evaluation shows that the ACC concept is capable of tracking an engine clearance transient profile under engine-like temperature and pressure conditions, while maintaining an acceptable level of error. If a commercial controller was implemented in place of the PC based controller used in this laboratory study, the communication lag that exists between the PC and the NI motion controllers would be eliminated. This would likely reduce observed clearance error to less than 0.001 in.

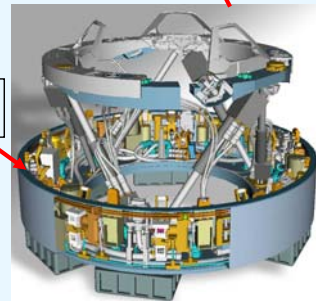
**Exploration Systems:
Seals Challenges and Project Supported
CEV Docking and Berthing System**

Low Impact Docking System (LIDS)

What is the Low Impact Docking System (LIDS)?

System under development by JSC to:

- Provide gender-neutral (androgynous) interface permitting docking/berthing between any two space vehicles
- Reduce impact loads between two mating space craft.
- Become new Agency standard for docking/berthing systems.
- Supports autonomous rendezvous and mating between space vehicles and structures including:
 - Crew Exploration Vehicle (CEV)
 - International Space Station (ISS)
 - Other future exploration vehicles
- Definitions:
 - Docking - vehicle "mates" under its own power
 - Berthing - vehicle "mates" using Remote Manipulating System (RMS)



Interface Seal

LIDS



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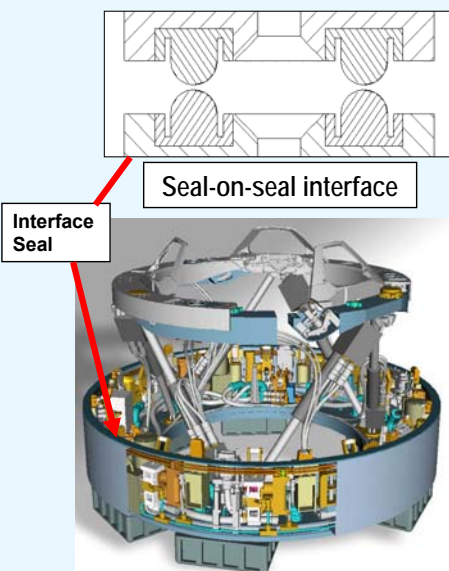
In preparation for the Exploration Initiative, NASA has identified the need for a standard docking and berthing system to allow easy docking between space faring vehicles and platforms orbiting either Earth (e.g. the Space Station) the Moon or Mars. NASA Johnson is developing a Low Impact Docking System (LIDS) that has several important features:

- + The system will be androgynous or gender-neutral permitting docking and berthing between any two space vehicles, giving NASA and the astronauts maximum mission planning flexibility.
- + Using a soft capture system, minimal loads will be imparted between systems minimizing potential for damage.

For additional information regarding the LIDS project and system, see Brandon Burns' presentation in this 2006 Workshop Proceedings.

Advanced Docking and Berthing System: Seal Challenges

- Seal on seal interface for androgynous system
- Extremely high reliability: Man rating
- Size: Large diameters ≥ 54 ", Small Width <1.5 "
- Extremely low leakage rates: 0.01 lb/day
- Temperature: -50°C to $+50^{\circ}\text{C}$ and thermal gradients
- Exhibit low forces: Sealing & Adhesion
- Long mating periods and repeated docking



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A unique seal challenge posed by the androgynous LIDS system is the need for a seal-on-seal interface as shown in the upper inset figure. This seal prevents leakage of cabin pressure while the two vehicles are mated together.

Challenges posed by this new system include:

Extremely high reliability: for man rating

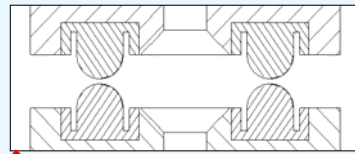
Relative large diameter ≥ 54 "

Extremely low leakage rates: <0.01 lb/day

Temperature: -50°C to $+50^{\circ}\text{C}$ and thermal gradients

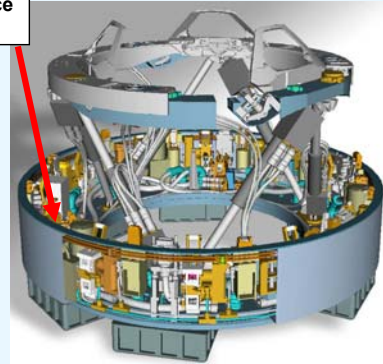
Advanced Docking and Berthing System: Seal Challenges (Cont'd)

- Long term exposure to space environments: Atomic Oxygen (AO); Ultraviolet (UV) radiation, Ionizing Radiation, Seal surface damage
 - Cracking
 - Embrittlement
 - Material loss
 - Loss in strength
 - Reduced deformability
 - Micro-meteoroid/orbital debris (MMOD) damage



Seal-on-seal interface

Interface Seal



MMOD Impact:
Elastomer Target



MMOD Impact:
Stainless Steel Target



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Seal Team

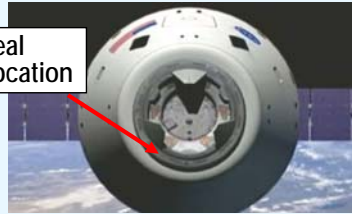
Additional seal challenges posed by this new system include:

Long term exposure to space environments: Atomic Oxygen (AO); Ultraviolet (UV) radiation, Seal surface damage due to micro-meteors and orbital debris (MMOD). The lower images show the results of small 0.5 mm particles impacting silicone rubber and stainless steel targets at hyper-velocities (7.5 km/sec). NASA Glenn is implementing test programs to evaluate the effects of each of these environments on seal performance.

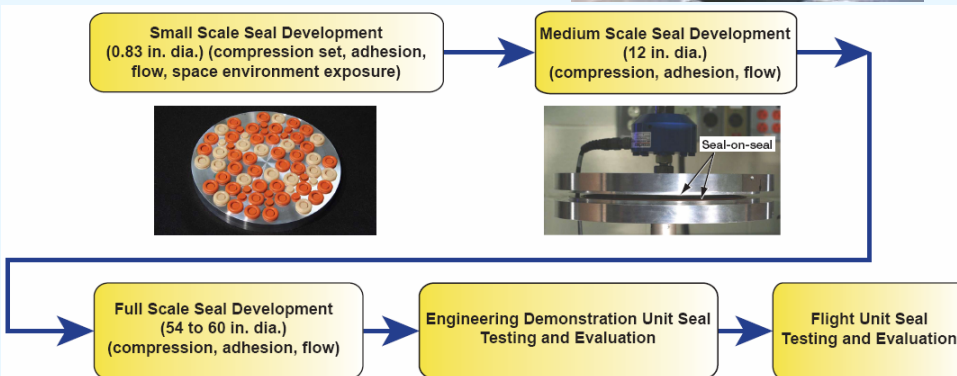
NASA GRC's Support of LIDS Project

Goal: Provide JSC with a seal-on-seal system that meets all performance requirements.

Seal Location



Approach:



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Seal Team

NASA Johnson requested the GRC Seal Team to assist in assessing and developing candidate seal technology for the LIDS system, shown in an artist's rendering of the Crew Exploration Vehicle.

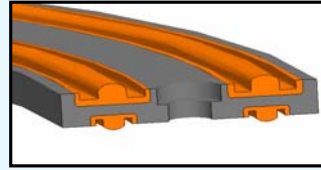
The following elements are planned during the development project:

- + Perform coupon-level and small-scale environmental exposure and flow tests of candidate sub-scale seals
- + Down-select between competing concepts and materials based on requirements
- + Perform full-scale flow tests. Using a new test rig under design, candidate full-scale seals will be subjected to both nominal and off-nominal conditions (e.g. variable gap and offset conditions). The seal's ability to seal under both warm and cold conditions will also be assessed while tested in a seal-on-seal condition.
- + Assess loads: compression, separation
- + Support JSC through flight qualification for CEV and other applications

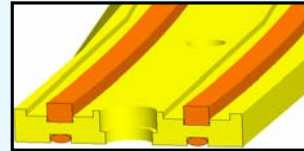
Seal Concepts Under Development/Evaluation

Elastomeric Seals

- **Gask-O Seal**
 - Able to form near-hermetic seal
 - Able to perform under gapping / misalignment conditions
 - Currently flying as static berthing seal on Space Station: Common Berthing Module
 - Concerns:
 - » Long term space exposure
 - » Seal-to-seal adhesion
 - » Examining remedies.
- **Gasket Seal:**
 - Near Term Risk Reduction Unit (RRU) trial seal
 - Using to check-out JSC and GRC test hardware



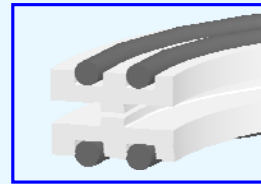
Gasko Seal



Gasket Seal

Metallic Seals

- **Metal Face Seal:**
 - Immune to UV, AO, IR effects
 - No known adhesion issue
 - Concerns:
 - » Very low leakage,
 - » Large diameter, precision flat surfaces



Metallic Face Seal



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Seal Team

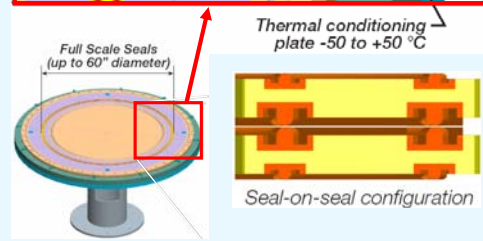
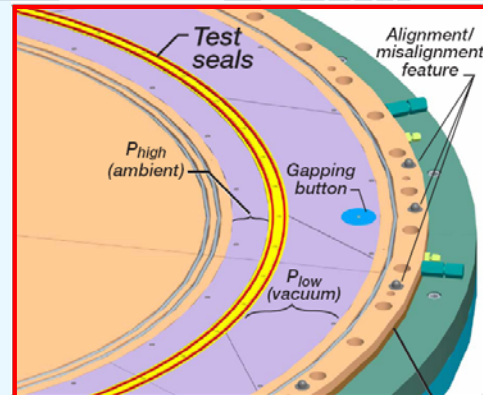
Several competing seal concepts are being evaluated including elastomeric (both gasket and molded Gask-O) seals and metallic seals shown. As shown in the chart, each type of seal comes with its own attributes and concerns.

Full Scale LIDS Seal Test Rig Development

Goal: Evaluate full-scale seal leakage rates under anticipated thermal, vacuum, and engagement conditions

Features:

- Static seal-on-seal or seal-on-plate configurations
- Seal diameters:
 - Risk reduction unit.....54"
 - Engineering demonstration unit58"
 - Flight unit.....TBD
- Simulated environmental conditions
 - Thermal -50 °C to +50 °C
 - Simulates: Vehicle seal in: sun or shade
- Pressure (ΔP)
 - Operational: Ambient pressure to vacuum
 - Pre-flight checkout: 15 psig to ambient
- Engagement conditions
 - Vehicle alignment/misalignment (± 0.060 ")
 - Gapping: Non-uniform clamping engagement (0.040")



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NASA Glenn has designed and is fabricating a new test fixture which will be used to evaluate the leakage of candidate full-scale seals under simulated thermal, vacuum, and engagement conditions. This includes testing under seal-on-seal or seal-on-plate configurations, temperatures from -50 to 50°C (-58 to 122°F), operational and pre-flight checkout pressure gradients, and vehicle misalignment (+/- 0.381 cm (0.150 in.)) and gapping (up to 0.10 cm (0.040 in.)) conditions.

Elastomer Material Property Characterization

Goal: Acquire basic material property data at temperatures required for FEA modeling:

- Constitutive properties (e.g. Hyper-elastic properties)
- Other
- Three materials:
 - Parker Hannifin S0383-70
 - Parker Hannifin S0899-50
 - Kirkhill-TA XELA-SA-401
- Stress vs. Strain for temps: -50, 23, 50 & 125°C
- Hyperelastic material tests -50, 23, 50 & 125°C
 - Uniaxial strain
 - Compression & tension
 - Pure shear
 - Biaxial extension
 - Volumetric compression
- Friction (elastomer on self) -50, 23, 50 & 125°C
- Material properties
 - Coefficient of Thermal Expansion
 - Heat Capacity
 - Density
- Other properties (Mullins effect, etc.)
- Allows for material constitutive law selection



Photograph of biaxial extension test

**Partner Organization:
Axel, Ann Arbor, MI**



NASA Glenn Research Center
Seal Team

Silicone compounds exhibit hyper-elastic behavior. To aid in the finite element modeling of the silicone seals, Glenn contracted Axel of Ann Arbor Michigan to acquire basic constitutive constants at temperatures of -50, 23, 50 & 125°C. This is the first known time that this property data has been acquired for the Parker Hannifin S0383-70, Parker Hannifin S0899-50, and Kirkhill-TA XELA-SA-401 compounds, being considered for the LIDS seals. This property data is being used by the Seal Team to properly model the load displacement characteristics of the seals (see also Jay Oswald's presentation in this 2006 Seal Workshop Proceedings)

Elastomer O-ring Experiment Flight Experiment

- Objective

- Expose candidate elastomers to space environments in low Earth orbit using Material International Space Experiment (MISSE) and evaluate effects on performance

- Justification

- Simultaneous effects of long term exposure to space environments AO,UV, ionizing radiation, thermal cycling, and micrometeoroids and orbital debris (MMOD) are impossible to simulate in terrestrial laboratories.

- Approach

- Sub-scale O-ring seals manufactured from three candidate elastomers will be exposed to combined environments of:
 - »AO Side: AO, UV, ionizing radiation, thermal cycling, and MMOD under hard vacuum conditions of space
 - »Non-AO Side: UV, ionizing radiation, and thermal cycling under hard vacuum conditions of space

Experiment to fly on ISS



**Seal-on-Seal
Compression
Fixture (Non AO)**



**O-ring Exposure Fixture
(AO and Non AO sides)**

NASA Glenn has also designed and built hardware to fly on a Materials International Space Station Experiment (MISSE-6) scheduled to fly in February, 2008. In these tests both fully exposed (right hand figure) and fully compressed seals (left figure) will be flown on the International Space Station to characterize the effects of space environments on candidate seal materials. The O-rings being flown include seals made from Parker Hannifin S0383-70, Parker Hannifin S0899-50, and Kirkhill-TA XELA-SA-401 compounds. Pre- and post-flight performance characteristics will be measured including leakage flow, adhesion, compression set, and durometer.

**Surface Operations:
In-Situ Resource Utilization
Seal Challenges**

In-Situ Resource Utilization (ISRU) + Seal Challenges

- Benefits of ISRU: *In-situ production of mission critical consumables (propellants, life support consumables, and fuel cell reactants) significantly reduces delivered mass to surface.*
- Extraction and refinement of valuable resources from lunar regolith requires thermal and chemical or electrochemical processes in reusable enclosed reactors.



Seal Challenges:

- Long term (years) exposure to space environments: Ultraviolet (UV) radiation, Micrometeoroid damage
- Dust: abrasive and electrostatically charged
- Temperatures: Cryogenic (propellants) thru high temperatures for regolith processing
- Low leakage rates to maximize product yield
- Extremely high reliability

Applications

- Resource processing
- Mission consumable production (Life Support & Propellant)
- Surface cryogenic fluid & propellant storage & distribution
- Chemical reagent storage & distribution
- Gas storage & distribution
- Water & earth storable fluid storage & distribution



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NASA is evaluating In-Situ Resource Utilization (ISRU) technologies that would help allow astronauts to “live-off-the-land.” for either Lunar or Martian missions. These technologies would help increase mission success for a manned mission to Mars that would entail a 6 month transit time and a 500 day stay.

Some of the technologies under consideration, include production of mission critical consumables including:

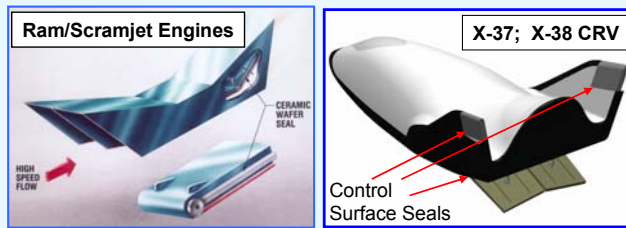
- + propellants (e.g. harvesting the Martian atmosphere carbon-monoxide to make methane fuel)
- + life support consumables, (e.g. harvesting Lunar ice believed to be at the poles)
- + fuel cell reactants

Achieving these ambitious goals however requires solving several important seal challenges, as shown in the chart.

**Hypersonic Vehicle:
Goals and Seal Challenges**

NASA GRC Structural Seal Development Goals

- Develop hot (2000-2500+°F), flexible, dynamic structural seals for ram/scramjet propulsion systems (TBCC, RBCC)
- Develop reusable re-entry and hypersonic vehicle control surface seals to prevent ingestion of hot boundary layer flow



Advanced Hypersonic Vehicles (e.g. FALCON)

High temperature seals critical for mission success



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Seal Team

NASA is currently funding research on advanced technologies that could greatly increase the reusability, safety, and performance of future hypersonic vehicles. Research work is being performed on both high specific-impulse ram/scramjet engines and advanced re-entry vehicles.

NASA GRC is developing advanced structural seals for both propulsion and vehicle needs by applying advanced design concepts made from emerging high temperature ceramic materials and testing them in advanced test rigs that are under development. See Dunlap 2006, et al, and DeMange 2006, et al in this Seal Workshop Proceedings and Dunlap 2006, 2005, 2004, and 2003, et al; and DeMange 2006 and 2003, et al; for further details.

NASA Glenn is working to develop high temperature seal technology and test techniques for future hypersonic vehicles under DARPA (Defense Advanced Research Project Agency) sponsorship. Vehicle thermal protection system (TPS) seals are required for control surfaces, leading edges and acreage TPS locations. Seals are required to operate under extreme temperatures of hypersonic flight (2000+°F), survive flight times of approximately 2 hrs, and be reusable.

Seal Challenges and Design Requirements

- **Control surface seals:**

- Limit hot gas flow and heat transfer to underlying low-temperature structures
- Withstand temperatures of 1800-2200°F:
- Stay resilient for multiple load/heating cycles
- Limit loads against sealing surfaces
- Resist scrubbing damage



Baseline control surface seal design

- **Propulsion system seals:**

- Withstand temperatures of 2000-2500+ °F and high heat fluxes with minimal cooling
- Limit leakage of hot gases and unburned propellant into backside cavities
- Survive in chemically hostile environment (e.g., oxidation, hydrogen embrittlement)
- Seal distorted sidewalls and remain resilient for multiple heating cycles
- Survive hot scrubbing with acceptable change in flow rates



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NASA GRC is developing high temperature seals and preloading techniques to help meet the challenges posed by future re-entry and hypersonic vehicle control-surfaces. These seals must limit hot gas ingestion and leakage through sealed gaps to prevent damage of low-temperature structures (including actuators) downstream of the seal. Gas temperatures that reach the seal can be as $>2200^{\circ}\text{F}$. The seals must be able to withstand these extreme temperatures and remain resilient, or “springy”, for multiple heating cycles. The upper image on this chart shows what happens to a baseline Shuttle thermal barrier/seal incorporating an knitted Inconel X750 spring tube after exposure to 1900°F temperatures in a compressed state. The seals took on a permanent set. This can be a problem if the seal does not stay in contact with the opposing sealing surface and allows hot gases to pass over the seal and into regions where low-temperature materials reside.

Oswald et al 2005, performed finite element analyses on various spring tube designs defining desirable knit parameters to minimize stress while still supporting the necessary loads. Taylor et al 2005, identified the benefits of Rene’41 material over conventional Inconel X-750. Substituting specially heat treated Rene’41 wires raised the operating temperature 250°F to approximately 1750°F . The Seal Team is also working on preloading techniques with higher temperature capability and on seal designs that will be more resistant to wear than the conventional seals shown.

Ram/scramjet propulsion system seals must withstand similar punishing temperatures while using minimum cooling. The seals must limit leakage of hot gases and unburned propellant into backside cavities. They must exhibit good resiliency and flexibility to maintain sealing contact with adjacent walls all while resisting the extreme heat fluxes shown in this NASA GRC hydrogen rocket test chamber.

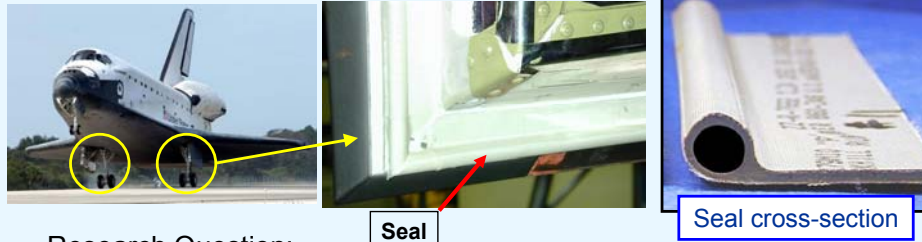
Space Shuttle Main Landing Gear Door Seal Assessments

Main
Landing
Gear
Door

Seal



Shuttle Main Landing Gear Door Seal: Long Term Compression Tests



- Research Question:
 - How well do environmental seals perform (e.g. recover) after a long term compression?
- Objective:
 - Measure seal spring-back (e.g. recovery) after hold periods to aid NASA JSC and KSC engineers with seal operations and maintenance planning.
- NASA Johnson Space Center requested testing of MLG environmental seals at GRC
 - Compress seals for 1 hr, 1 day, 1 and 3 month durations at various levels of compression level
 - Assess seal recovery via non-contacting laser recovery test fixture

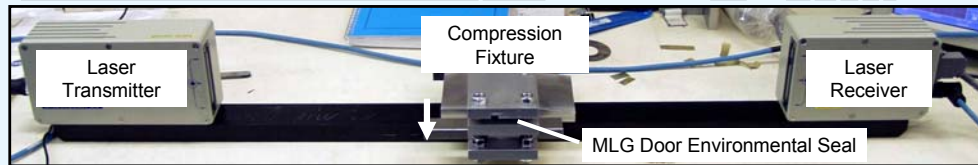


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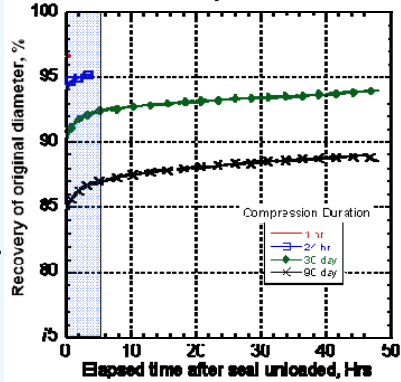
In preparing Shuttle Discovery for the Return-to-Flight mission, engineers at NASA Kennedy Space Center (KSC) and NASA Johnson Space Center (JSC) uncovered a problem in which the environmental seals around the perimeter of the main landing gear doors were preventing the doors from closing completely. This condition is unacceptable for flight because the outer mold line must be smooth during a mission. Raised areas and steps in that surface (such as can be caused by a door that is not fully closed) disrupt the flow of hot reentry gases over the surface and can lead to excessive heating in localized areas.

When this problem was identified, engineers at NASA JSC asked the Seals Team at GRC to help them solve this problem by performing room temperature compression and flow tests on the seals to characterize their performance and determine an optimal compression on the seals to minimize leakage without putting excessive loads on the doors. Additional details of these tests can be found in Finkbeiner, 2005 et al.

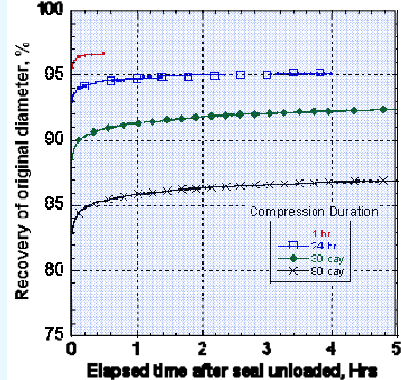
Shuttle Main Landing Gear Door Seal: Long Term Hold and Recovery Results



Unload Test Sequence: Full Data



Unload Test Data: 0 - 5 hr



Long term hold reduces the amount of recovery

JSC asked GRC to evaluate the time for the seal bulb to recover from long term compression hold times of 1 day, 30 days, and 90 days, simulating periods of time the seals may be compressed prior to and during flight.

Example observations of seal recovery after 30 day hold include the following (Data recorded for 48 hrs. after compression shim removed)

Seal recovered more gradually

- ~86% recovery within first 0.25 sec
- ~90% recovery within 5 min
- ~94% recovery after 48 hrs

Summary

- **NASA's Exploration Initiative requires advanced sealing technology to meet system goals:**

- Performance
- Life/Reusability
- Safety
- Cost



- **Fundamental Aeronautics Project aimed at developing foundational technologies that will enable a range of future aeronautic missions:**
 - Long life, low leakage seals essential for meeting efficiency, performance and emission goals.
- **NASA Glenn**
Partnering with key government and contractor organizations to
 - Develop advanced seal technology
 - Provide technical consultation and test capabilities



NASA Glenn Research Center
Seal Team

NASA Glenn is currently performing seal research supporting both advanced turbine engine development and advanced space vehicle/propulsion system development. Studies have shown that decreasing parasitic leakage through applying advanced seals will increase turbine engine performance and decrease operating costs.

Studies have also shown that higher temperature, long life seals are critical in meeting next generation space vehicle and propulsion system goals in the areas of performance, reusability, safety, and cost.

Advanced docking system seals need to be very robust resisting space environmental effects while exhibiting very low leakage and low compression and adhesion forces.

NASA Glenn is developing seal technology and providing technical consultation for the Agency's key aero- and space technology development programs.

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