# OVERVIEW OF NASA GLENN SEAL PROJECT


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NASA Glenn hosted the Seals/Secondary Air System Workshop on November 18, 2008. 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 a conference proceedings. Those papers that are publicly available will also be made available on-line through the web page addresses listed at the end of this presentation.


The first day of presentations included overviews of current NASA programs. Mr. Baumeister reviewed the goals and objectives of NASA's Orion and Altair projects to develop the new Crew Exploration Vehicle that is planned to replace the Shuttle and allow missions to the International Space Station, and to the Moon. Dr. Ajay Misra presented NASA's fundamental aeronautics project that is developing advanced technologies for subsonic rotary and fixed wing aircraft, supersonic and hypersonic aircraft.

Dr. Steinetz presented an overview of NASA seal developments for both NASA's aeronautic and space projects. Mr. Hendricks presented exciting work that GRC and other researchers are performing to develop alternate aviation fuel sources. Though improved sealing technology can play a role in reducing fuel burn by improving engine efficiency (Steinetz, Hendricks, Munson 1998), there is a need to start addressing alternate energy sources to help ward-off a future aviation energy crisis. Mr. Hendricks reviewed sustainable alternate aviation fuels under development.

Mr. Munson presented an overview of exciting foil face seal development to significantly reduce leakage flows in a turbine engine. This seal combines foil thrust bearing technology with face seal architecture. The foil bearing/seal needs only to support itself axially and accommodates out-of-flat distortion; the secondary seal accommodates axial excursion and some angular misalignment. Ms. Proctor presented work underway at NASA GRC on a new finger seal showing promise of non-contacting operation. Dr. Lattime shared efforts at Timken developing low torque seals for their product line.

## Workshop Agenda
### Tuesday, Nov. 18, Afternoon

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| **Turbine Seal Development Session II** | **1:30-2:20** |
| An Overview of Non-Metallic Brush Seal Technology | Dr. Eric Ruggiero/GE Global Research Center |
| Update on DOE Advance IGCC/H2 Gas Turbine | Dr. Ray Chupp/GE Energy |
| **Break** | **2:20-2:35** |
| **Structural Seal Development Session** | **2:35-4:15** |
| Overview of LIDS Docking Seals Development | Mr. Pat Dunlap/NASA GRC; Dr. Chris Daniels/U. of Akron; Dr. B. Steinetz, Henry deGroh/NASA GRC; I. Smith, J. Wasowski, N. Garafolo/U. of Akron; N. Penney/OAI |
| Design and Analyses of Molded Elastomer Seals | Mr. Paul Yetter, Dr. Kai Zhang/Parker Composite Sealing Systems Division |
| Overview of CEV Heat Shield Interface Seal Development | Mr. Jeff DeMange, Shawn Taylor/U. of Toledo; P. Dunlap, J. Finkbeiner, Dr. B. Steinetz /NASA GRC |
| High Temperature Metallic Seal / Energizer Development For Aero Propulsion and Gas Turbine Applications | Mr. Jesse Newman/Parker Hannifin Corporation |
| **Tour of NASA Seal Test Facilities:** | **4:15-5:30** |
| **Adjourn** | |
| **Dinner at: 100th Bomb Group** | **6:30** |
| To attend: Please sign up at registration table | |

NASA Glenn Research Center
Seal Team

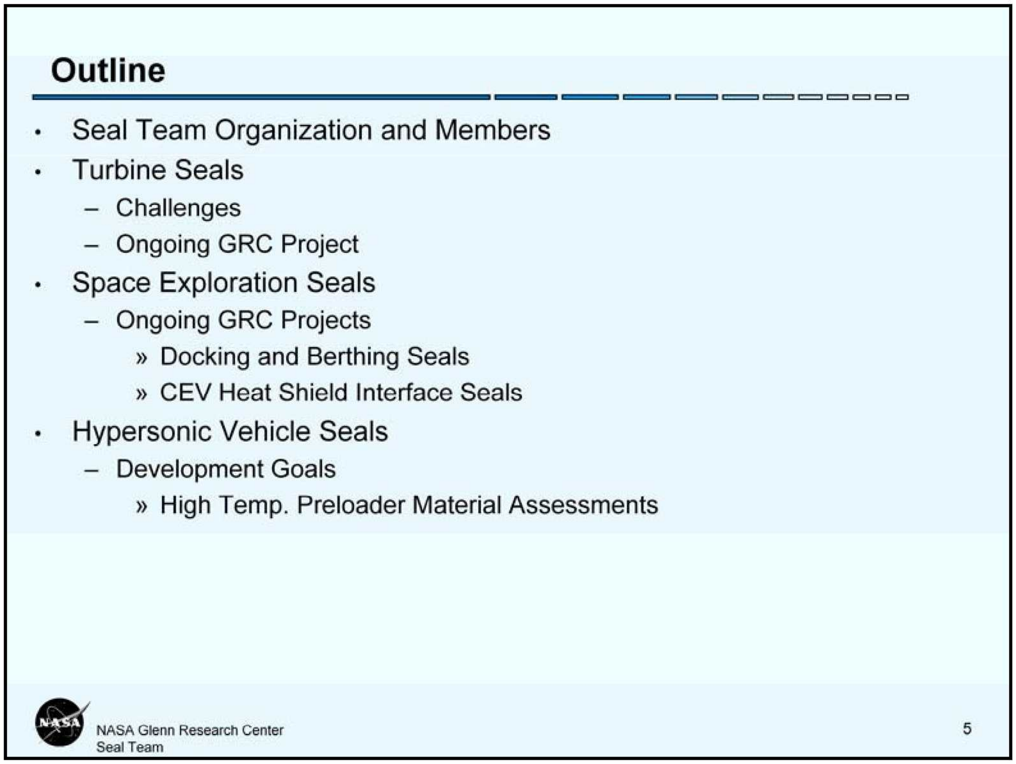
3

Mr. Ruggiero of GE Global Research reviewed their current progress in applying non-metallic fiber brush seals (see also Ruggiero et al, 2007 and 2008) to turbine applications. Dr. Chupp presented an overview of a DOE project called the IGCC/H2 gas turbine.

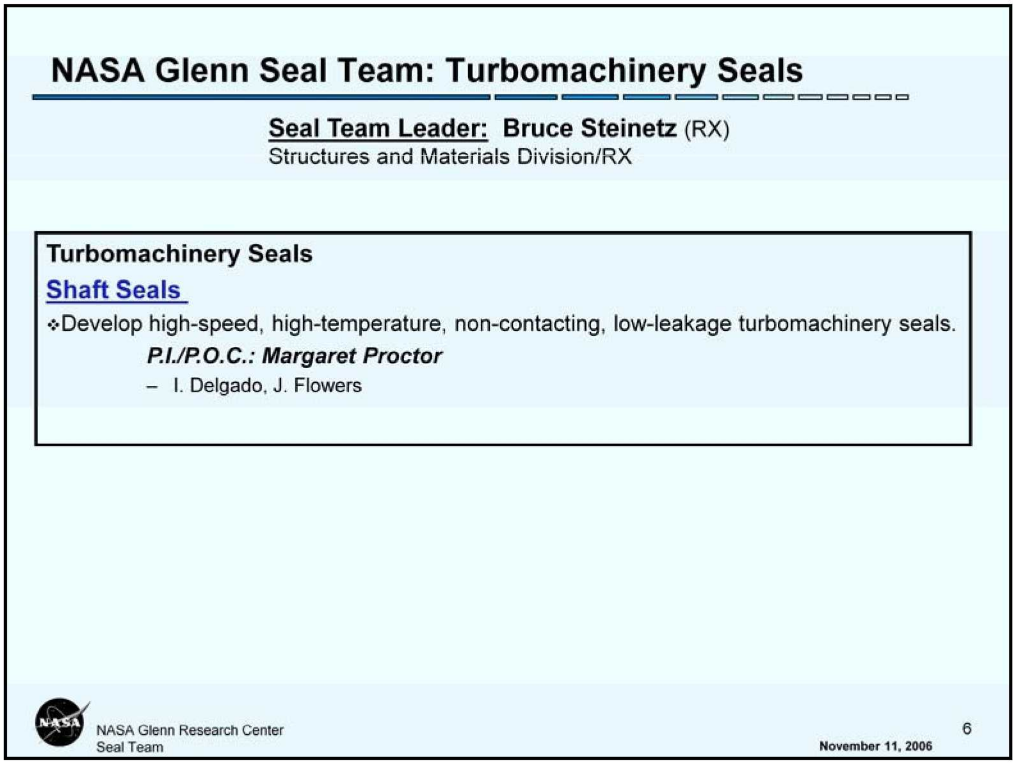
There were also several presentations describing structural seal developments underway. Mr. Dunlap presented GRC's efforts in developing seals for the Low Impact Docking System (LIDS) project. LIDS is the Agency's new standard for docking systems. Mr. Yetter, Parker Composite Sealing Systems, presented design and analyses of their GaskO molded elastomer seals, a prime candidate for the LIDS docking seal. On the high temperature front, Mr. DeMange presented GRC's efforts in developing the sealing system for the Orion Crew Exploration Vehicle Heat Shield. Mr. Newman presented Parker's work in developing high temperature spring preloaders and seals for ultrahigh temperature service (1600-1700°F).

Participants were also treated to a tour of NASA GRC's extensive seal test facilities.

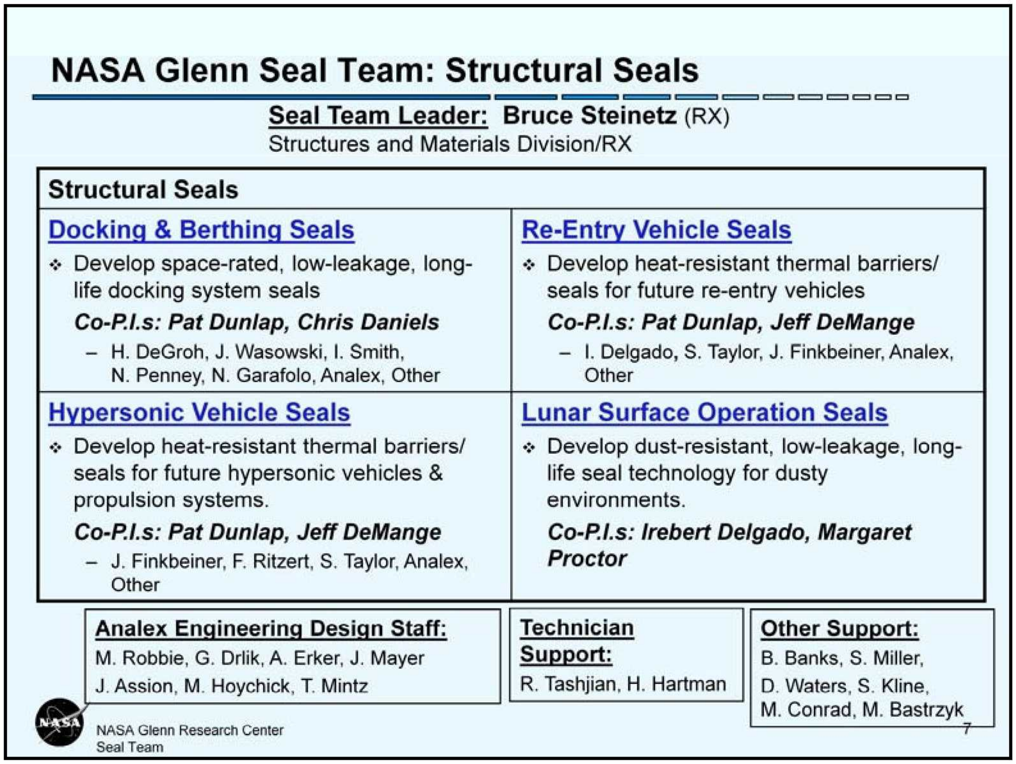

NASA Glenn is the lead center for developing advanced seal technology to meet the challenges of NASA's future aero and space missions. Dr. Steinetz's presentation reviews a portion of the Seal Team's extensive efforts, as outlined on the next chart.




Dr. Steinetz's presentation is divided into these major discussion areas.




As NASA pursues research in Fundamental Aeronautics, advanced seal development is important. A key area that NASA Glenn is pursuing includes non-contacting shaft seals to reduce leakage enabling lower specific fuel consumption and emissions and increase engine service lives. Members of the Turbomachinery Seal are shown.




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 seals are being developed to ensure that vehicles can dock and prevent leakage of limited astronaut cabin pressure air.

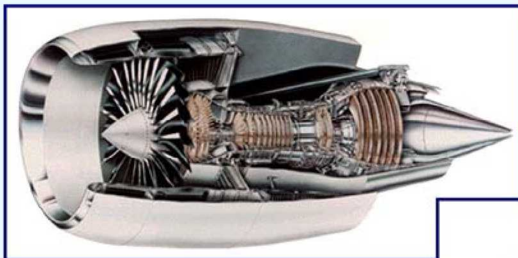
+ Re-entry vehicle heat shield and penetration thermal barriers/seals are being pursued to ensure hot plasma re-entry gases do not compromise the function of the thermal protection system, including for the CEV vehicle.

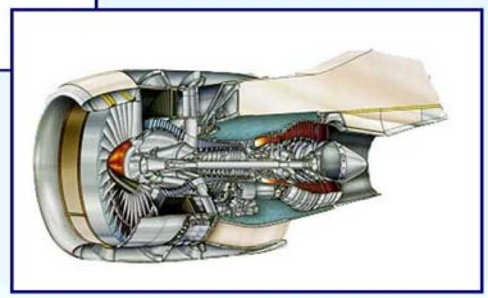
+ Though currently a relatively small area, technologies for dust resistant, surface operation seals are being investigated for: robotic experimental payloads, space suits, airlocks, quick disconnects, and the like. Dust resistant seals exhibiting low-leakage, and long life are essential to ensure long-term mission success.

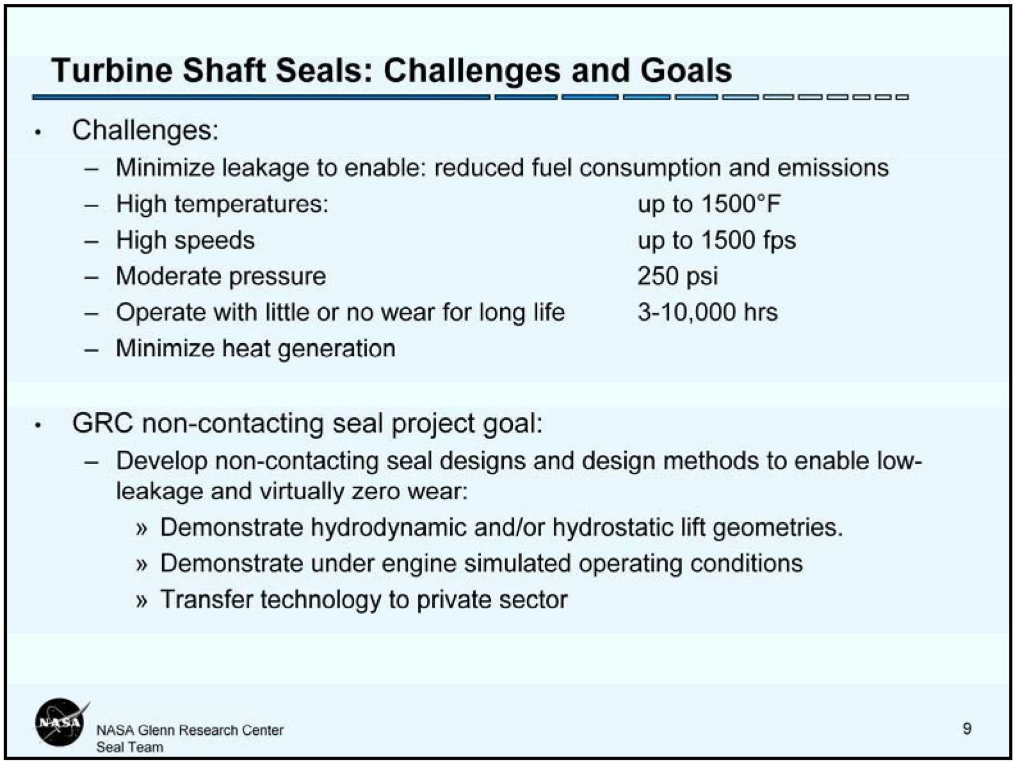
+ Hypersonic vehicle and propulsion system thermal barriers/seals are being developed to enable future single-stage and two-stage access-to-space options.

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.

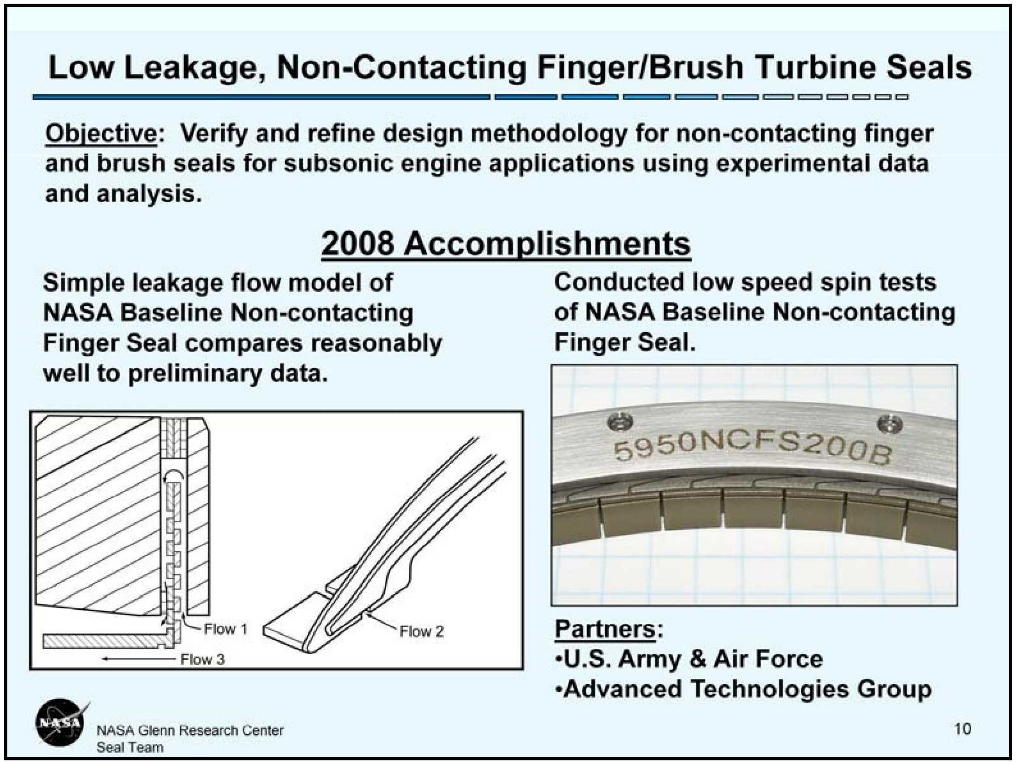
## Turbine Engines: Seal Challenges and Projects Supported





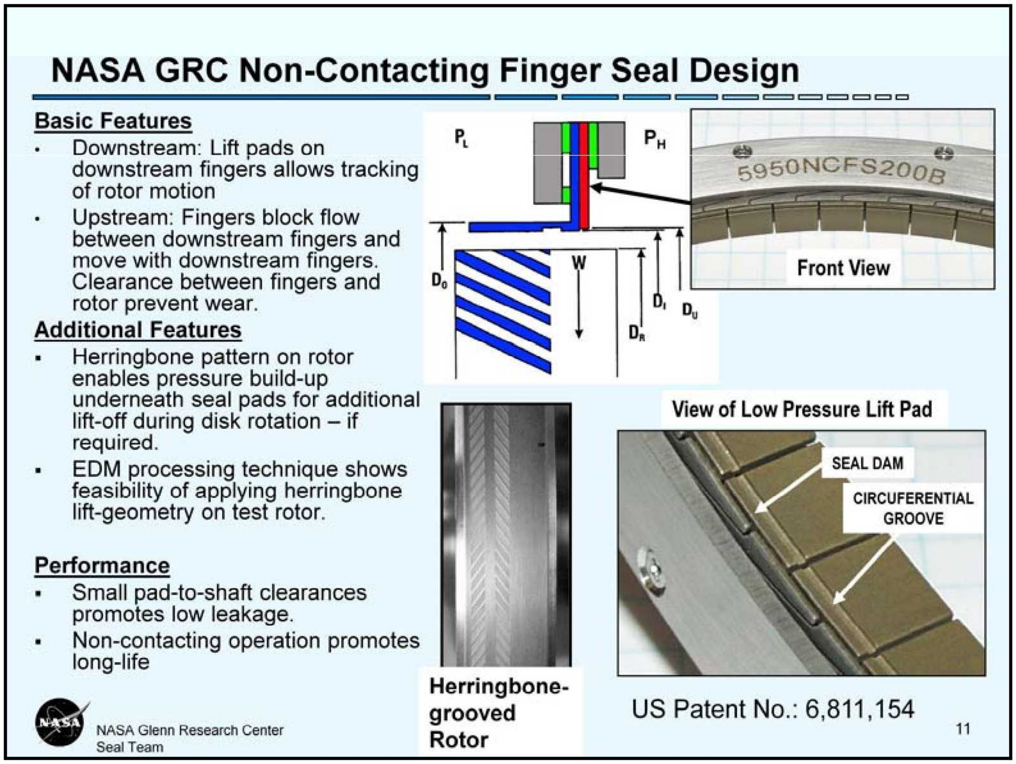



Designers of future turbine engine seals face ever increasing challenges (Steinetz, Hendricks, Munson 1998), including high temperature, high speed operation, the need to operate for long lives with little or no wear while minimizing heat generation. One of NASA GRC's turbine engine seal goals is to 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.




An important objective of the turbine seal development project is to verify and refine design methodology for non-contacting finger and brush seals for subsonic engine applications using experimental data and analysis.

The Seal Team also completed low speed spin tests of NASA baseline non-contacting finger seal shown in the figure, and explained further in the next chart. (See also Proctor and Delgado, 2008) The seal team also predicted the leakage flow rate using a simple model of the flow paths through the baseline non-contacting finger seal and found reasonably good comparison to preliminary test results.

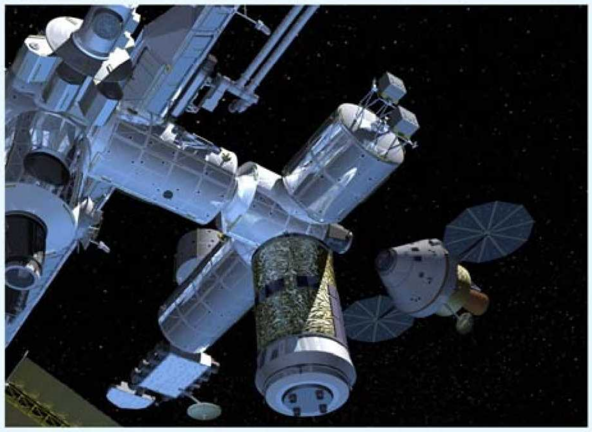


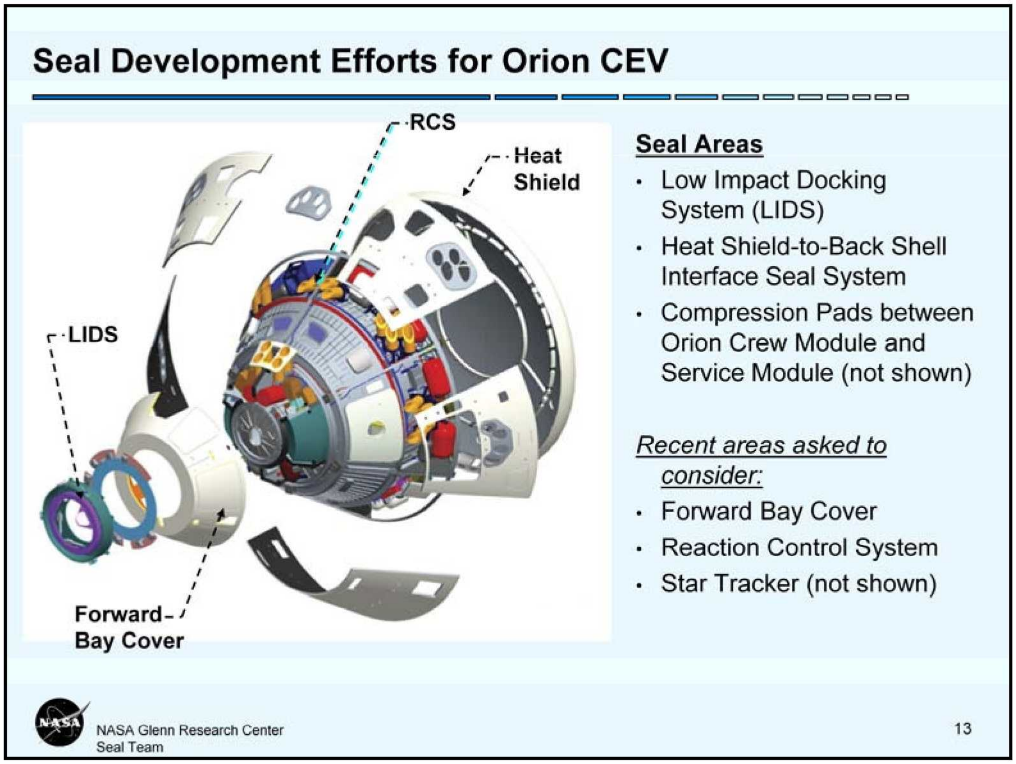

Conventional finger seals like brush seals attain low leakage by operating in running contact with the rotor (Proctor, et al, 2002). The drawbacks of contacting seals include wear over time, heat generation, and power loss.

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 the static leakage has been tested in GRC's turbine seal test rig. The seal was tested against a rotor that has a herringbone lift geometry that is fashioned onto the rotor surface using a Electro Discharge Machining process.

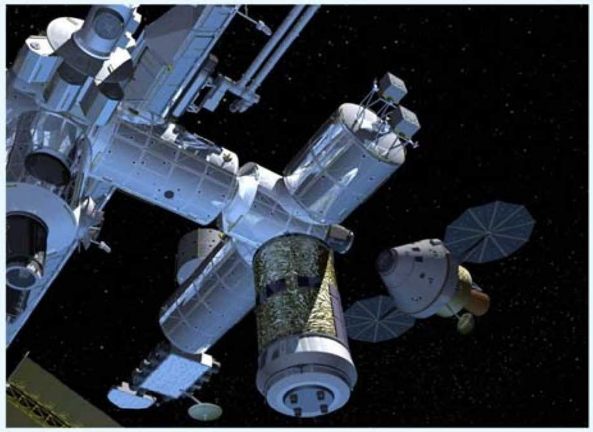
## Exploration Systems:
## Seals Challenges and Project Supported

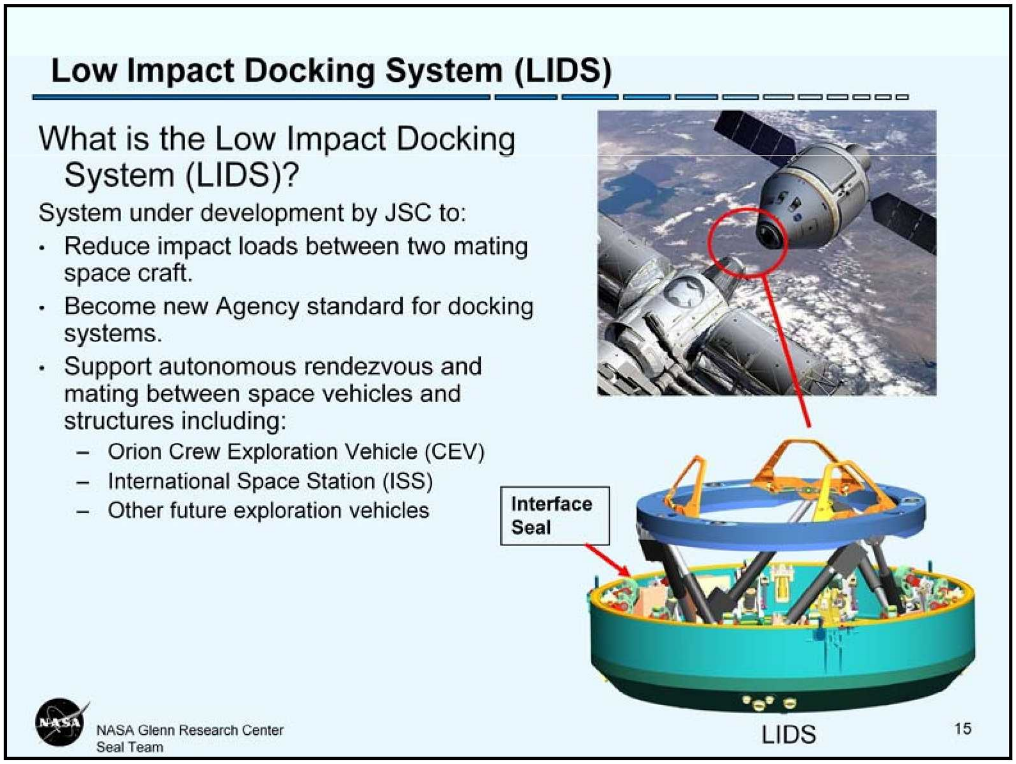





The Orion spacecraft has many sealing locations as illustrated in the chart. Three areas that GRC is actively supporting include the Low Impact Docking System (LIDS), Heat Shield-to-Back Shell Interface Seal System, and the Compression Pads between Orion Crew Module and Service Module (not shown). The first two locations will be described at length by Dunlap and DeMange later in this proceedings.

## Orion Docking and Berthing System



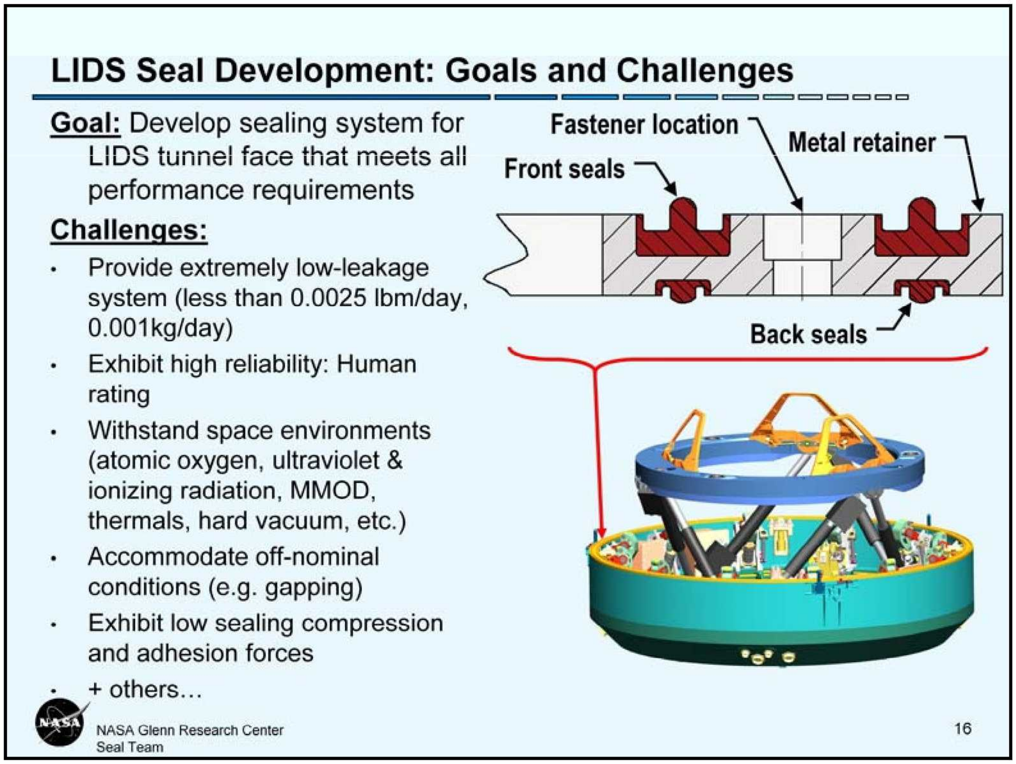



In preparation for the Exploration Initiative, NASA has identified the need for a standard docking system to allow easy docking between space faring vehicles and platforms orbiting either Earth (e.g. the Space Station) the Moon or Mars. NASA is developing a Low Impact Docking System (LIDS) that has several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

+ Using a soft capture system, minimal loads will be imparted between systems minimizing potential for damage.

+ Using sophisticated control laws, the system will support autonomous (e.g. computer controlled) docking between mating spacecraft.

As illustrated in the figure, a large diameter, low leakage face seal is required on the top of the docking flange that seals during final "hard capture."



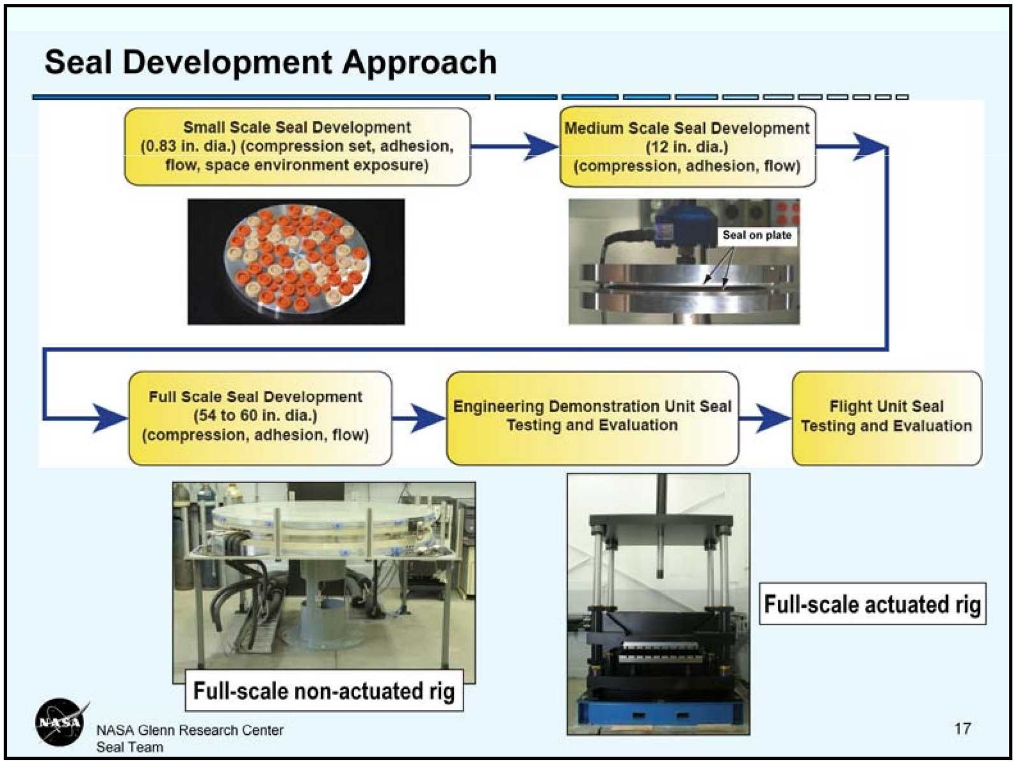

As indicated in the accompanying chart, challenges posed by this new system include:

Extremely high reliability: for man rating

Relative large diameter 54-58"

Extremely low leakage rates: <0.0025 lbm/day

Docking Temperatures: -50°C to +75°C and thermal gradients




NASA Johnson requested the GRC Seal Team to assist in assessing and developing candidate seal technology for the LIDS system

The following elements are planned during the development project:

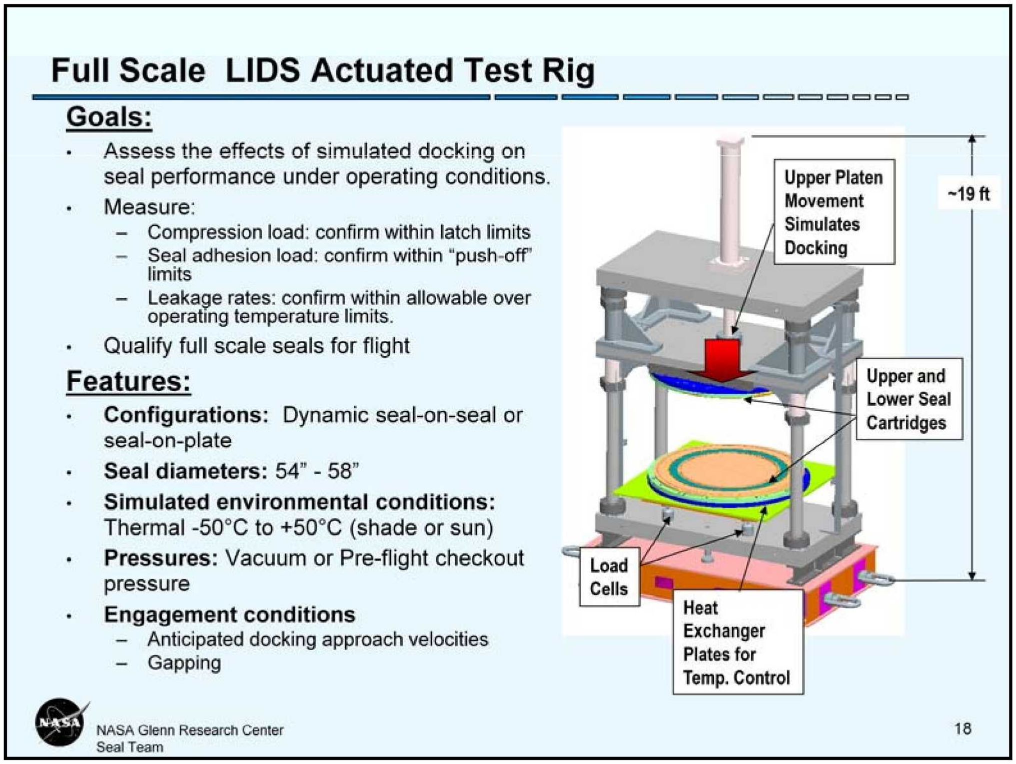
+ Perform coupon-level and small-scale environmental exposure and flow tests of candidate sub-scale seals to determine space environments effects on different seal compounds.

+ Down-select between competing concepts and materials based on requirements

+ Perform full-scale flow tests using the full-scale non-actuated test rig (lower left image) at both warm and cold conditions.  For additional detail see Dunlap et al 2007, & 2009 and Wasowski et al 2009.

+ Perform full scale adhesion and compression tests using the full-scale actuated rig being assembled (lower right image) at both warm and cold conditions. (See next chart for additional details.)

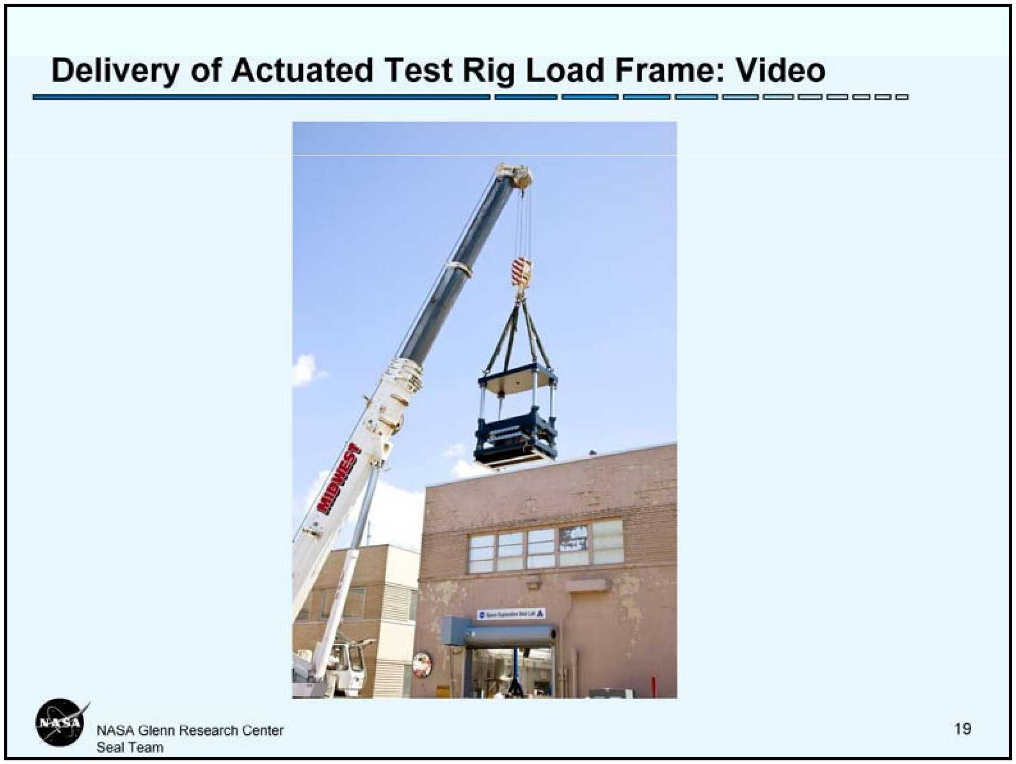
+ Support JSC through flight qualification for CEV and other applications




The Seal Team has fabricated through vendor Instron, a new large load frame that will allow us to assess the effects of simulated docking on seal performance under operating conditions. A large load frame measuring approximately 19' high by 8' wide by 5' deep is in final assembly stages that will accommodate full scale face-seal hardware between the upper and lower platens. The movable upper platen will allow us to simulate the two vehicles approaching one another. After compressed or "docked", seal tests will commence with seal hardware similar to the "non-actuated" rig discussed previously. Load cells below the lower platen will allow measurement of compression loads at sealing (up to 100,000 lbs of force) and adhesion forces during simulated un-docking.

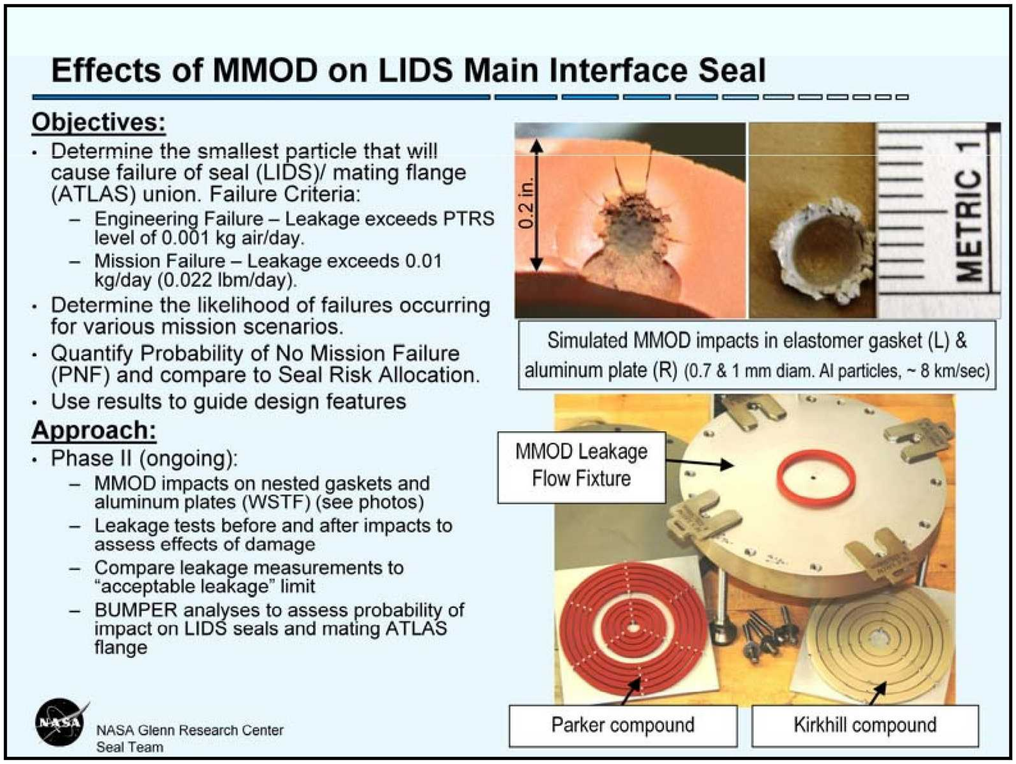
This test rig will allow us to measure:

Compression load: confirm within latch limits
Seal adhesion load: confirm within "push-off" limits
Leakage rates: confirm within allowable over operating temperature limits.




The sheer size of the new load frame required a creative delivery approach as it would not easily fit through the front garage door. The Space Exploration Seal System Lab's roof hatch is removable allowing riggers to lower it through the roof as shown in this still frame from the movie shown during the workshop.

## LIDS Seals MMOD Investigations




Because the LIDS seal on Orion and the mating flange on ISS will not be covered, the Seal Team is assessing the threat of Micro Meteoroid and Orbital Debris (MMOD) strikes to the sealing surfaces while on-orbit. The overall objective of this work can be summarized as follows:

**Objectives:**

Define critical MMOD particle parameters that cause unacceptable seal leakage change

- Particle density
- Kinetic energy
- Incident angle

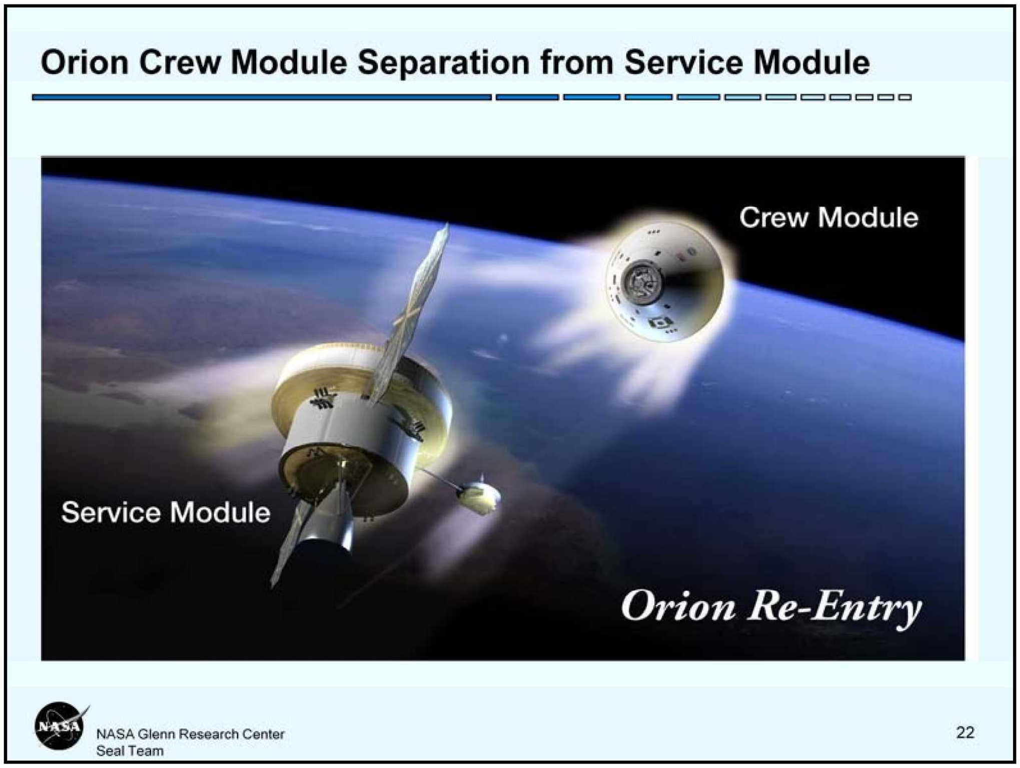
Determine probability that seals or flange surfaces would be hit by such a particle

Evaluate impact-response of design parameters

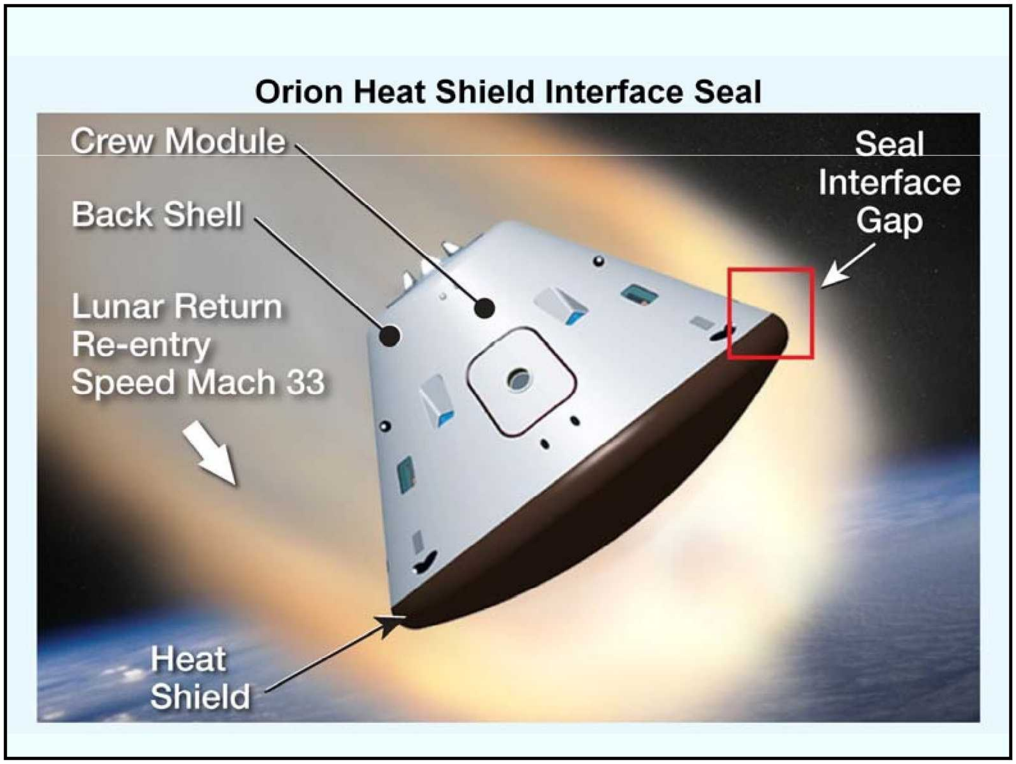
- Bulb width
- Silicone compound
- Temperature
- Aluminum surface treatment: bare, anodized, electroless nickel

Develop a methodology based on empirical findings to assess different candidate seal designs relative to project defined seal risk allotment

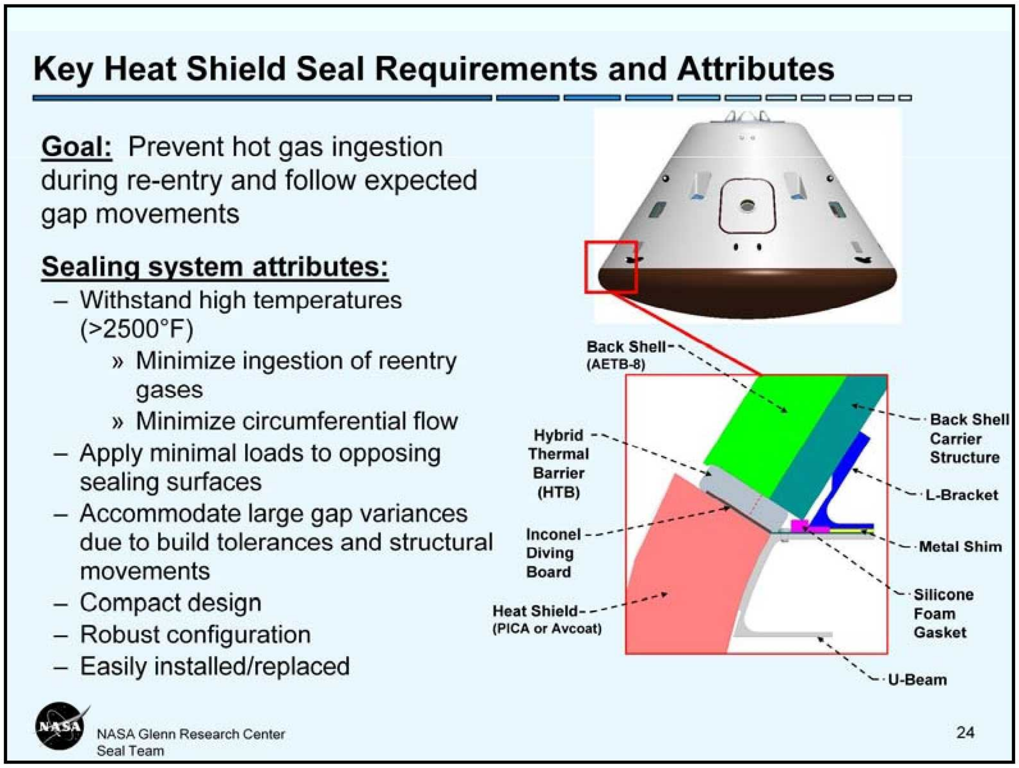
More information on the methods can be found in DeGroh et al (2009) and DeGroh and Steinetz (2009)



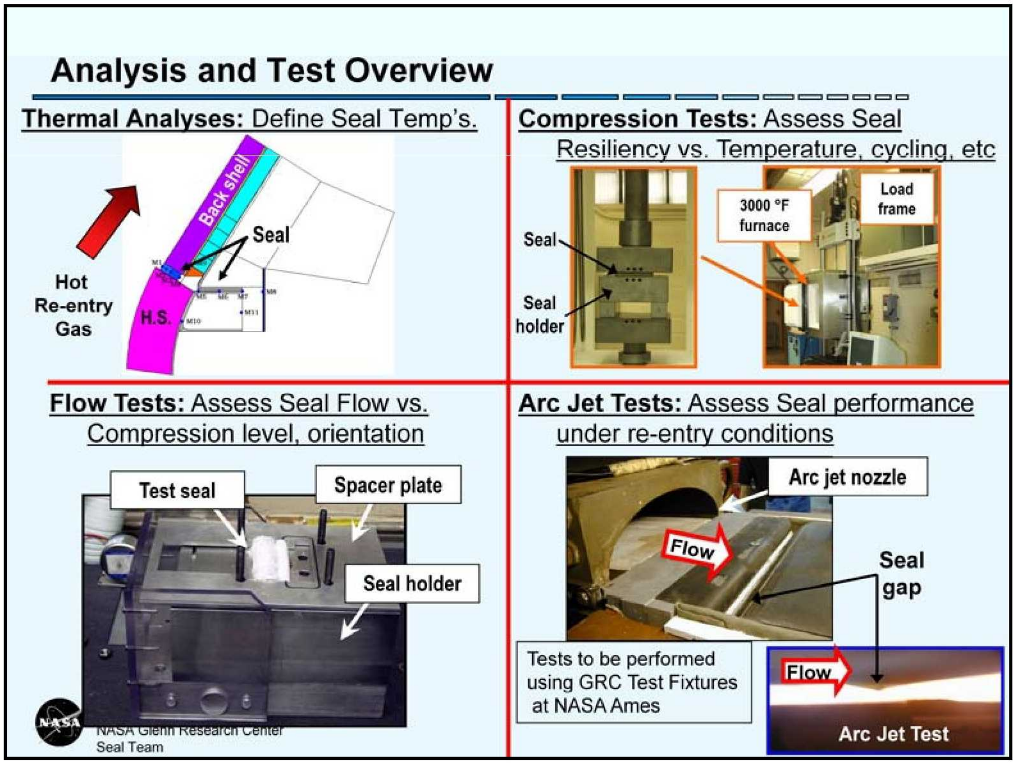

The Orion spacecraft is being designed to ferry astronauts either to the International Space Station or to the Moon. Upon return and during final stages of the mission, the Crew Module separates from the Service module and prepares to re-enter the Earth's atmosphere during which time extensive aeroheating occurs requiring a robust thermal protection system (TPS) and corresponding seals.




NASA GRC is developing a high temperature sealing system to block the high temperature re-entry gases from penetrating the interface between the ablative heat shield and the back-shell covered with Shuttle tile.




Orion uses an ablative heat shield to protect the spacecraft and crew from the intense aeroheating generated during a return from both Low Earth Orbit and Lunar missions. A seal system is being designed to prevent ingress of high temperature re-entry gases at the interface between the heat shield and back shell. The proposed seal system consists of an outer hybrid thermal barrier and an inner gasket seal. The hybrid thermal barrier is a compliant high temperature barrier that can accommodate gap changes between the heat shield and back shell. The inner seal comprises a bolted flange connection with a silicone gasket.




GRC is pursuing the following basic approach for the CEV Heat Shield Seal Development:

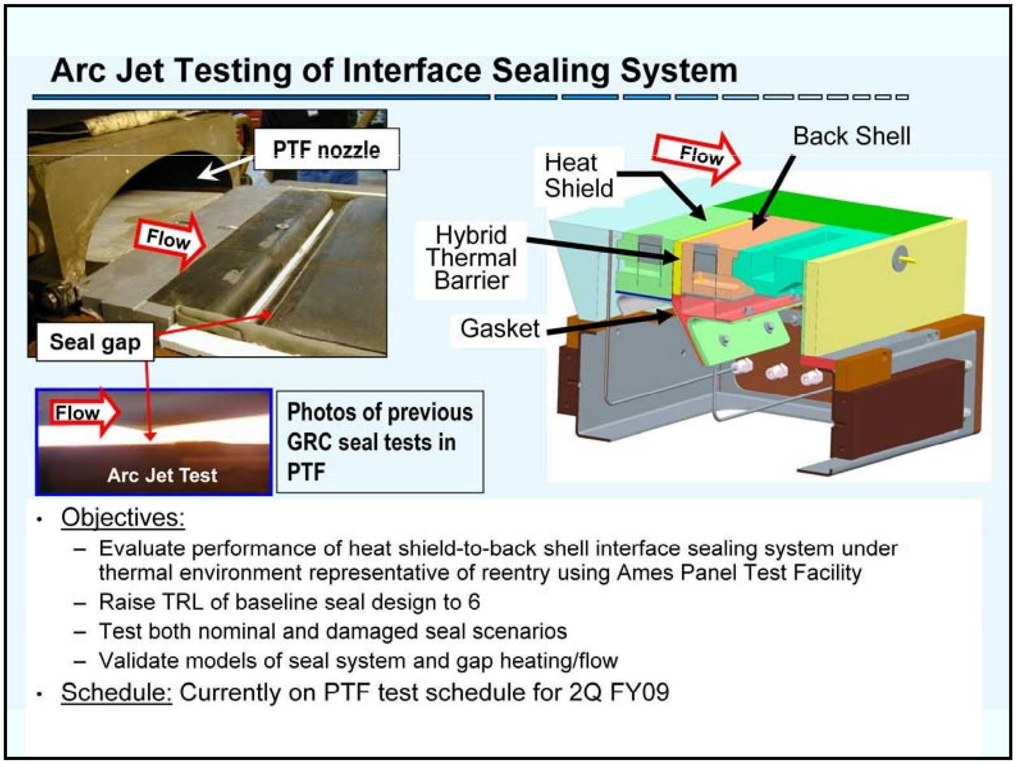
• Identify candidate seal designs to evaluate: gap fillers, thermal barriers, and pressure seals

• Perform supporting aerodynamic and thermal analyses

• Perform critical function performance tests (compression, flow) under simulated environmental conditions

• Perform arc jet tests on full sealing system to evaluate seal performance and validate design

• Recommend final seal design to CEV prime contractor, Lockheed-Martin




To evaluate the robustness of the sealing system in a simulated re-entry heating environment, we are designing a new arc jet test fixture. A solid model of test fixture is shown in the right hand image. The modular test fixture will allow us to accomplish the following:

Test of different gap and step configurations and simulate different gap flow angles on CEV moving circumferentially around vehicle from Windward to Leeward sides.

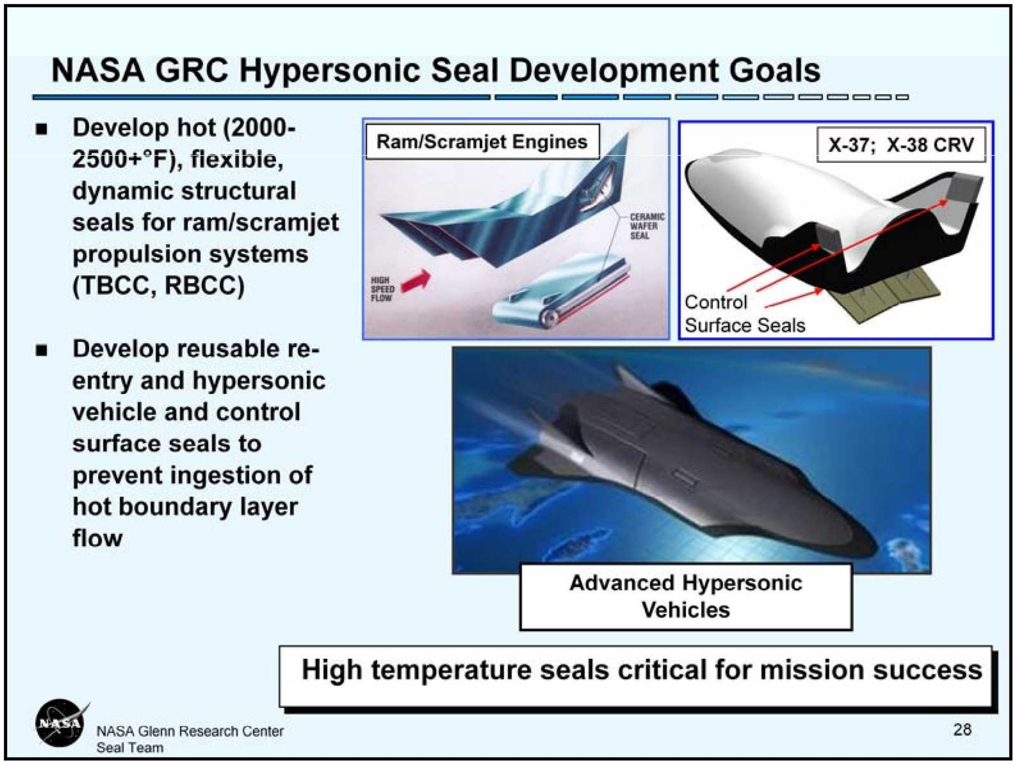
Allows test of different material candidates

- Heat Shield: PICA (standard or densified) or AVCOAT
- Back Shell (e.g. AETB-8)

Allows test of main seal system elements:

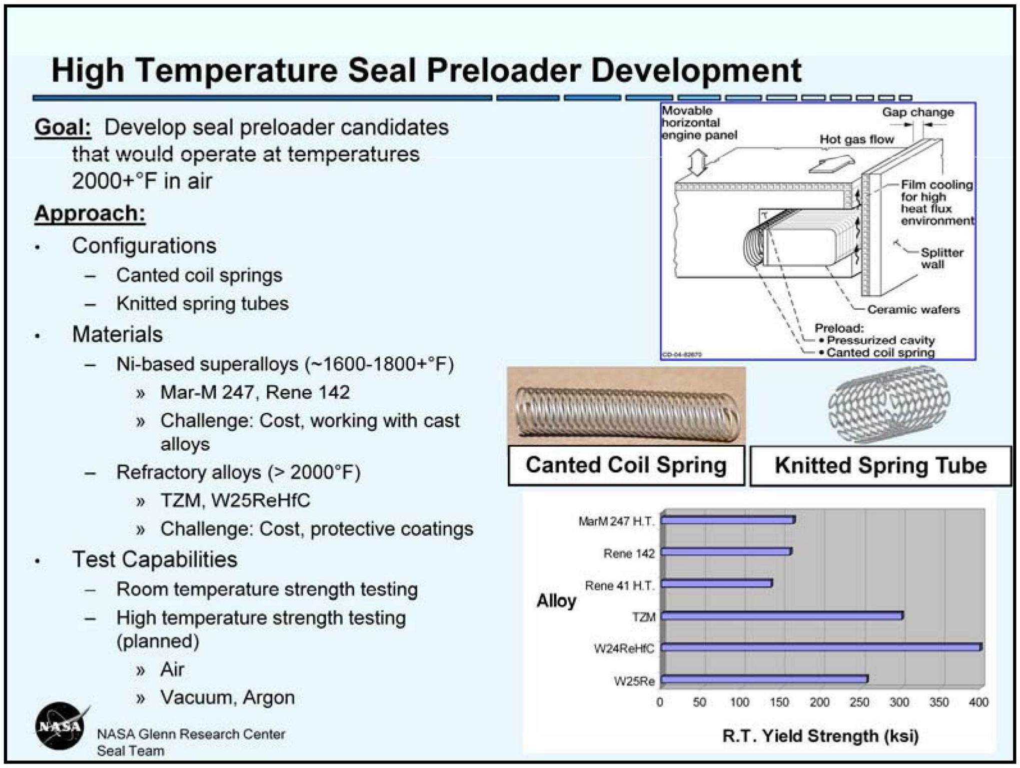
- Hybrid Thermal Barrier
- Gasket Seal

# Hypersonic Vehicle Seals



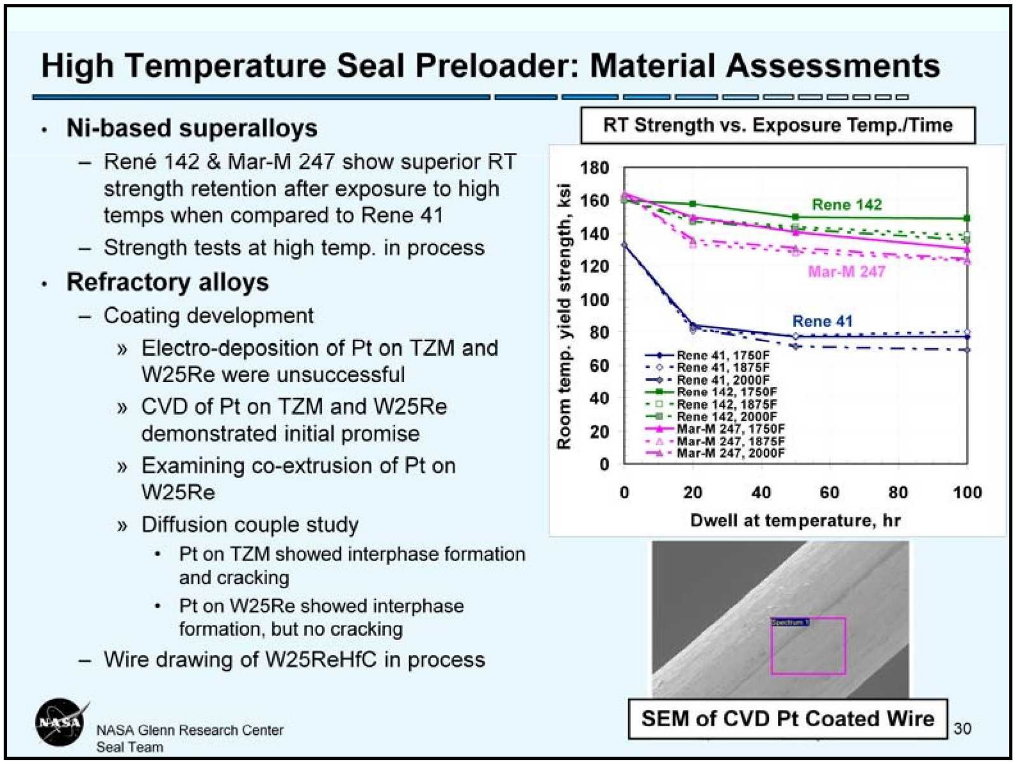

NASA is currently performing research on advanced technologies that could greatly increase the reusability, safety, and performance of future hypersonic vehicles. Research work is being performed on both high specific-impulse ram/scramjet engines and advanced re-entry vehicles.

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



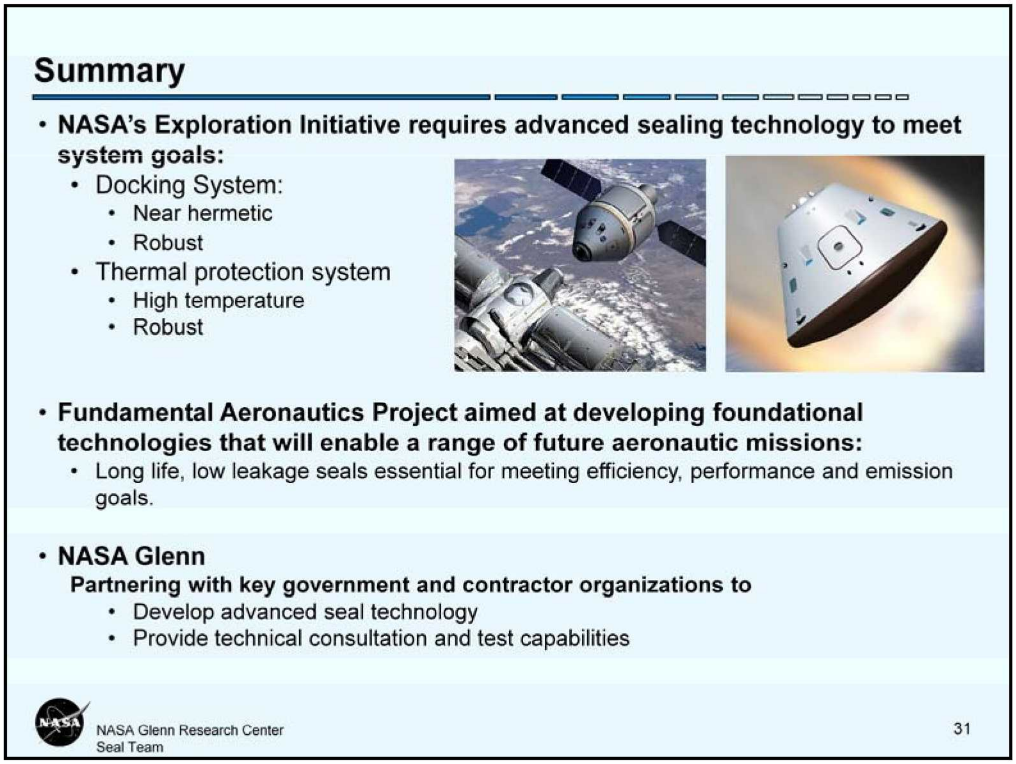

NASA GRC is developing high temperature seals and preloading techniques to help meet the challenges posed by future re-entry and hypersonic vehicle control-surfaces. These seals must limit hot gas ingestion and leakage through sealed gaps to prevent damage of low-temperature structures (including actuators) downstream of the seal. Gas temperatures that reach the seal can be >2200°F. The seals must be able to withstand these extreme temperatures and remain resilient for multiple heating cycles.

To confront these higher temperatures, NASA Glenn has a small internal effort aimed at identifying alloys that can maintain adequate yield strengths at temperature. Some of the alloys being considered include advanced cast blade alloys (e.g. MARM-247) for temperatures 1600°F, and refractory alloys (TZM and W25ReHfC) for temperatures 2000°F. Representative material strengths are shown in the lower right hand figure.




As part of this effort, GRC is examining effects of moderate term exposures (e.g. up to 100 hrs) on retained room temperature strength to see if any of the listed alloys would be suitable.

Refractory wires such as TZM and W25ReHfC are very strong at temperature but require an oxidation resistant coating to survive the environment. Frank Ritzert of GRC is examining several different approaches to apply platinum to protect the underlying base wire materials from oxidation, including electro-deposition, chemical vapor deposition (CVD), and co-extrusion.




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 by 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.


The Seal Team maintains several web pages to disseminate publicly available information in the areas of turbine engine and structural seal development. Please visit these web sites to obtain past workshop proceedings and copies of NASA technical papers and patents. Readers may also want to browse the Tribology and Mechanical Components Branch Web Page that will link to the Seal web pages and other work being done in the Branch.

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