

## 2008 NASA Seal/Secondary Air System Workshop

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- Write to: NASA Center for AeroSpace Information (CASI) 7115 Standard Drive Hanover, MD 21076–1320

#### NASA/CP-2009-215677



## 2008 NASA Seal/Secondary Air System Workshop

Proceedings of a conference held at and sponsored by 2008 Seal/Secondary Air System Workshop NASA Glenn Research Center Cleveland, Ohio November 18, 2008

National Aeronautics and Space Administration

Glenn Research Center Cleveland, Ohio 44135

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#### **Executive Summary**

The 2008 NASA Seal/Secondary Air System Workshop covered the following topics: (i) Overview of NASA's new Orion project, (ii) Overview of NASA's fundamental aeronautics technology project, (iii) Overview of NASA Glenn's seal project aimed at developing advanced seals for NASA's turbomachinery, space, and reentry vehicle needs; (iv) Reviews of NASA prime contractor, vendor, and university advanced sealing concepts, test results, experimental facilities, and numerical predictions; and (v) Reviews of material development programs relevant to advanced seals development.

Mr. Baumeister reviewed the goals and objectives of NASA's project to develop the new Orion 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 an overview of NASA's fundamental aeronautics project that is developing advanced technologies for subsonic rotary-and fixed-wing aircraft and supersonic and hypersonic aircraft. Mr. Hendricks reviewed sustainable alternate aviation fuels under development, to confront both decreasing petroleum supplies and increased prices. NASA and other organizations are investigating synthetic and biomass fuels made from a number of sources including algae, halophytes, crop seed oils, and various waste products, amongst others. Dr. Steinetz presented an overview of NASA Glenn seal developments for both NASA's aeronautic and space projects. Glenn is developing the seals for NASA's new Low Impact Docking System (LIDS) that requires a robust seal design to resist the deleterious effects of space environments while exhibiting very low leakage. Glenn is also developing high-temperature seal technology for the Orion spacecraft's thermal protection system, requiring thermal barriers that can withstand temperatures over 2500 °F.

Turbine engine studies have shown that reducing parasitic flows through better sealing technologies will boost engine efficiency and reduce engine emissions and operating costs helping NASA meet many of the goals of the Fundamental Aeronautics Program. Mr. Munson presented an overview of foil face seal development to significantly reduce leakage flows in a turbine engine. This seal combines foil thrust bearing technology with face seal architecture. Ms. Proctor presented work underway at NASA Glenn on a new finger seal showing promise of noncontacting operation. Dr. Lattime shared efforts at Timken developing low torque seals for their product line. Mr. Ruggiero of GE Global Research reviewed their current progress in applying nonmetallic fiber brush seals. Dr. Chupp presented an overview of a Department of Energy (DOE) project called the Advanced IGCC/H<sub>2</sub> Gas Turbine including seal needs and development efforts underway.

New developments in structural seals were also discussed. Mr. Dunlap presented greater detail on the LIDS seals progress underway including extensive test fixtures under development at Glenn to evaluate both seal leakage and loads over the full operating temperature expected during the missions. Mr. Yetter presented design and analyses of their GaskO molded elastomer seals, the primary candidate for the LIDS docking interface amongst other locations on Orion. On the high temperature front, Mr. DeMange presented Glenn's efforts in developing a sealing system for the Orion Crew Exploration Vehicle Heat Shield. Mr. Newman presented their work in developing high-temperature spring preloaders and seals for ultra-high-temperature service (1600 to 1700 °F), utilizing single-crystal technology.

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NASA's Constellation Program  Joseph Baumeister, NASA Glenn Research Center
Fundamental Aeronautics Program Ajay Misra, NASA Headquarters
Overview of NASA Glenn Seal Project Bruce M. Steinetz, Patrick H. Dunlap, Jr., Margaret Proctor, Irebert Delgado, Joshua Finkbeiner, Henry deGroh, and Frank Ritzert, NASA Glenn Research Center; Christopher Daniels, The University of Akron; Jeff DeMange and Shawn Taylor, University of Toledo; Janice Wasowski and Ian Smith, The University of Akron; Nicholas Penney, Ohio Aerospace Institute; and Nicholas Garafolo, The University of Akron
Synthetic and Biomass Alternate Fueling in Aviation Robert Hendricks, NASA Glenn Research Center; and Dennis Bushnell, NASA Langley Research Center
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Design and Analysis of Molded Elastomer Seals Paul Yetter and Kai Zhang, Parker Hannifin
Overview of CEV Thermal Protection System Seal Development Jeff DeMange and Shawn Taylor, University of Toledo; Patrick Dunlap, Bruce Steinetz, Irebert Delgado, and Josh Finkbeiner, NASA Glenn Research Center; and John Mayer, Analex Corp
Ultra-High Temperature Metallic Seal/Energizer Development for Aero Propulsion and Gas Turbine Applications
Ken Cornett and Jesse Newman, Parker Hannifin Corporation; and Amit Datta, Advanced Components & Materials
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#### Vision for Space Exploration

Complete the International Space Station

Safely fly the Space Shuttle until 2010

Develop and fly the Crew Exploration Vehicle (by 2015)

Return to the moon (by 2020)

Sustained and affordable human and robotic program

Develop innovative technologies, knowledge, and infrastructures

Promote international and commercial participation



NASA is building a new spacecraft that will become America's primary vehicle for human space exploration in the next decade. The new spacecraft, Orion, is part of the Constellation Program to send explorers to the moon and onward to other destinations in the solar system.



NASA has established 6 Themes for Exploration

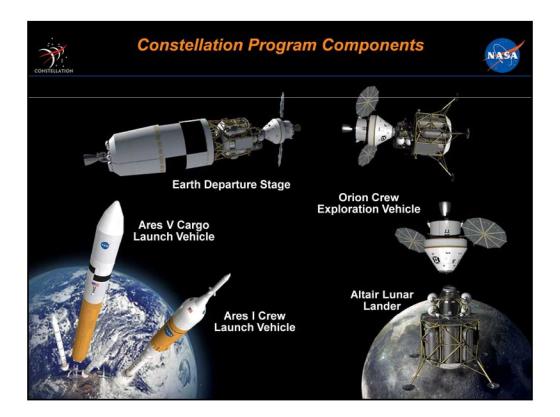
USE THE MOON: Reduce risks and cost and increase productivity of future missions by testing technologies, systems, and operations in a planetary environment other than the Earth

PURSUE SCIENTIFIC: Engage in scientific investigations of the Moon (solar system processes), on the Moon (use the unique environment), and from the Moon (to study other celestial phenomena)

EXTEND PERMANENT HUMAN PRESENCE: Develop the capabilities and infrastructure required to expand the number of people, the duration, the self-sufficiency, and the degree of non-governmental activity

EXPAND EARTH'S ECONOMIC SPHERE: Create new markets based on lunar activity that will return economic, technological, and quality-of-life benefits

ENHANCE GLOBAL SECURTIY: Provide a challenging, shared, and peaceful global vision that unites nations in pursuit of common objectives ENGAGE, INSPIRE: Excite the public about space, encourage students to pursue careers in high technology fields, ensure that individuals enter the workforce with the scientific and technical knowledge necessary to sustain exploration

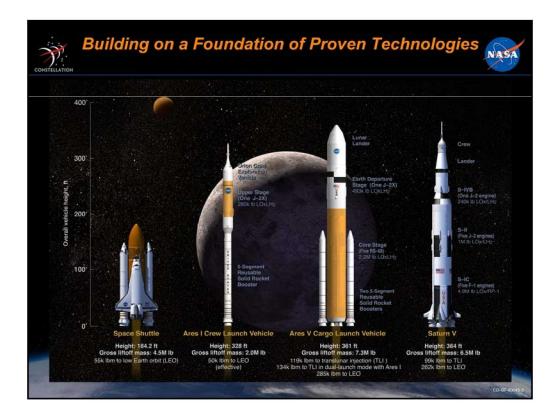


The Orion crew exploration vehicle will be launched into Earth orbit by the Ares I crew launch vehicle. Orion and its launch abort system will be placed at the top of the Ares I rocket to eliminate the threat to the crew from falling debris on launch and ascent.

For missions to the moon, Orion will dock in low Earth orbit with a lunar lander module, Altair, and an Earth departure stage. The Earth departure stage will propel Orion and Altair to the moon.

Once they have reached lunar orbit, astronauts will use the landing craft to travel to the moon's surface.

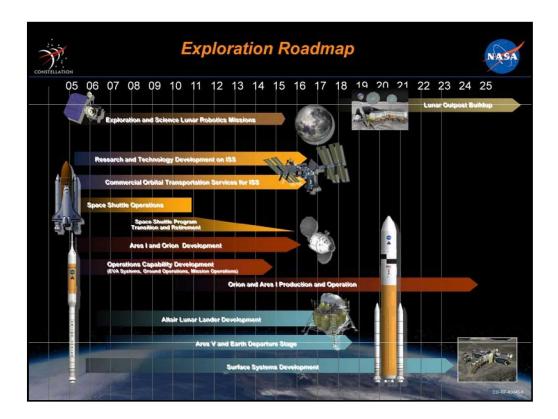
Orion will stay in lunar orbit waiting for the crew to return in a part of the lander called the ascent module. When all the astronauts are back inside Orion, the spacecraft will break out of the lunar orbit and head home to Earth, propelled by the main engine of its service module.



To make these new launch systems safer and simpler, NASA is using proven technologies from the Apollo Saturn V and the Space Shuttle programs. Common propulsion elements between the two systems will reduce operations costs to promote the long-term investigation of Earth's cosmic neighborhood and worlds beyond.

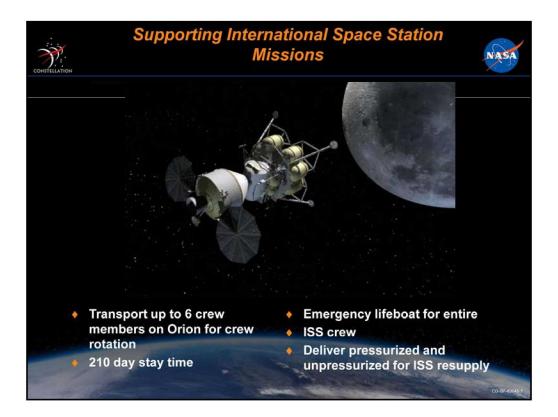
The Ares I includes a first stage evolved from the Shuttle's reusable solid rocket booster and an upper stage powered by a J-2X engine, with heritage from the Saturn V. The Ares I will carry the Orion crew exploration vehicle to Earth orbit.

The Ares V propulsion includes two reusable solid rocket boosters, much like the booster used in the Ares I's first stage. It also uses five commercial RS-68 engines fueled by a 33-foot-diameter tank, close in size to the Saturn V. The Earth departure stage, which transports the lunar lander and Orion toward the Moon, is powered by a J-2X engine, the same as that used for the Ares I's upper stage.



Information based on a September 25, 2008, industry briefing.

The first crewed flight of the Orion spacecraft aboard an Ares I rocket is scheduled for no later than 2015, when it will fly to the International Space Station. Altair's first landing on the moon with an astronaut crew is planned for no later than 2020.



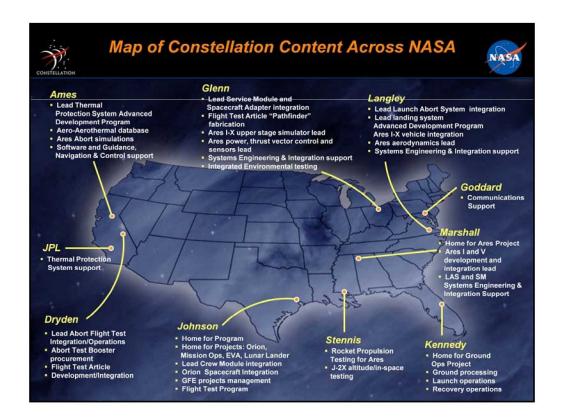
NASA has engaged its workforce to enable the safe and reliable transport of humans to the International Space Station, moon and Mars.

The International Space Station (ISS) is the largest and most complicated spacecraft ever built. It is allowing NASA to conduct scientific research to improve life on Earth and to prepare for long-duration space flights to the moon and other destinations.



### The main components are:

- 1. The launch abort system
- 2. The crew exploration vehicle (Orion)
- 3. The service module
- 4. The jettison panels
- 5. The spacecraft adapter

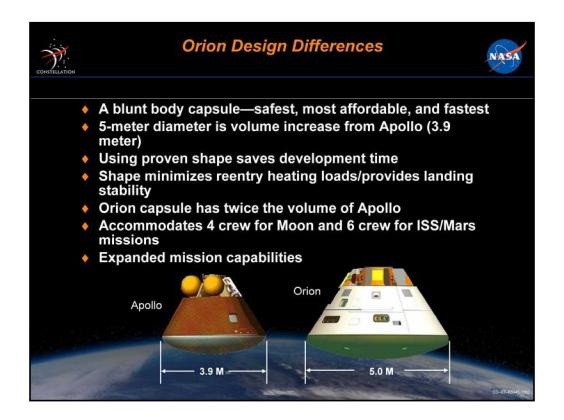


#### **KEY POINTS:**

Constellation Program work is distributed across the country.

This chart shows areas of responsibility at the 10 NASA centers.

Contractors have facilities at many other locations that also support Constellation.



Orion will be similar in shape to the Apollo spacecraft, but larger, with 2-1/2 times the volume of the Apollo capsule.

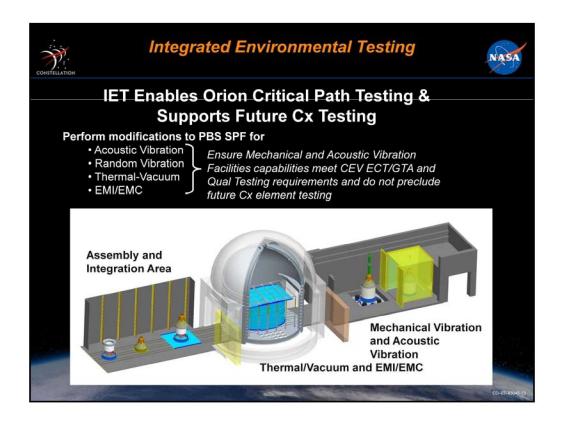


#### Crew Module couch area exposed

Diameter – 16.5 ft. (5 m)
Pressurized volume (total) – 690.6 ft3
Habitable volume (net) – 316 ft3
Propellant – hydrazine
Oxygen/nitrogen/water – 51.2 lbs
Landing weight – 18,345 lbs
Can be reused up to 10 flights



Orion will use 5.5m (18ft) in diameter radial UltraFlex solar arrays. Recent tests validated the UltraFlex array's acceleration capability, up to 2.7g, required for Orion's lunar missions. Smaller-scale arrays are powering NASA's Phoenix Lander that is on Mars.



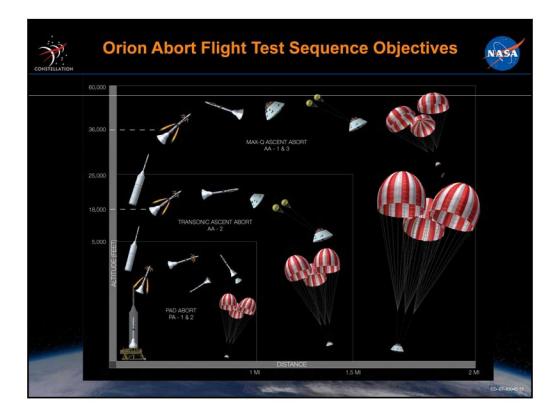
The NASA Glenn Research Center operates the Plum Brook Station—a vast complex over 10 square miles near Sandusky, Ohio. Plum Brook Station is home of the SPF which houses the world's largest space environment simulation chamber.

The chamber's wide-ranging capabilities have been extensively used to test launch vehicle payload fairings, orbital hardware including International Space Station systems, and planetary landing systems like the Mars Pathfinder and the Mars Exploration Rovers' airbag systems. SPF will serve as the primary location for Integrated Environmental Testing (IET) of the Orion Crew Exploration Vehicle (CEV) Ground Test Article and Qualification vehicle. SPF's unique capabilities will permit complete environmental testing of the Orion CEV in a single facility at a single location.

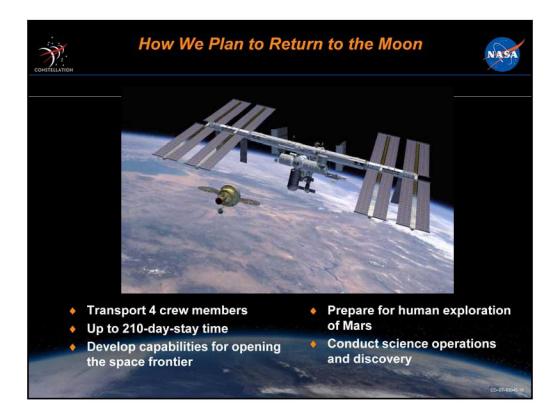
This "one-stop shopping" capability reduces project risk by eliminating the need to ship the vehicle to different locations to complete the gamut of testing required for design and production necessary for human space flight. For more information go to exploration.nasa.gov.



Last October, a \$50 million renovation project began at Plum Brook, home of the world's largest thermal vacuum chamber. The upgrade to the two separate vibration chambers— The Reverberant Acoustic Test Facility (RATF) and the Mechanical Vibration Facility (MVF) — will support vibration and acoustic testing of the Orion Crew Exploration Vehicle, exposing it to the shakes, rattles and rolls of a spaceflight.



- Propulsion system burns can be initiated in one-third of the time budgeted for Apollo.
- Abort landings can be better controlled, with free-fall time being a key parameter.
- Test Designation 57AS
- 7.5% model/3 configurations
- Tested in GRC 8X6 aero-acoustic tunnel
- 100 Pressure Sensors on Model
- 57AS confirms the same quiet levels for ALAS11-rev3 for both nominal ascent and unpowered abort situation



For missions to the moon, Orion will dock with a lunar landing module and Earth departure stage in low Earth orbit. The Earth departure stage will propel Orion and the module to the moon. Once they have reached the moon's orbit, astronauts will use the lunar landing craft to travel to the moon's surface. Orion will stay in the lunar orbit awaiting return of the crew. The astronauts will return to the orbiting Orion using a lunar surface ascent module. When the crew has reunited with the Orion spacecraft, the service module main engine will provide the power that Orion needs to break out of the lunar orbit and return to Earth.



#### Descent module

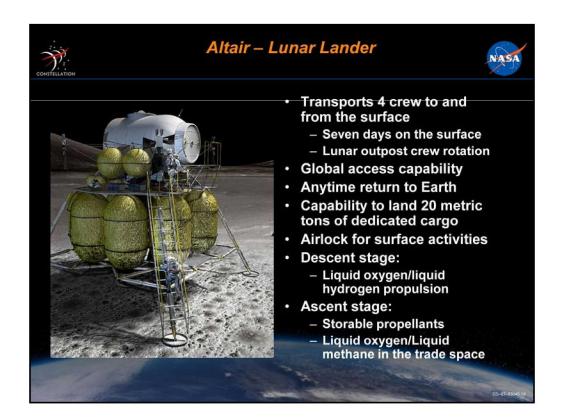
Propulsion for LOI and powered descent Power during lunar transit, descent, and surface ops Platform for lunar landing/liftoff of ascent module

#### Ascent module

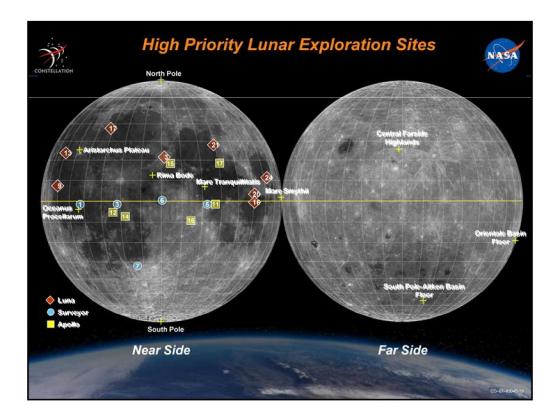
Propulsion for ascent from lunar surface Habitable volume for four during descent, surface, and ascent operations Contains cockpit and majority of avionics

#### Airlock

Accommodates 2 astronauts per ingress/egress Connected to ascent module via short tunnel Remains with descent module on lunar surface

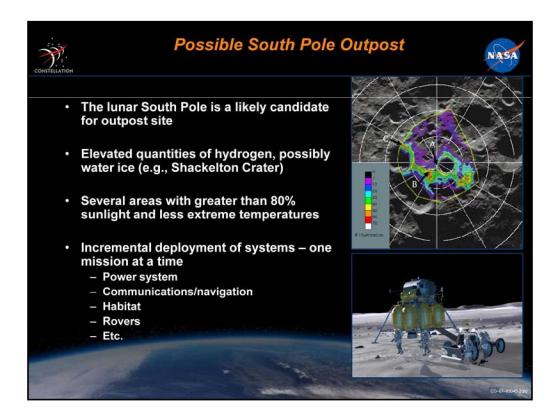


Altair will be capable of landing four astronauts on the moon, providing life support and a base for weeklong initial surface exploration missions, and returning the crew to the Orion spacecraft that will bring them home to Earth. Altair will launch aboard an Ares V rocket into low Earth orbit, where it will rendezvous with the Orion crew vehicle.



NASA's Lunar Reconnaissance Orbiter, or LRO, is scheduled to launch April 24 aboard an Atlas V rocket. The orbiter will carry seven instruments to provide scientists with detailed maps of the lunar surface and enhance our understanding of the moon's topography, lighting conditions, mineralogical composition and natural resources. Information gleaned from LRO will be used to select safe landing sites, determine locations for future lunar outposts and help to mitigate radiation dangers to astronauts.

Note: Apollo was equatorial and "front-side" only.



Accompanying the Lunar Reconnaissance Orbiter will be the Lunar Crater Observation and Sensing Satellite, a mission that will impact the moon's surface in its search for water ice. Right now the Shackelton Crater at the South Pole, the largest basin in the solar system, is being targeted for possible water. It is also in almost constant sunlight. The Shackelton crater lies entirely within the rim of the immense South Pole—Aitken basin, which is the largest known impact formation in the Solar system.



Recently, two NASA instruments traveled to the moon to begin a two—year mission of mapping the lunar surface. The Moon Mineralogy Mapped will assess mineral resources, and the Miniature Synthetic Aperture Radar, or Mini-SAR, will map the polar regions and look for ice deposits. Data from the two instruments will contribute to NASA's increased understanding of the lunar environment as it implements the nation's space exploration policy, which calls for robotic and human missions to the moon.

The Moon Mineralogy Mapped is a state-of-the-art imaging spectrometer that will provide the first map of the entire lunar surface at high spatial and spectral resolution, revealing the minerals that make up the moon's surface. Scientists will use this information to answer questions about the moon's origin and geological development, as well as the evolution of terrestrial planets in the early solar system. The map also may be used by astronauts to locate resources, possibly including water, that can support exploration of the moon and beyond.

The Mini-SAR data will be used to determine the location and distribution of water ice deposits on the moon. Data from the instrument will help scientists learn about the history and nature of objects hitting the moon, and the processes that throw material from the outer solar system into the inner planets.



It is planned that one day Mars-bound vehicles will be assembled in low-Earth orbit. Orion will be the Earth entry vehicle for lunar and Mars returns.

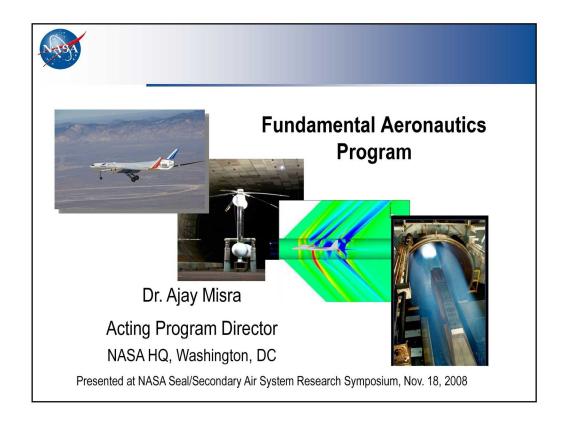


For more information go to:

www.nasa.gov

#### FUNDAMENTAL AERONAUTICS PROGRAM

Ajay Misra
National Aeronautics and Space Administration
Headquarters
Washington, DC



# **Fundamental Aeronautics Program** Dr. Ajay Misra **Acting Program Director** NASA HQ, Washington, DC

Presented at NASA Seal/Secondary Air System Research Symposium, Nov. 18, 2008



# **ARMD Mission and Principles**

# The Overarching Mission of NASA's Aeronautics Research Mission Directorate (ARMD):

- To advance U.S. technological leadership in aeronautics in partnership with industry, academia, and other government agencies that conduct aeronautics-related research.
- ARMD supports the Agency's goal of developing a balanced overall program of science, exploration, and aeronautics, and ARMD's research plans also directly support the National Aeronautics R&D Policy and accompanying Executive Order 13419.

### The Three Core Principles of ARMD:

- We will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of Aeronautics for the Nation in all flight regimes.
- We will focus our research in areas that are appropriate to NASA's unique capabilities.
- We will directly address the fundamental research needs of the Next Generation Air Transportation System (NextGen) in partnership with the member agencies of the Joint Planning and Development Office (JPDO).



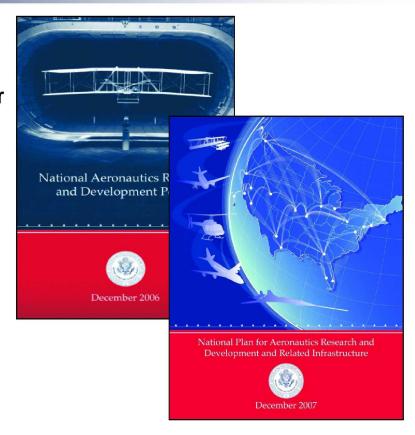
# ARMD Addresses National Aeronautics R&D Policy and Plan Objectives

## Policy

- Executive Order signed December 2006
- Outlines 7 basic principles to follow in order for the U.S. to "maintain its technological leadership across the aeronautics enterprise"
- Mobility, national security, aviation safety, security, workforce, energy & efficiency, and environment

## •Plan (including Related Infrastructure)

- Plan signed by Pres. Bush December 2007
- Goals and Objectives for all basic principles (except Workforce, being worked under a separate doc)
- Summary of system-level challenges in each area and the facilities needed to support related R&D
- Specific quantitative targets where appropriate



Executive Order, Policy, Plan, and Goals & Objectives all available on the web For more information visit: http://www.ostp.gov/cs/nstc/documents\_reports



# Research in Fundamental Aeronautics Will Enable Next Generation Air Transportation System (NextGen)

### **NextGen Vision for Environment:**

Provide environmental protection that allows sustained aviation growth



### Factors:

- 2X increase in system by 2025
- Fundamental system changes
- Increased importance of environment
- Vision to grow aviation while reducing significant environmental impacts

### NASA Research Activities:

- Aggressive goals for reducing noise, emissions, and fuel burn for subsonic fixed wing, supersonic, and subsonic rotary wing vehicles
- Research the issues associated with deploying new or advanced air vehicles within NextGen





# **Aeronautics Programs**

### **Fundamental Aeronautics Program**

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

### **Aviation Safety Program**

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



### Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.



## **Fundamental Aeronautics Program Goals**

- Conduct long-term cutting-edge research in all flight regimes to address main concerns of modern air transportation
  - Public concerns over noise and emissions
  - Sustainability of affordable air travel with increasing cost and availability of jet fuel
  - Providing for *mobility* to meet increasing demand for air transportation
  - Lack of progress towards faster means of transportation
- Enhance capability for future space exploration by addressing aeronauticsrelated challenges associated with
  - Airbreathing access to space
  - Entry into a planetary atmosphere











# **NASA Fundamental Aeronautics Program**

### Hypersonics

 Conduct fundamental and multidisciplinary research to enable airbreathing access to space and high mass entry into planetary atmospheres

### Supersonics

- Eliminate environmental and performance barriers that prevent practical supersonic vehicles (cruise efficiency, noise and emissions, performance)
- Develop supersonic deceleration technology for Entry, Descent, and Landing into Mars



Develop concepts/technologies for enabling dramatic improvements in *noise*,
 *emissions and performance* (fuel burn and reduced field length)
 characteristics of subsonic/transonic aircraft



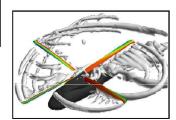
Radically Improve capabilities and civil benefits of rotary wing vehicles (vs fixed wing) while maintaining their unique benefits

<u>Common for all projects</u>: Develop **prediction and analysis tools** for reduced uncertainty in design process and advanced **multidisciplinary design and analysis capability** to guide our research and technology investments and realize integrated technology advances in future aircraft









# SFW System Level Metrics

.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts







## **Approach**

- Enable Major Changes in Engine Cycle/Airframe Configurations
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes
- Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies
- Conduct Discipline-based Foundational Research

<sup>\*\*</sup> An additional reduction of 10 percent may be possible through improved operational capability

<sup>\*</sup> Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

<sup>---</sup> EIS = Entry Into Service; IOC = Initial Operating Capability



# Performance - Fuel Burn - N+1

### **Detailed System Analysis**

### "N + 1" Conventional Small Twin

- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies

25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials

+50 deg. F compressor temperatures (T3)

+100 deg. F turbine rotor inlet temperatures

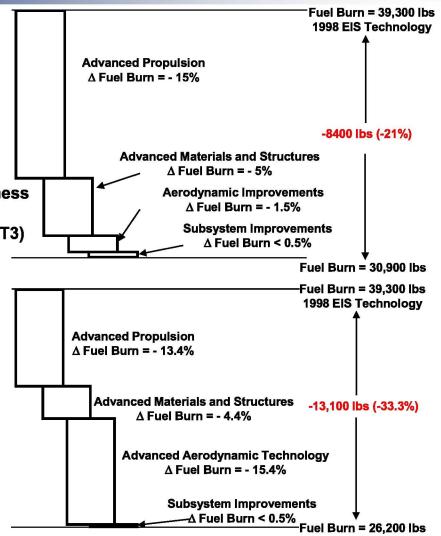
- -15% airframe structure weight
- -1% total vehicle drag
- -15% hydraulic system weight

### "N + 1" Advanced Small Twin □

All technologies listed above plus:

 Hybrid Laminar Flow Control
 67% upper wing,
 50% lower wing,
 tail, nacelle

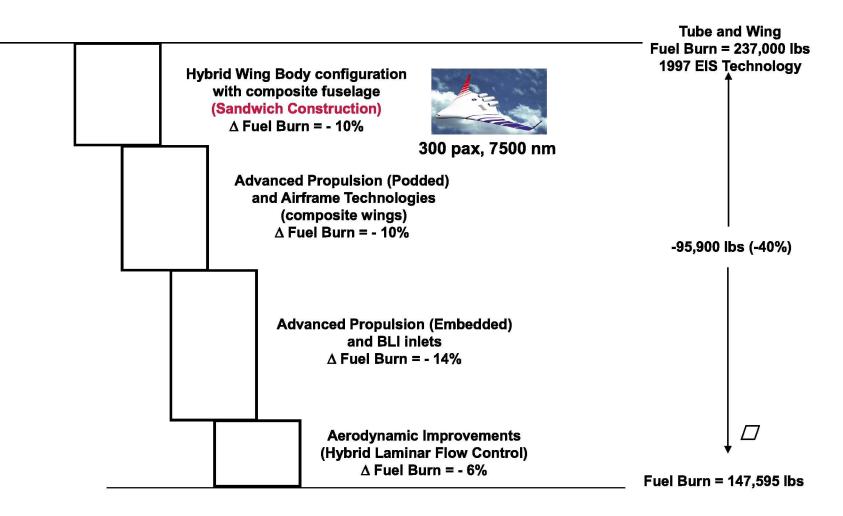
 Result = -17% total vehicle drag





# Performance - Fuel Burn - N+2

### **Detailed System Analysis**





# **Supersonics – System Level Goals and Metrics**

	N+1 Supersonic Business Jet Aircraft (2015)	N+2 Small Supersonic Airliner (2020)	N+3 Efficient Multi-Mach Aircraft (2030-2035)
Cruise Speed	Mach 1.6-1.8	Mach 1.6-1.8	Mach 2.0 Unrestricted Flight 1.6-2.0 Low Boom
Range (nmi)	4,000	4,000	6,000
Payload	6-20 pax	35-70 pax	100-200 pax
Sonic Boom	65-70 PLdB	65-70 PLdB	65-70 PLdb low boom flight 75-80 PLdB unrestricted flight
Airport Noise (cum below Stage 3)	10 EPNdB	10-20 EPNdB	20-30 EPNdB
Cruise Emissions Cruise Nox El	Equivalent	<10	<5
Other	to Subsonic	?	?
Fuel Efficiency	Baseline	15% Improvement	25% Improvement

N+1 "Conventional"



N+2 Small Supersonic Airliner



N+3 Efficient Multi-Mach Aircraft





## **Supersonics Project Technical Elements - Part 1**

Deliver Knowledge, Capabilities, and Technologies Addressing Supersonics Challenges

### **Cruise Efficiency**

- Tools and technologies for integrated propulsion and vehicle systems level analysis and design
- High performance propulsion components
- Drag reduction technologies

### **Airport Noise**

 Improved supersonic jet noise models validated on innovative nozzle concepts

### **Sonic Boom Modeling**

- Realistic propagation models
- Indoor transmission and response models

### **Aero-Propulso-Servo-Elasticity**

- ASE/flight dynamic and propulsion analysis and design tool development and validation
- APSE analysis and design tools

# **Light Weight and Durability at High Temperature**

 Materials, test and analysis methods for airframe and engine efficiency, durability and damage tolerance

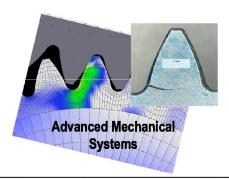
### **High Altitude Emissions**

- Improved prediction tools
- Low emissions combustors



# Subsonic Rotary Wing (SRW) Project

# Goal: Radically Improve the capabilities and civil benefits of rotary wing vehicles

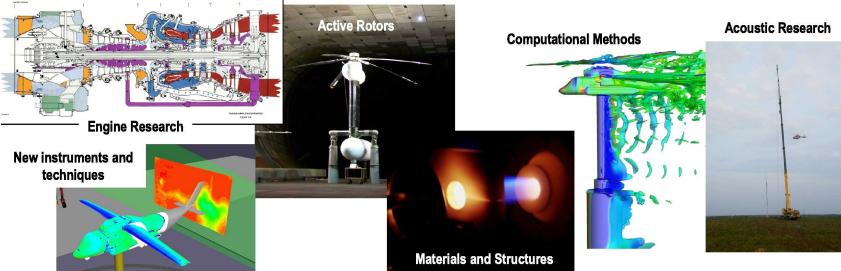


# Civil Requirements (support NextGen) Reduce airport congestion Community acceptance Reduce emissions Research Areas Increase speed and Noise propagation Increase propulsion

Decrease cost, increase utility

Safe operations for advanced concepts

Increase speed and range
Noise propagation and reduction
Increase propulsion efficiency
Increase payload
Improve control systems





# **SRW High Level Goals**

- Increase speed and range
  - Increase cruise speed of wide range of configurations by 100 knots
- Noise propagation and reduction
  - External noise contained within landing area
  - Internal noise reduced to 77dB
- Increase propulsion efficiency
  - 50% reduction in main rotor rpm
- Increase payload
  - 90 passengers, 10 tons
- Improve control systems
  - Achieve L1 Handling Qualities for advanced, high-speed concepts



# **Hypersonics-HRRLS Project Focus**

Highly Reliable Reusable Launch Systems (HRRLS) NASA Two Stage To Orbit (TSTO) Reference Vehicle

Ceramic Matrix Composites Structurally-integrated TPS Hot Structures Actively-cooled propulsion Integrated Controls

CFD Methods
Physics-based Models
Physics-based MDAO
Vehicle Studies

Turbine-based Combined Cycle Propulsion Rocket-based Combined Cycle Propulsion Combustion Physics Non-Intrusive Diagnostic Tools

### Addressing challenges in:

- Large uncertainty in prediction of aerothermal environment
- Integration, operability, and control of multi flow-path propulsion system
- Lightweight high temperature materials and structures
- High-fidelity multidisciplinary design analysis and optimization tools



# **Hypersonics HRRLS Goals**

- Decrease uncertainty in aeroheating prediction by 50%
- Develop multi-use 3000°F structurally-integrated Thermal Protection Systems
- Develop air-breathing propulsion technology for Two-Stage-to-Orbit Vehicles
- Develop physics-based integrated multi-disciplinary design tools



# **High-Mass Mars Entry Systems (HMMES)**

### **Challenge**

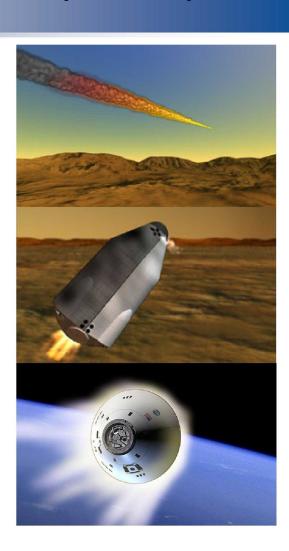
Current technologies for atmospheric entry fall short of what is needed for landing high masses (> 1 MT) on Mars. Current studies indicate landed-mass capabilities must increase by two orders of magnitude to permit human-scale Mars landings.

### **Goal**

Develop new Entry, Descent, and Landing (EDL) technologies, along with the tools to design and analyze them, which enable High-Mass Mars Entry Systems.

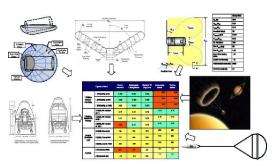
### **Projects**

Hypersonics, Supersonics





## **Aeronautics Challenges for High-Mass Mars Entry Systems (HMMES)**



### **Vehicle System**

- Physics-based models
- Physics-based MDAO
- Innovative concepts



**Propulsive Deceleration** 

- Analytical tools and methods
- Reaction control systems



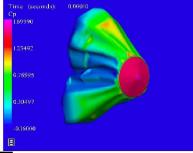


- Performance

Flexible TPS

### Fluid-Structures Interaction

- Simulation tools for design
- Flexible membrane structures
- High-speed deployment





### **Advanced Ablators**

- New materials
- High fidelity ablation models

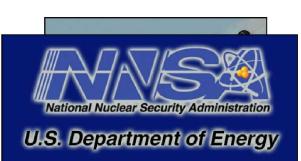


**Inflatable Decelerator** 



# **Cementing Partnerships...**



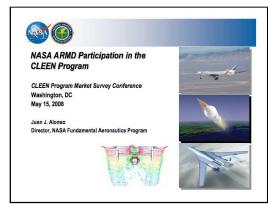


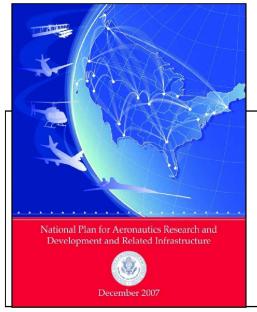






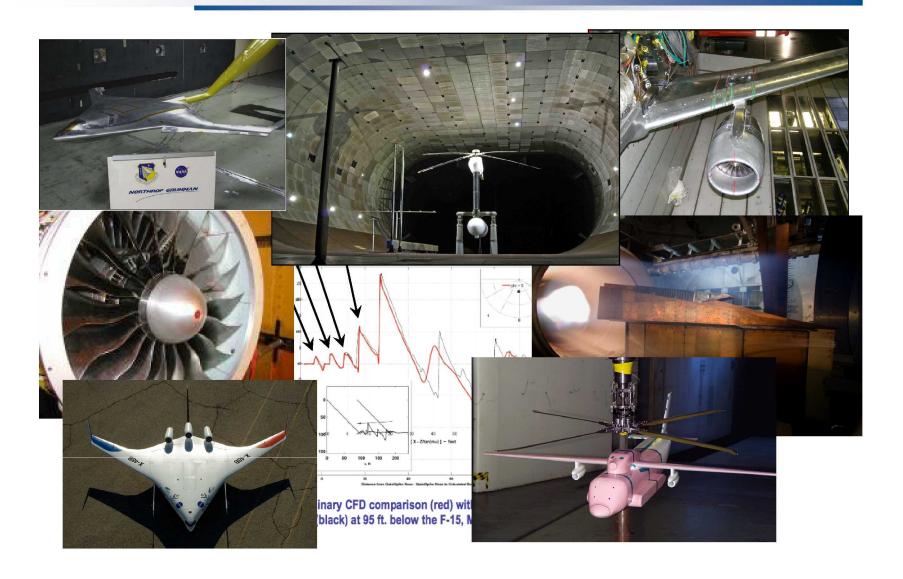








# ...Delivering Results





# **Technical Accomplishments - FAP**



- Completed 30 X-48B flights to demonstrate low speed flying, handling capabilities, and flight under stall conditions
  - Partnership with Boeing and AFRL



- Completed integration and interference test of high by-pass geared turbofan engine in ARC 11-ft tunnel to address integration of high bypass engine with the aircraft
  - Partnership with Pratt and Whitney



- Completed smart rotor testing in NFAC to demonstrate effectiveness of flap for noise and vibration control and to validate acoustic prediction code
  - Partnership with DARPA and Army



- SJX61-2 engine flight qualified for X-51A test vehicle through testing in high temperature wind tunnel
  - Partnership with Boeing, Pratt and Whitney, and AFRL

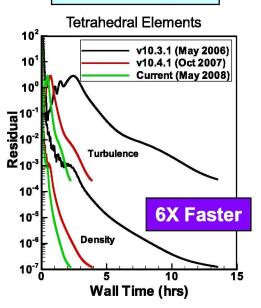


- Completed flight validation of non-coalescing shocklets produced from Quiet Spike configuration
  - Partnership with Gulfstream



# Improving Time-to-Solution for Unstructured Grids

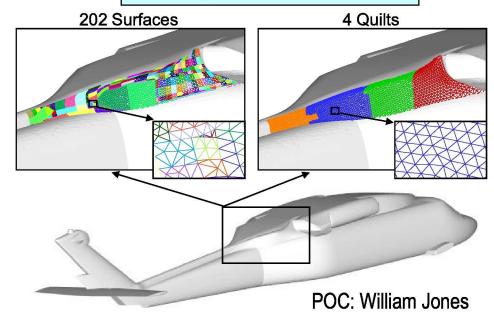
# Improve FUN3D Efficiency



- 5.6M node Drag Prediction Workshop Wing/Body
- 64 Processors
- 3.6 Ghz P4 2GB w/GigE

**POC: Eric Nielsen** 

### "Quilting" for Grid Generation



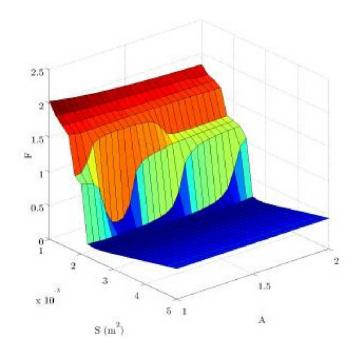
- Higher-Order Time (4th) for Moving Grids
- Overset Mesh-Movement Masking
- •1/N<sub>BLADE</sub> per Revolution Loose Coupling

FUN3D collaborative software development framework: new capabilities continuously and seamlessly inherited by all code users



# Multidisciplinary Analysis and Optimization is a Key Element of All Projects

"Develop fast and effective physics based multi-disciplinary analysis and design tools with quantified levels of uncertainty that enable virtual expeditions through the design space."



Virtual Expeditions through Design Space

- Enable unconventional vehicle synthesis and analysis through a shift from empirically based, nonintegrated, low fidelity deterministic methods to more physics based, integrated, variable fidelity probabilistic methods.
- Enable the critical sizing and early configuration trade studies of both conventional and unconventional designs.



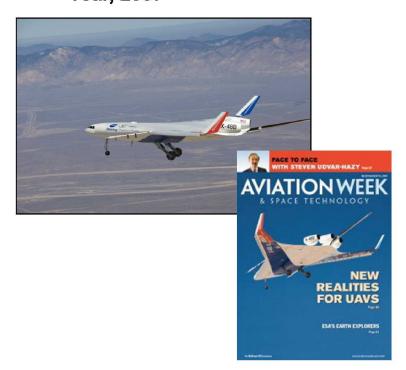
# Being Recognized for What We Do

Quiet Spike: Gulfstream, NASA

X48B: Boeing, NASA, AFRL

Thank you to our sponsors. AVIATION WEEK would like to thank all of our sponsors for making the 51st Annual Laureate Awards, presented on March 4, 2008, a memorable and successful evening. The Quiet Spike Flight Yest NASA/ Gulfstream Team Robert Cowart, Project Engineer, Guifstream Aerospace. Donald Howe, Staff Scientist, Technical Fellow, Gulfstream Aerospace, Leslie Molzahn, Flight Test Operations Engineer, NASA Dryden Research Center: Frank Simmons III, PhD. P.E., Gulfstream Aerospace, and James Smolka. Research Test Pilot, NASA Dryden Research Center Capt. Karen D. Airlines, Capt. Rei Manager, UPS Al Jack Pelton, Chairman, CEO and President, Cessna Aircraft

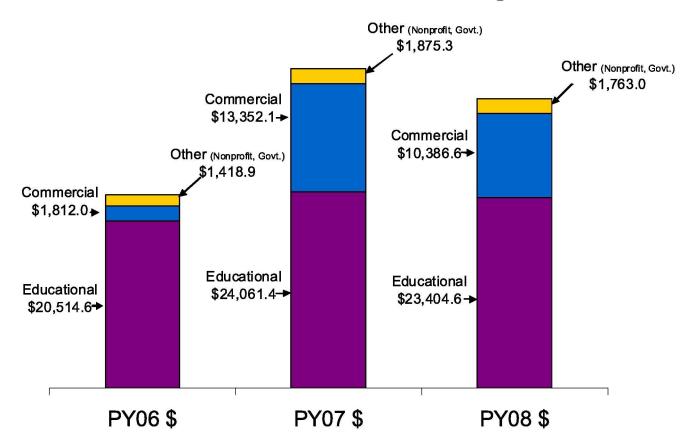
Time Magazine: Best Innovations of the Year, 2007





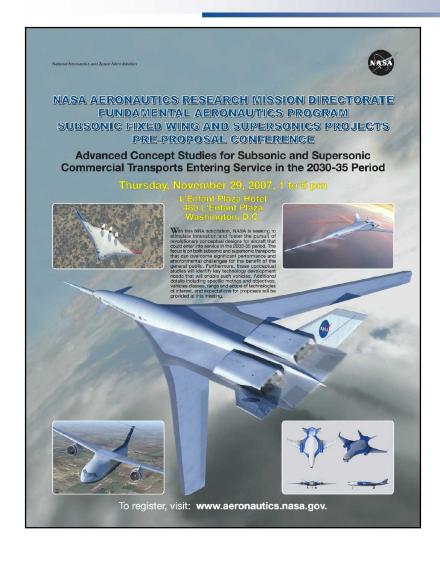
# **Fundamental Aeronautics Program**

### **Fundamental Aeronautics NRA Funding Trends**





# NASA NRA Pre-Proposal Conference, Nov 29



- Advanced Concept Studies for Subsonic and Supersonic Commercial Transports Entering Service in the 2030-35 Period
- November 29, 2007, 1-5 pm
- L'Enfant Plaza Hotel, Washington, DC
- Stimulate innovation and foster the pursuit of revolutionary conceptual designs for aircraft that could enter service in the 2030-35 time period. Overcome significant performance and environmental challenges for the benefit o the public.
- Phase I: 12-Months, Phase II: 18 Months to Two Years, with significant technology demonstration



### NASA N+3 NRA Selections

- Six teams have been selected and awards are in place. Four subsonic teams and 2 supersonic teams:
  - Subsonic Ultra-Green Aircraft Research (SUGAR), Boeing
  - Advanced Concept Studies for Subsonic Commercial Transport Aircraft Entering Service in the 2030-35 Time Period, Northrop Grumman
  - Aircraft & Technology Concepts for an N+3 Subsonic Transport, MIT
  - Small Commercial Efficient & Quiet Air Transportation for 2030-35, GE Aviation
  - NASA N+3 Supersonics Three Generations Forward in Aviation Technology, Lockheed Martin
  - Advanced Concept Studies for Supersonic Commercial Transport Aircraft Entering Service in the 2030 -35 Time Period, Boeing
- Phase I: 18-Months, Phase II: 18 Months to Two Years, with significant technology demonstration
- Pursuing significant improvements to address some of the challenges of NextGen









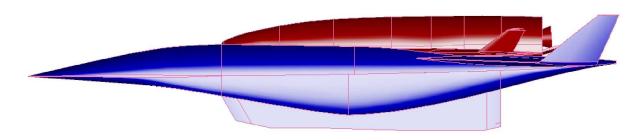






# **National Hypersonic Science Centers**

✓ Laminar-Turbulent Transition (Boundary Layer Control)



✓ Materials & Structures

✓ Air-breathing Propulsion

Joint Effort with AFOSR
3 Centers

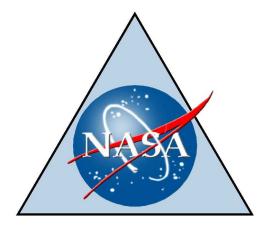
5 Years maximum with annual renewal \$30M maximum for all Centers combined White Papers Due October 17, 2008 Final proposals due December 12, 2008



# **Partnering Philosophy**

- Enhance the state of Aeronautics for the Nation
- Help foster a collaborative research environment in which ideas and knowledge are exchanged across all communities
- Maximize the return on investment to the taxpayer (our main stakeholder)
- Every element of our portfolio targets innovative, pre-competitive research that will advance our Nation's aeronautical expertise
- In accordance with NASA's Space Act (as amended) and the National Aeronautics R&D Policy, we will provide for the widest practical and appropriate dissemination of our research results (consistent with national security and foreign policy)

Universities NRA/TWGs/TIMs



Government Agencies MOUs/TWGs/TIMs

Industry
NRA/SAAs/TWGs/TIMs



# Learn more about NASA Aeronautics.....

# www.aeronautics.nasa.gov

Overview of the entire NASA Aeronautics Program

- Fundamental Aeronautics Program
- Aviation Safety Program
- Airspace Systems Program
- Aeronautics Test Program

# www.aeronautics.nasa.gov/fap/index.html

Overview of the entire NASA Fundamental Aeronautics Program

- Subsonic Fixed Wing Project
- Subsonic Rotary Wing Project
- Supersonics Project
- Hypersonics Project

### **OVERVIEW OF NASA GLENN SEAL PROJECT**

Bruce M. Steinetz, Patrick H. Dunlap, Jr., Margaret Proctor, Irebert Delgado,
Joshua Finkbeiner, Henry deGroh, and Frank Ritzert
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Christopher Daniels The University of Akron Akron, Ohio

Jeff DeMange and Shawn Taylor University of Toledo Toledo, Ohio Janice Wasowski and Ian Smith The University of Akron Akron, Ohio

Nicholas Penney Ohio Aerospace Institute Brook Park, Ohio

Nicholas Garafolo The University of Akron Akron, Ohio



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.

Registration at OAI	8:00-8:30
Introductions	8:30-8:50
Introduction	Dr. Bruce Steinetz, Robert Hendricks/NASA Glenn
Welcome	Dr. Jih-Fen Lei, Director, R&T Dir./NASA GRC
Program Overviews and Requirements	8:50-10:50
Orion /Altair Project Overview	Mr. Joseph Baumeister/NASA GRC CEV Proj. Off.
Overview of the NASA Fundamental Aeronautics Prog.	Dr. Ajay Misra /NASA Headquarters
Overview of NASA Glenn Seals Projects	Dr. Bruce Steinetz/NASA GRC
Sustainable Secure Alternate Aviation Fueling	Mr. Robert Hendricks/NASA GRC
Break	10:50 -11: 05
Turbine Seal Development Session I	11:05-12:30
Foil Face Seal Development	Mr. John Munson/Rolls Royce
Preliminary Test Results of a Non-Contacting Finger Seal on a Herringbone-Grooved Rotor	Ms. Margaret Proctor, Irebert Delgado/NASA GRC
Low-Torque Seal Development at the Timken Co.	Mr. Scott Lattime, Richard Borowski/Timken Co.
Lunch (OAI Sun Room)	12:30-1:30

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.

	New York Control of the Control of t
Turbine Seal Development Session II	1:30-2:20
An Overview of Non-Metallic Brush Seal Technology Update on DOE Advance IGCC/H2 Gas Turbine	Dr. Eric Ruggiero/GE Global Research Center Dr. Ray Chupp/GE Energy
opdate 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 System 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 To attend: Please sign up at registration table	6:30

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.

# Outline Seal Team Organization and Members Turbine Seals Challenges Ongoing GRC Project Space Exploration Seals Ongoing GRC Projects Docking and Berthing Seals CEV Heat Shield Interface Seals Hypersonic Vehicle Seals Development Goals High Temp. Preloader Material Assessments

5

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

NASA Glenn Research Center

# NASA Glenn Seal Team: Turbomachinery Seals Seal Team Leader: Bruce Steinetz (RX) Structures and Materials Division/RX Turbomachinery Seals Shaft Seals Develop high-speed, high-temperature, non-contacting, low-leakage turbomachinery seals. P.I./P.O.C.: Margaret Proctor I. Delgado, J. Flowers

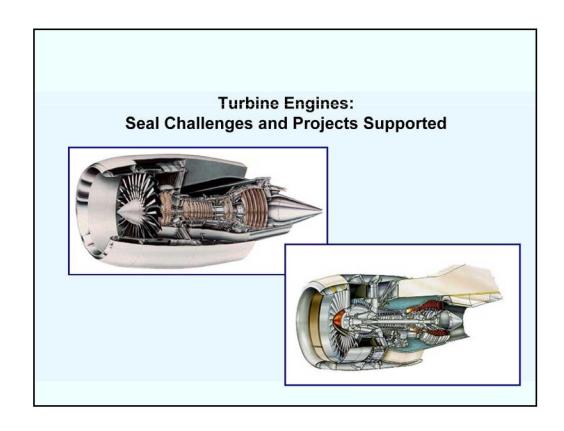
As NASA pursues research in Fundamental Aeronautics, advanced seal development is important. A key area that NASA Glenn is pursuing includes non-contacting shaft seals to reduce leakage enabling lower specific fuel consumption and emissions and increase engine service lives. Members of the Turbomachinery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

Seal Team Leader: Bruce Steinetz (RX) Structures and Materials Division/RX  Structural Seals			
<ul> <li>Develop space-rated, low-leakage, long- life docking system seals</li> </ul>	<ul> <li>Develop heat-resistant thermal barriers/ seals for future re-entry vehicles</li> </ul>		
<ul> <li>Co-P.I.s: Pat Dunlap, Chris Daniels</li> <li>H. DeGroh, J. Wasowski, I. Smith,</li> <li>N. Penney, N. Garafolo, Analex, Other</li> </ul>	Co-P.I.s: Pat Dunlap, Jeff DeMange  I. Delgado, S. Taylor, J. Finkbeiner, Analex, Other		
Hypersonic Vehicle Seals	Lunar Surface Operation Seals		
<ul> <li>Develop heat-resistant thermal barriers/ seals for future hypersonic vehicles &amp; propulsion systems.</li> </ul>	<ul> <li>Develop dust-resistant, low-leakage, long- life seal technology for dusty environments.</li> </ul>		
Co-P.I.s: Pat Dunlap, Jeff DeMange  – J. Finkbeiner, F. Ritzert, S. Taylor, Analex, Other	Co-P.I.s: Irebert Delgado, Margaret Proctor		
Analex Engineering Design Staff:	Technician Other Support:		
M. Robbie, G. Drlik, A. Erker, J. Mayer	Support:   B. Banks, S. Miller,		

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 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

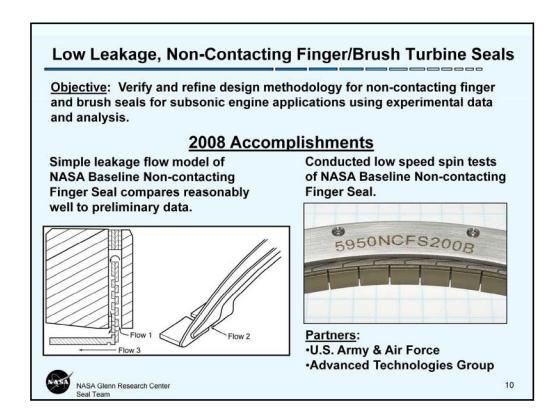
- Minimize heat generation

- GRC non-contacting seal project goal:
  - Develop non-contacting seal designs and design methods to enable lowleakage and virtually zero wear:
    - » Demonstrate hydrodynamic and/or hydrostatic lift geometries.
    - » Demonstrate under engine simulated operating conditions
    - » Transfer technology to private sector



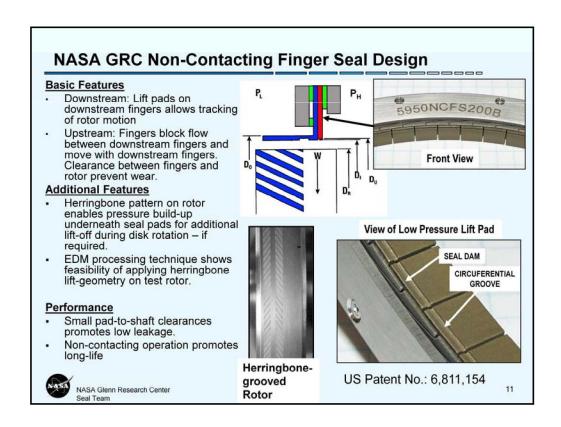
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Designers of future turbine engine seals face ever increasing challenges (Steinetz, Hendricks, Munson 1998), including high temperature, high speed operation, the need to operate for long lives with little or no wear while minimizing heat generation.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

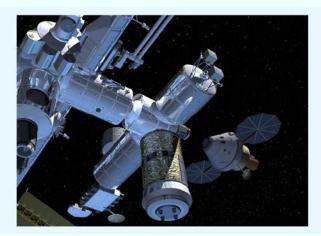


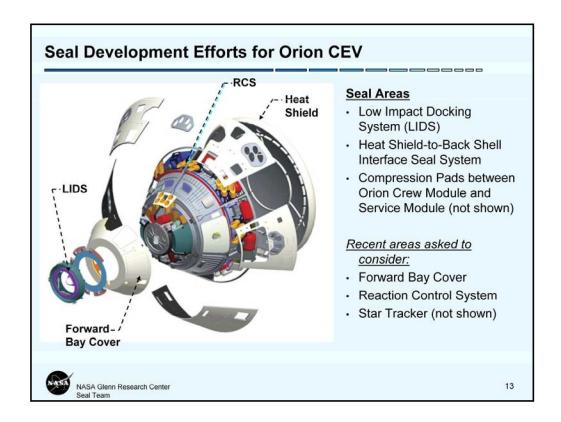
Conventional finger seals like brush seals attain low leakage by operating in running contact with the rotor (Proctor, et al, 2002). The drawbacks of contacting seals include wear over time, heat generation, and power loss.

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.

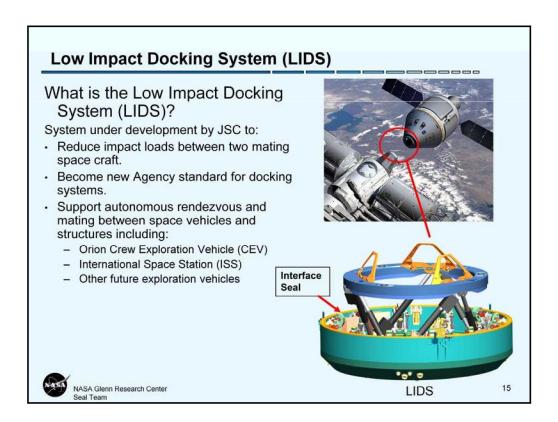
## Exploration Systems: Seals Challenges and Project Supported





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.

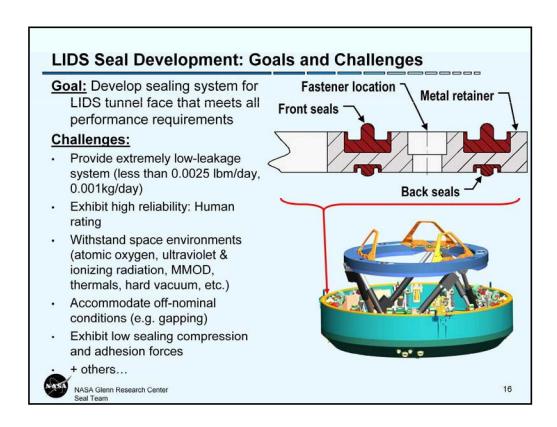
# Orion Docking and Berthing System



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."



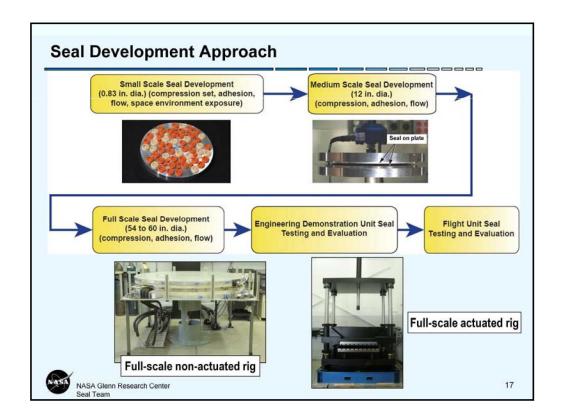
As indicated in the accompanying chart, challenges posed by this new system include:

Extremely high reliability: for man rating

Relative large diameter 54-58"

Extremely low leakage rates: <0.0025 lbm/day

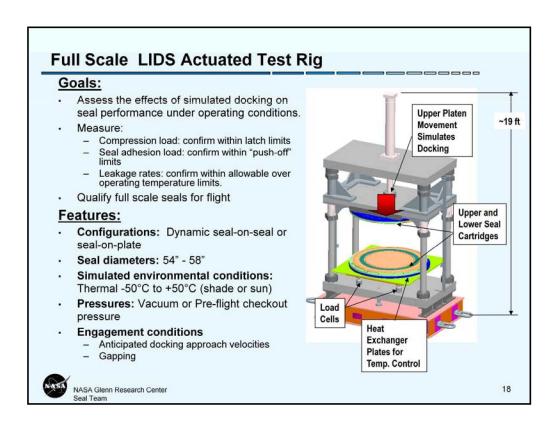
Docking Temperatures: -50°C to +75°C and thermal gradients



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.

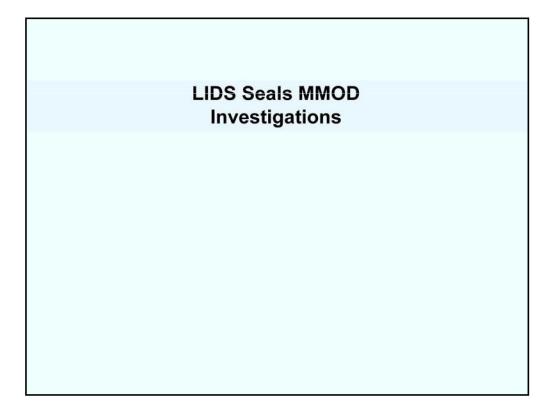
This test rig will allow us to measure:

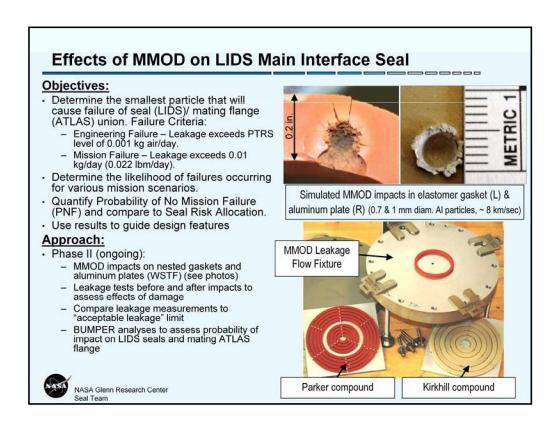
Compression load: confirm within latch limits
Seal adhesion load: confirm within "push-off" limits

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.





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** 

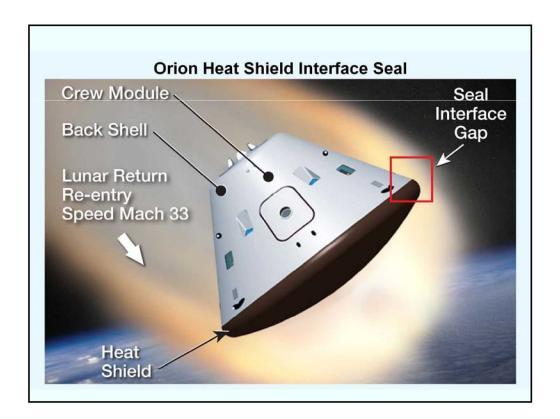
Aluminum surface treatment: bare, anodized, electroless nickel

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

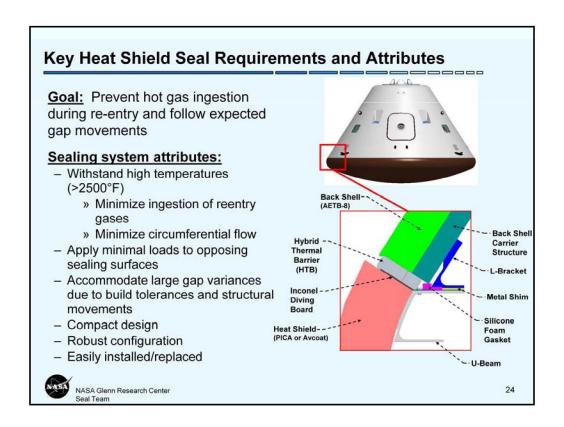
More information on the methods can be found in DeGroh et al (2009) and DeGroh and Steinetz (2009)



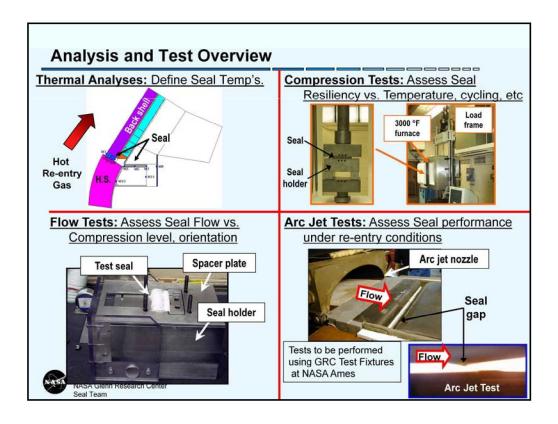
The Orion spacecraft is being designed to ferry astronauts either to the International Space Station or to the Moon. Upon return and during final stages of the mission, the Crew Module separates from the Service module and prepares to re-enter the Earth's atmosphere during which time extensive aeroheating 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 backshell covered with Shuttle tile.

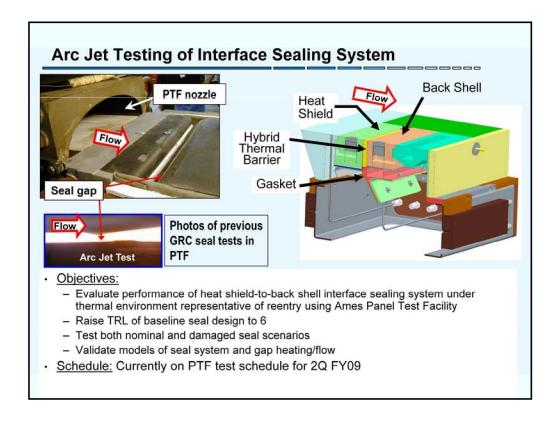


Orion uses an ablative heat shield to protect the spacecraft and crew from the intense aeroheating generated during a return from both Low Earth Orbit and Lunar missions. A seal system is being designed to prevent ingress of high temperature re-entry gases at the interface between the heat shield and 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

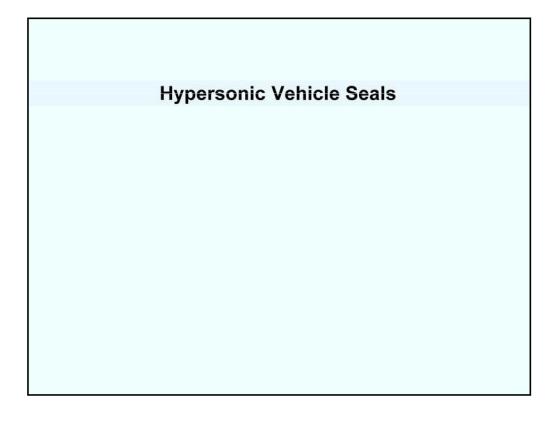
Heat Shield: PICA (standard or densified) or AVCOAT

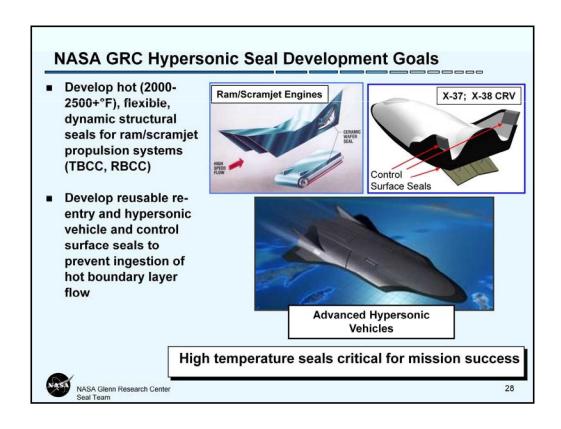
Back Shell (e.g. AETB-8)

Allows test of main seal system elements:

Hybrid Thermal Barrier

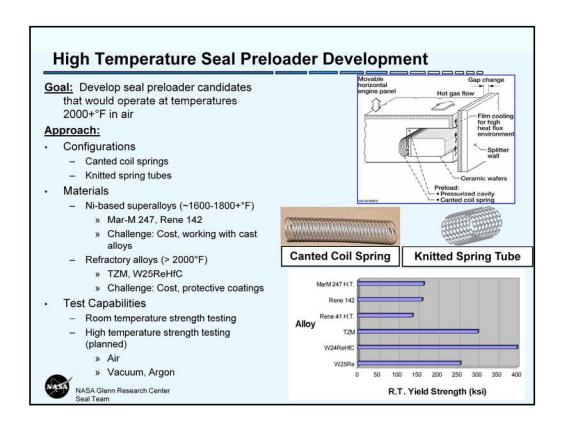
Gasket Seal





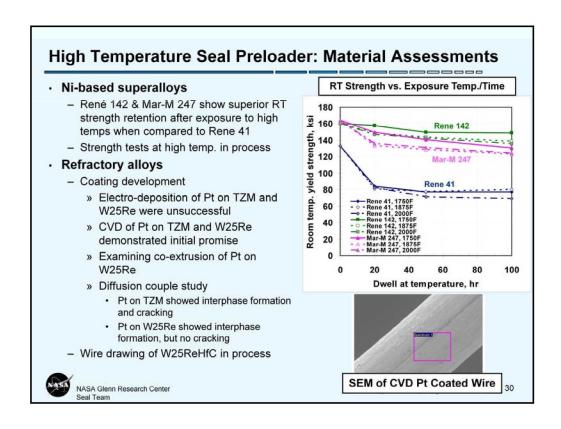
NASA is currently performing research on advanced technologies that could greatly increase the reusability, safety, and performance of future hypersonic vehicles. Research work is being performed on both high specific-impulse ram/scramjet engines and advanced re-entry vehicles.

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.

### Summary

- NASA's Exploration Initiative requires advanced sealing technology to meet system goals:
  - · Docking System:
    - Near hermetic
    - Robust
  - · Thermal protection system
    - · High temperature
    - Robust





- 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



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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.

### **NASA Seals Web Sites**

- Turbine Seal Development
  - http://www.grc.nasa.gov/WWW/TurbineSeal/TurbineSeal.html
    - » NASA Technical Papers
    - » Workshop Proceedings
- Structural Seal Development
  - http://www/grc.nasa.gov/WWW/structuralseal/
    - » NASA Technical Papers
    - » Discussion
    - » Seal Patents
  - http://www/lerc.nasa.gov/WWW/TU/InventYr/1996Inv Yr.htm
- Tribology and Mechanical Components Branch Research Areas Link:

http://www.grc.nasa.gov/WWW/StructuresMaterials/TribMech/research.html



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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.

### References

- DeGroh, H., Gallo, C., Nahra, H., 2009, "Meteoroid and Orbital Debris Threats to NASA's Docking Seals: Initial Assessment and Methodology," 1st AIAA Atmospheric and Space Environments Conference, AIAA-2009-3524 DeGroh, H, and Steinetz, B.M. 2009, Effects of Hypervelocity Impacts on Silicone Elastomer Seals and Aluminum Mating Surfaces, Presented at the 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Paper Number: AIAA-2009-5249.
- DeMange, J.J., Dunlap, P.H. Jr., Steinetz, B.M., 2006, "Improved Seals for High Temperature Airframe Applications." Paper Number: AlAA-2006-4935, TM 2006-214465, Presented at the 2006 AlAA/ASME/SAE/ASEE Joint Propulsion Conference, Sacramento, CA.

  DeMange, J.J., Dunlap, P.H., Steinetz, B.M., 2003, "Advanced Control Surface Seal Development for Future Space Vehicles," Presentation and Paper at 2003 JANNAF Conference, Dec. 1-5, Colorado Springs, CO. NASA TM-2004-212898.

- 212898.

  Dunlap, P.H., Daniels, C., Wasowski, J.L., Garafolo, N., Penney, N., Steinetz, B.M., 2009, "Pressure Decay Testing Methodology for Quantifying Leak Rates of Full-Scale Docking System Seals," Presented at the 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Paper Number: AIAA-2009-5319.

  Dunlap, P.H., Daniels, C., Steinetz, B., Erker, A., Robbie, M., Wasowski, J., Drilk, G., Tong, M., 2007, "Full Scale System for Quantifying Leakage of Docking System Seals for Space Applications," Paper Number: AIAA-2007-5742

  NASA TM-2007-215024, Presented at the 43<sup>rd</sup> AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cincinnati, OH.

  Dunlap, P.H. Jr., DeMange, J.J., Steinetz, B.M., 2006, "Performance Evaluations of Ceramic Wafer Seals," Paper Number: AIAA-2006-4934, NASA/TM-2006-214416. Presented at the 2006 AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Sacramento, CA.
- Conference, Sacramento, CA.

  Dunlap, Jr., P.H., Finkbeiner, J.R., Steinetz, B.M., DeMange, J.J., 2005," Design Study of Wafer Seals for Future
  Hypersonic Vehicles," AIAA-2005-4153, presented at the 41st AIAA/ASME/SAE/ASEE Joint Propulsion Conference,
  Tucson, AZ, July 10-13 also NASA TM-2005-213858.

  Dunlap, P.H., Steinetz, B.M., and DeMange, J.J.: 2004, "Further Investigations of Hypersonic Engine Seals." NASA
  TM-2004-213188, AIAA-2004-3887, August 2004. Presented at the 2004 AIAA/ASME/SAE/ASEE Joint Propulsion
  Conference, July, Ft. Lauderdale, FL.
- Dunlap, P.H., Steinetz, B.M., DeMange, J.J., 2003, "High Temperature Propulsion System Structural Seals for Future Space Launch Vehicles," Presentation and Paper at 2003 JANNAF Conference, Dec. 1-5, Colorado Springs, CO. (NASA TM-2004-212907).



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- Proctor, M.P; Kumar, A.; Delgado, I.R.; 2002, "High-Speed, High Temperature, Finger Seal Test Results," NASA TM-2002-211589, AIAA-2002-3793.
- Proctor, M.P., Steinetz, B.M. Non Contacting Finger Seal, U.S. Patent 6,811,154, Issued 11/02/04, (LEW 17,129-1).
- Ruggiero, E.J., Allen, J., Susini, P. and Lusted, R.M., 2008, Heat Generation Characteristics of Carbon Fiber Brush Seals Paper Number: AIAA-2008-4508
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  Ruggiero, E.J., Demiroglu, M., Sevincer, E., Lusted, R.M., 2007, "Heat Generation Characteristics of a Kevlar Fiber Brush Seal" Paper Number: AlAA-2007- 5738
  Steinetz, B.M., Hendricks, R.C., and Munson, J.H., 1998, "Advanced Seal Technology Role in Meeting Next Generation Turbine Engine Goals," NASA TM-1998-206961. Presented at the 2007 AlAA/ASME/SAE/ASEE Joint Propulsion Conference, Cincinnati, OH.
  Wasowski, J.L., Penney, N., Garafolo, N., Daniels, C.C., "Leak Rates of a Candidate Main Interface Seal at Selected Temperatures," Presented at the 45th AlAA/ASME/SAE/ASEE Joint Propulsion Conference, Paper Number: AlAA-2009-5320.
- Wenger, E. "Communities of Practice: Learning, Meaning, and Identity," Cambridge University Press, 1998.



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### SYNTHETIC AND BIOMASS ALTERNATE FUELING IN AVIATION

Robert Hendricks
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Dennis Bushnell
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

National Aeronautics and Space Administration



# **Synthetic and Biomass Alternate Fueling in Aviation**

R.C. Hendricks
Robert.C.Hendricks@grc.nasa.gov
D.M. Bushnell
Dennis.M.Bushnell@nasa.gov

NASA GRC Seals and Secondary Flow Symposium

18 November 2008 OAI-NASA Cleveland OH 44135

www.nasa.gov



# **Hydrocarbon (HC) Addiction**

Our planet is gripped by our addiction to hydrocarbon energy generation sources.

"Addiction is a terrible thing. It consumes and controls us, makes us deny important truths and blinds us to the consequences of our actions."

U.N. Secretary-General Ban Ki-Moon

"We take pride in our clean, green identity as a nation and we are determined to take action to protect it. We appreciate that protecting the climate means behavior change by each and every one of us." Prime Minister Helen Clark, New Zealand



# **Civil Aviation Alternate Fueling Progress**

- ➤ Feb. 24, 2008, Virgin Atlantic 747–400 40-min. biojet fueled flight One of four GE CF6-80C2B5F turbofan engines London to Amsterdam (320 km) altitude to (7.6 km) 80% Jet-A: 20% processed babassu nut-coconut oils (Parente) Ground tests to 60JetA:40biojet no discernable problems
- February 1, 2008, Airbus A380 3-hr GTL fueled flight One of four Rolls-Royce Trent 900 engines fueled Bristol to Toulouse to assess environmental impact GTL (gas-to-liquid) fueling 50% Jet-A: 50% Blend Goal regulatory 50:50 blend (2009): 100% GTL (2013)
- ➤ Continental GE plan CFM56–7B biofuel 737 test (2009)
- CAAFI Civil Aviation Alternate Fuels Initiative
   Research, Emissions, Business, Regulatory Groups

**National Aeronautics and Space Administration** 



# Military Aviation Alternate Fueling Progress

- March 2008 B1B flew supersonic (50%JP8: 50%SPK)
- SPK (Synthetic Paraffinic Kerosene) Standard MIL-DTL-83133F 11 April 2008 Sperseeds MIL-DT-83133E 1 April 1999.
- SPK: CAAFI-ASTM modification for ASTM D1655.
- 17 Sept 2008 **50yr-old KC135 and F22 Raptor**

Fueled 50:50 JP8-SPK



National Aeronautics and Space Administration



# Heat Engine Exhaust Emissions (HC)-Fueled Systems Health Hazards

 Particulate pollution: ultrafine particulates directly translocate to promote vascular system diseases. [Ultrafine: < 0.1 µm (< 100 nm)]</li>

Journal of America College of Cardiology (JACC) \*. chronic respiratory diseases due to particulates are better known \*\*

 Exhaust (tailpipe) emissions (20-140 nm) includes aircraft, mobility/stationary systems

•Simkhovich, B.Z, Kleinman, M.T., Kloner, R.A. (2008) Air Pollution and Cardiovascular Injury Epidemiology, Toxicology, and Mechanisms, Journal American College of Cardiology, 2008; 52:719-726, doi:10.1016/j.jacc.2008.05.029 (Published online 13 August 2008). <a href="http://content.onlinejacc.org/cgi/content/short/52/9/719">http://content.onlinejacc.org/cgi/content/short/52/9/719</a>
\*\* Schwartz, J. (1993) Particulate Air Pollution and Chronic Respiratory Disease, Environmental Research, 62, pp. 7-13



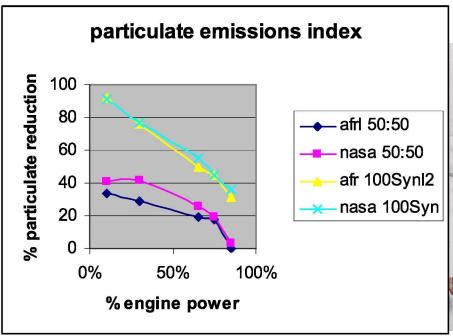
# **Civil-Military Engine Emissions Testing**

March 2008 PW-308 Engine Emissions FT- Jet A fuel test

Fuels AFRL-FT, NASA-FT (Fischer-Tropsch), Jet A

Decreased particulate number with % power decrease for

FT and Blends vs. Jet A.





**Exhaust Emissions Rake** 

National Aeronautics and Space Administration

# Aviation Ground Rules 2nd Generation Biomass Fueling



Criteria	KLM	Virgin Atlantic.	Boeing	Airbus	Air Transport Association
Water	No use of drinking water	Should not divert water away form food agriculture or drinking water	Does not require freshwater irrigation	Does not compete with water use for food crops or with drinking water	
Defores tation	No deforestation or forced relocation of people	Should not lead to deforestation	Does not lead to deforestation directly or indirectly	Does not compete with natural carbon sinks such as rainforest	
Soil	No soil degradation	Should apply sustainable agronomy principles (e.g., equivalent of FSC)	Apply sustainable practices	Apply sustainable practices	
Land and Food	Not compete with food or make use of arable land	Should not conflict with staple food crops	Does not compete with food	Does not compete with land use for food crops	
Emissio ns	No negative influence on biodiversity	Should have lower life cycle carbon emissions	Reduce CO2 (ie on order of -50% from current Jet A fuel)	Beneficial on a life cycle basis both in terms of global warming and local air quality	Voluntary Emissions Reduction
Supply			Supply sufficient quantity of lipids that could be converted to biojet fuel [ 11.5B US gal (2026)]	Aspirational goal to have up to 30% of commercial aviation fuel being biofuel in 2030.  Set as a stretched goal to support scenarios discussion.	Reliable supply is critical; must be compatible with existing fueling infrastructure; must meet regulatory and standards required by FAA
Economic Feasibility			Have some hope of becoming economic feasible (ie Processed biofuel costs no higher than today's Jet A fuel ( <\$4/gal)	To be demonstrated	Beneficial to both suppliers and purchasers
Feedsto ck			Assume the raw oil from multiple feedstocks could be equally easily converted into biojet fuel	Multiple feedstock will have to be used	Feedstock neutral; fuel must satisfy Safety and Quality, Environmental benefits, Reliability of supply, and be Economically feasible

# What are Our Abundant Resources?





> Arid Land (43% Earth's Lands)



> Seawater (97% Earth's Water)



➤ Brackish / Waste Waters



Halophytes are saltwater/brackishwater tolerant plants



**National Aeronautics and Space Administration** 



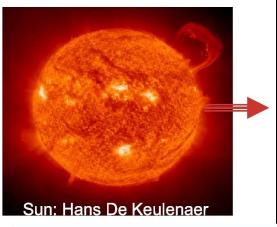
# Applying Abundant Resources and Halophyte Agriculture

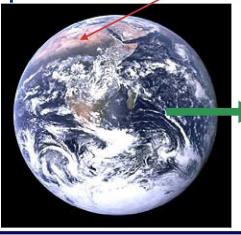
# **Assumptions**

- > Sun: solar incident radiation at 230 W/m2 daily
- > Seawater (brackish water) irrigation
- ➤ Arid Lands: Total size of the Sahara Dessert (8.6x10<sup>8</sup> ha,13.6% of world arid or semi-arid lands)



➤ Biomass: Developed to its theoretical limits [ 10% ]





Halophyte Agriculture
Could Produce
7.126 kQ/yr
16× the World Q (2004)

National Aeronautics and Space Administration



Water

Energy

Food

# Why Our Interests are Halophytes Algae Bacteria Weeds and Seeds

### In a nut shell, here is the basis for our interest in Halophytes and derivatives

- 97% earth's water is seawater
- 80% (or more) plant nutrients are in seawater
- 43% earth's land is arid or semiarid
- 40% population growth in next 40-50 yrs.



- Ample solar energy available ( to 16X total World Q in terms of biomass)
- Projected dearth: food supply, freshwater supply, energy supply current and projected environmental disasters + famines ... by 2050 cities consume 50% world's freshwater...soil losses 5-10M ha-arable/yr ...50% applied farm nutrients lost in runoff, leaching or erosion; worst is Gulf of Mexico
- Projected rise in ultrafine particulate health hazards impacts all living matter
- Inaction will lead to demise of humanity

### This is an existential matter



## Raw Biomass Costs for \$4/gal-biofuel

- Raw-Biomass conversion to fuel at 20% 5 kg-raw-biomass = 1kg-biofuel
- Non-biomass costs (ROI, marketing, personnel, transport etc...) 30% of fuel cost
- Maximum allowable raw-biomass cost

```
4/gal \times 4 \times gal/3.4kg-fuel
           = about $1/kg-fuel
```

1000 kg/ton / 5 kg-raw biomass

Less than \$200/ton-raw-biomass

Coal Spot (Sept.-Nov. 2008) \$150 - \$130 /ton (Volatility)



## Common plants, weeds and seeds address (Food, Energy, Water)

### Camelina

- Camelina looks like wild mustard plants.
- Can prosper on marginal (near arid) lands. Fast growing (85-105 days)
- Can survive winters of Montana and Dakota's. Banned in some states
- Oil-Seed yields to 3.2 mt/ha (1.4 t/a) with (35-45%) oils; High Omega-3
- General purpose food-fuel feedstock

Camelina



http://en.wikipedia.org/wiki/Camelina sativa

https://www.camelinacompany.com/Marketing/GrowerInformation.aspx

http://www.hort.purdue.edu/newcrop/proceedings1996/v3-357.html

http://aginfo.psu.edu/news/2008/6/camelinaforbiofuel.html

### Common plants, weeds and seeds addresses (Food, Energy, Water)

**Castor plant** 

Castor plant member of the economically important Euphorbia family.

Ricin laced seeds a potent poison, One milligram can kill an adult.

Grows rapidly in arable soils, yet cannot tolerate frost. Its tolerance to arid soils and saline conditions needs assessment.

Colorless to pale yellow liquid, one of the world's most useful and economically important natural plant oils. Yields to 1400L/ha 1.25mt/ha (0.5t/a)

> http://en.wikipedia.org/wiki/Castor oil plant http://www.castoroil.in/uses/fuel/castor oil fuel.html





## **Bacteria** Address (Energy, Food, Water)

- Cyanobacteria: oldest forms and found almost any habitat
- The chloroplast facilitates endosymbiotic relation between cyanobacteria living in plant or algae cells.
- Bacterial genomes easier to modify (maybe)
- Can fix either nitrogen or carbon
- Bacteria are prolific and reproduce rapidly. With proper conditioning can be harvested daily
- Natural blends or modified bacteria can absorb solar energy at different wavelengths,
- Some can tolerate extremes in temperature such in the hot springs at Yellowstone National Park.
- Bacterial biomass potential achieve or exceed 100 g/m2-day theoretical biomass limits set by Weismann (2007)

Weissman, Joseph C. (2007) From Laboratory to Pilot Plant – Lessons Learned from a Microalgae Biofuels Project Algae Biomass Summit, Nov. 15-16, Grand-Hyatt Hotel, San Francisco, CA, USA. http://www.wsgr.com/WSGR/Display.aspx?SectionName=news/emailer/Event141/info.htm



Genetic modeling





## Algae addresses (Food, Energy, Water)

- Availability of solar, seawater, spent freshwater (eg livestock) and arid land.
- > "there is only 0.03% CO2 in our (lower) atmosphere and on this thin thread hangs our very existence" [Spoher, 1953]
- ➤ Increasing CO2 concentration increases biomass
- Force CO2 fed algae systems
- CO2 source (about same productivity) Pond ("pure" CO2) tanks or pipelines Power Plant Desulphurized flue gas (FGD) CO2
- Bioreactors (horizontal and vertical)
- Round numbers, 2 kg-biomass requires 1 kg-water and 3 kg-CO2 plus maybe up to 1 kg N (nitrogen) nutrient fertilizers (seawater irrigation provides some 80% of the nutrients needed for plant growth)
- Yields vary 2000-6000 gal/a





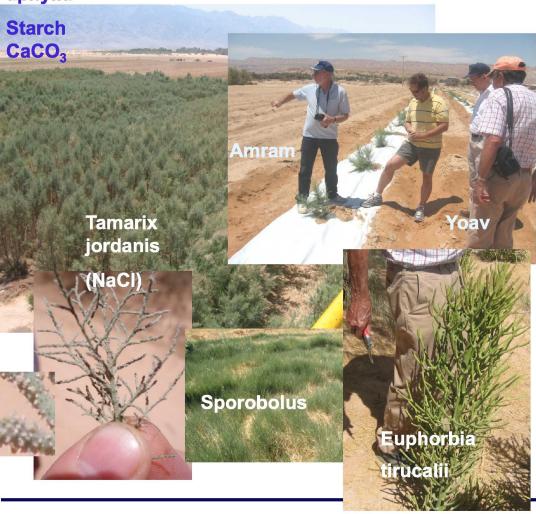




### **Halophyte Fields Yotvata**

**Tamarix** aphylla

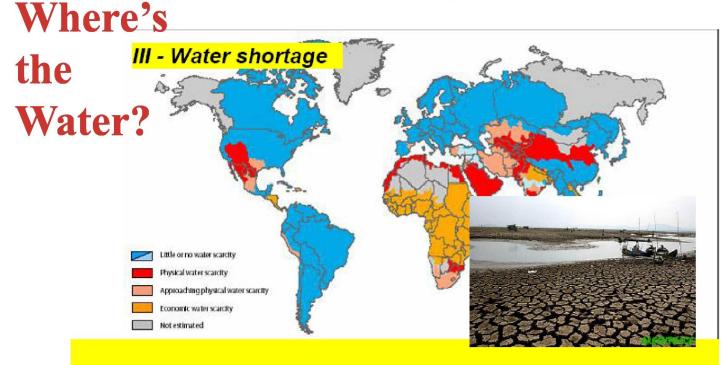
Yoav Waisel [ YoavW@tauex.tau.ac.il ] Amram Eshel [ AmramE@tauex.tau.ac.il ]



- Novel halophytes as well as classic ones.
- Biomass via invasive fir trees ( weeds ) Tamarix (Salt Cedar)
- 100 mt /(1.5yr) total biomass, 80mt/1.5yr carbon
- **Branches and needles** collect salts on surfaces
- Plant sap (more viscous in salt water, less in fresh ) bleeds similar to milkweeds
- Collect research data base on potential halophytes for fuels and food
- **Moving toward** sustainable saline agriculture



# World Freshwater and Spent-water Issues



Groundwater is in decline everywhere

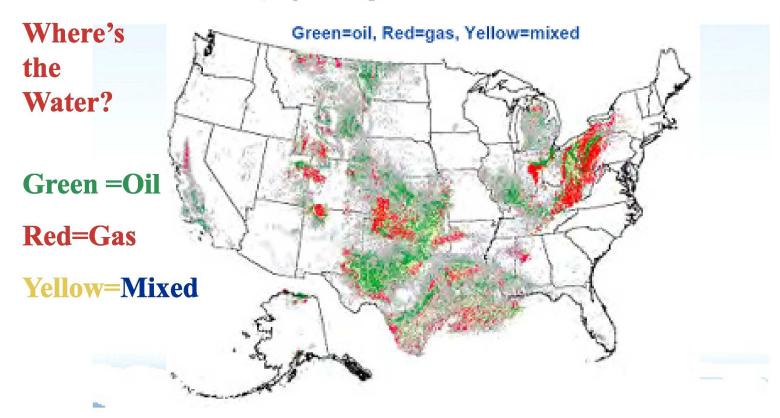
By 2050 cities will consume half the world's fresh water

(Julian Cribb, FTSE, May 2008)

Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy



### Water Issues: Oil and Gas Wells Producing and Abandoned Potential Halophyte Algae Bacteria Water Sources



- 1. [Pate, R. (2007)] Sandia National Labs
- 2. http://wrri.nmsu.edu/conf/brackishworkshop/presentations/johnson.pdf

## Water Issues: Coal Mine and Mineral Processing Plants

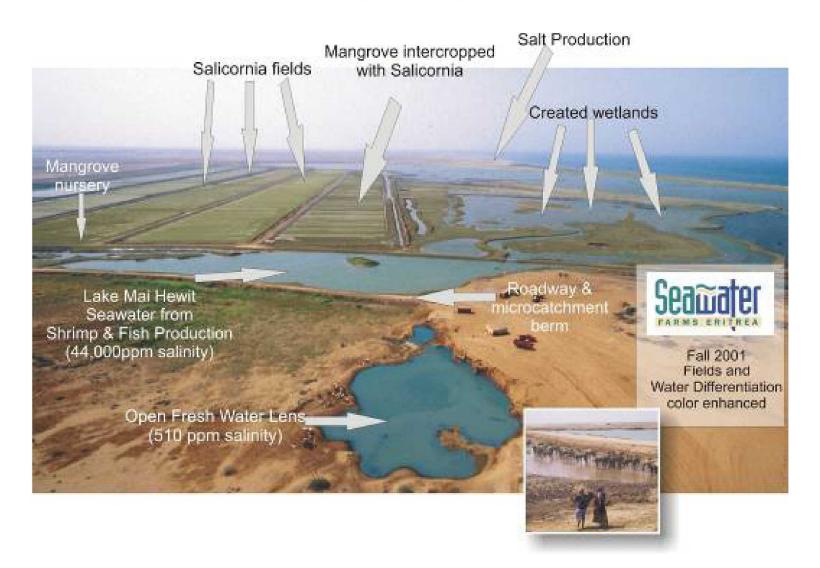
Producing and Abandoned, Impounded Brackish and Toxic Water, Waste

Water, Spent-Freshwater: Potential Halophyte Algae Bacteria Water Sources http://minerals.usgs.gov/minerals/pubs/mapdata/

Where's the Water?



## **Live Cycle Systems**





## Halophyte Production (salicornia)

- Salicornia [Annual] salt tolerant to 2X seawater optimum productivity to 1.3X seawater
- Over 6 years of field trials in Mexico (others United Arab Emirates, Saudi Arabia, Eritrea, India)
- Total Biomass 2 kg/m2; 20 m-t/ha (8.1 t/a)
- 0.22 kg/m2; **2.2 m-t/ha ( 0.9 t/a)** Oilseed Oil @35% 0.077 kg/m2; 0.77 m-t<sub>m</sub>/ha (0.31 t/a)

Sp.Gr. ~ 0.9 3.4kg/gal **226 gal/ha (92 gal/a)** 

Aviation grade

76 gal/ha (31 gal/a)

- Water requirements 1.35 X glycophyte irrigation (prevents salt build-up at roots)
- SeawaterFoundation Total Live Cycle System

Glenn et al. U Arizona, Scientific American Aug 1998; Hendricks & Bushnell ISROMAC12-2008-20241, Dr. Carl Hodges (2007,2008) http://www.seawaterfoundation.org/



## Halophyte Production (seashore mallow)

- Seashore Mallow [Perennial] (salt tolerant to coastal seawater)
- Over 4 years of field trials in Delaware Coastal Plain (others China, Egypt ) [ results for top-end harvest; less for production fields]
- Total Biomass 1.8 kg/m2; 18 m-t/ha (7.3 t/a)
- 0.145 kg/m2; 1.45 m-t/ha ( 0.59 t/a) Oilseed Oil @20% 0.03 kg/m2; 0.29 m-t/ha (0.12 t/a)

Sp.Gr. ~ 0.9 3.4kg/gal **85 gal/ha (35 gal/a)** 

Aviation grade

29 gal/ha (12 gal/a)

Water requirements < 1.5 X glycophyte irrigation + (prevents salt build-up at roots )

- + soil texture, drainage, natural rainfall, evapotransporation dependent
- Harvesting: Conventional Soybean Combine
- Soil remediator

Prof. John L. Gallagher, U. of Delaware http://www.ocean.udel.edu/people/profile.aspx?jackg

# So, Why Alternate Fueling?



## Ostensibly, foreign control of US

energy

food or

freshwater

supplies, implies the US would be quite limited politically,

> commercially and militarily

in the future



### What's the Problem Now?

- > We can make alternate Jet fuels
- CTL and GTL via FT processes
- Biomass fuels with conversion to Jet fuel

Common crop oilseed [ soybean, palm, coconut etc)

Algae

Bacteria

Halophyte

Wastes [municipal, livestock, forestry etc.)

- > So what's the problem?
- Why aren't we in control of our fueling sources ?



### The Problems

### How to make these Fuel Resources

Secure **Sustainable Economically viable Sufficient Supply** 

**And Satisfy the Ground Rules** 



## **Beyond Drop-in Fueled Aviation**

- Unmanned vehicles
- Solar powered
- Hydrogen fuel cell power
- Hybrid electric systems
- LH2 Compressed Air propulsion systems
- Combined solar-hydrogen fuel cell systems
- Single seat aircraft demonstrators with and without battery-boost TO
- Holds promise of Clean Flight Systems



# Solar-Electric ; LH2- Fuel Cell Electric

### http://www.avinc.com/

### Solar Powered Helios & Zephyr

http://news.bbc.co.uk/2/hi/science/nature/6916309.stm



# AeroVironment

### Stratospheric Persistent UAS (unmanned aircraft systems): **Global Observer**

### First Flight – June 2005

http://www.spacewar.com/reports/AeroVironment Flies Worlds First Liquid Hydrogen Powered **UAV.html** 

Missions: Communications Relay & Remote Sensing Features: Stratospheric Global Persistence (all latitude)

Endurance/Range: Up to several days/global

**Payload:** Up to 400 lbs. for GO-1 & 1,000 lbs for GO-2

Operating Altitude: 65,000 feet

**Propulsion System:** Liquid hydrogen powered

## 2008 Battery Assist Hydrogen Fuel Cell-Electric

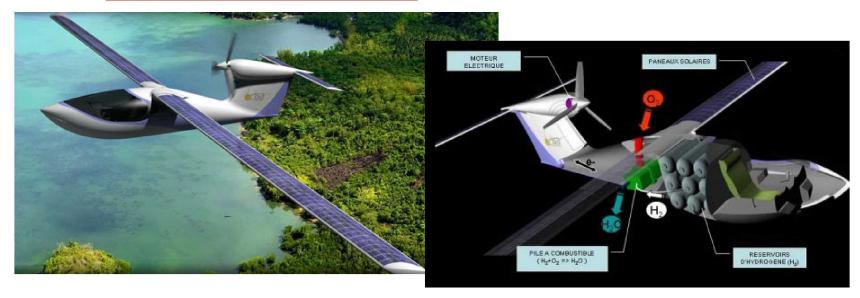
- Boeing 3 April 2008: 3 test flights at 1 km.
- Battery boosted TO; fuel cells only at cruise
- http://news.bbc.co.uk/2/hi/technology/7330311.stm
- Potential for fly-back battery booster vehicle separation at cruise.





## 2009 Solar-Hydrogen-Electric

- Hydrogen fuel cells power Electric engine that is more efficient at altitude; Range about 1500 km.
- Hy-Bird PV cells provide cruise on-board power and hydrogen fuel cell TO peaking. [no battery boost cited]
- www.hy-bird.com or www.lisa-airplanes.com
- http://news.bbc.co.uk/2/hi/americas/4643575.stm AeroVironment





# Conclusions

- > Must use Earth's most abundant natural resources Biomass, Solar, Arid land (43%), Seawater (97%) with nutrients (80%) plus brackish waters and nutrients resolve environmental triangle of conflicts energyfood-freshwater and ultrafine particulate hazards
- Requires Paradigm Shift Develop and Use Solar \* for energy; Biomass for aviation and hybrid-electriccompressed air mobility fueling with transition to hydrogen long term. \* PV-Thermal-Wind (thermal includes geothermal)



# **Consequences of Inaction**

- Imperative (existential) humanity Controls and Resolves Triangle of Conflicts [ energy, food, freshwater] Emissions, in particular CO2, CH4, nano and ultrafine HC emissions peaking Energy emissions levels Food emissions toxicity
- Current CO2 level and peaking have vivid similarities to Permian (~ 260 Mya) and dinosaur (~ 65Mya) periods
- Each of which led to **mass extinction** with multiple lesser extinctions over past 400 My.
- Known historical volcanic emissions, yet lack direct historical evidence to ultrafine particulate emissions.
- Ostensibly, **foreign control** of energy, food or freshwater supplies, implies limited world influence.







## **Biomass Fueling Test Examples**

- Heavy Duty Diesel Engines Diesel-Biodiesel Blends
- Emissions decrease with % increase in blend

CO<sub>2</sub> formation

CO

particulates

unburned HC

SOx

- Increases in NOx (to 10%)
- Renewable, non toxic, feedstock diversity
- T-63 Small Gas Turbine Engine JP8-Biodiesel Blends
- Particle number density (PND) decrease with % increase in blend at cruise and take-off power (small decrease in size ), but PND increases at idle.
- Pyrene and fluoranthene found in soot data
- Typical turbine engine particulate size 30-70 nm

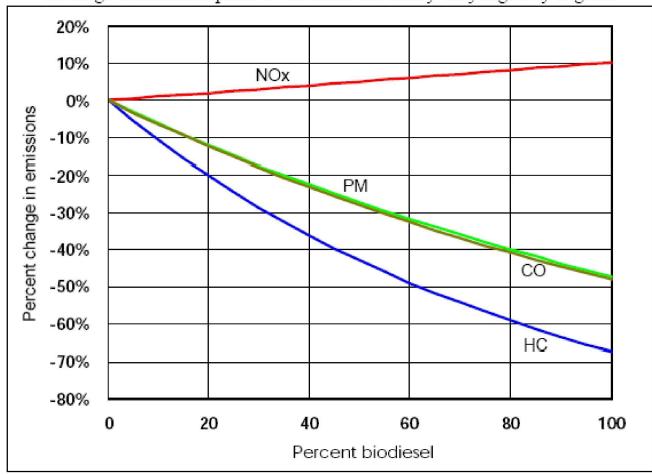
Effects of biomass burning: <a href="http://cat.inist.fr/?aModele=afficheN&cpsidt=14518203">http://cat.inist.fr/?aModele=afficheN&cpsidt=14518203</a>

Erie Ohio Biofuel producer: http://www.lakeeriebiofuels.com/



### Fig. 3 Diesel Engine with Diesel-Biodiesel Fueling

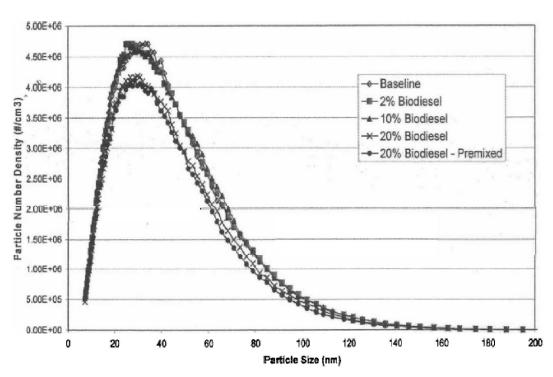
Average emission impacts of biodiesel for heavy-duty highway engines



http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf



### Fig. 4 Gas Turbine Engine Particulate Distribution



Particle size distribution from T63 engine at cruise for JP-8 and JP-8/biodiesel blends.

Pyrene: Toxic to kidneys and liver

Fluoranthene: carcinogenic

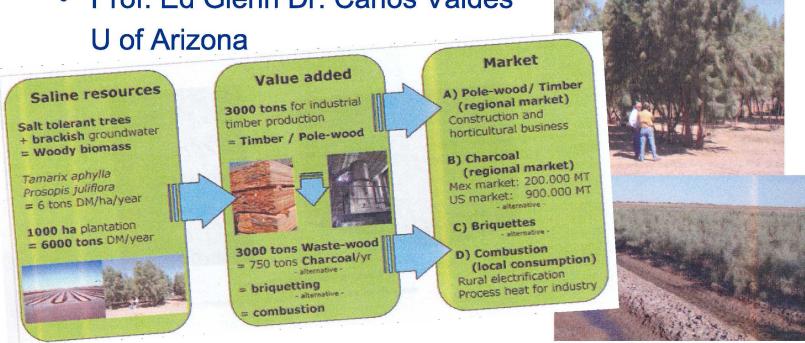
Corporan et al. (2005) Impacts of Biodiesel on Pollutant Emissions of a JP-8-Fueled Turbine Engine, Air & Waste Management, Association, 55 pp.940-949.



### Colorado Delta Project

### www.oasefoundaion.eu/project 34

- Tamarix aphylla [similar to Yotvata]
- Value added marketing
- Prof. Ed Glenn Dr. Carlos Valdes





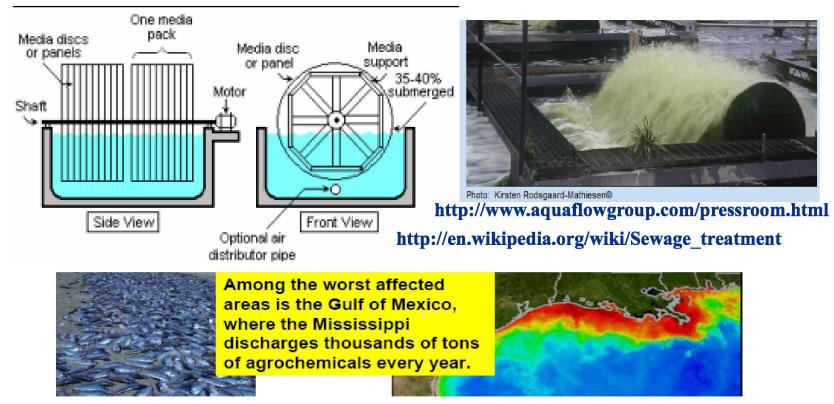
### Kibbutz Yotvata / Ketura – Advanced Technology

- Biogas facility at Kibbutz Yotvata
- Solids separated and waters sent to fermenter with clean waste water but sent to fields for irrigation CH4 to gas generators and electric generators
- Cows milked on rotating platform life cycle is well regimented
- Bio reactor horizontal larger pipes and vertical (Kibbutz KETURA)
- Red algae for coloring pond fed salmon prior to serving are not pink ( rather gray in color) adding algae dies salmon pink
- Bio reactor fowled by foreign matter ...shut down for 1.5 yr for cleanings? Algae need to be protected against extremes in heat



### Ocean and Bay Dead Zones [hypoxic – low oxygen] Spent-freshwater treatment and algae recovery Systems

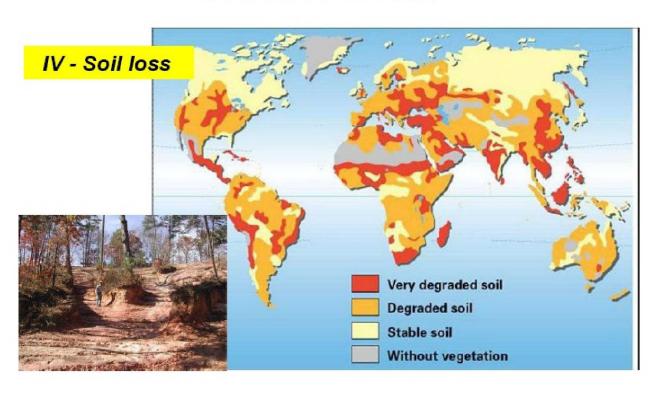
Spinning mesh wheel develops an algal biofilm that feed on the suspended wastes (German Concept)



Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy



### Soil Loss Issues

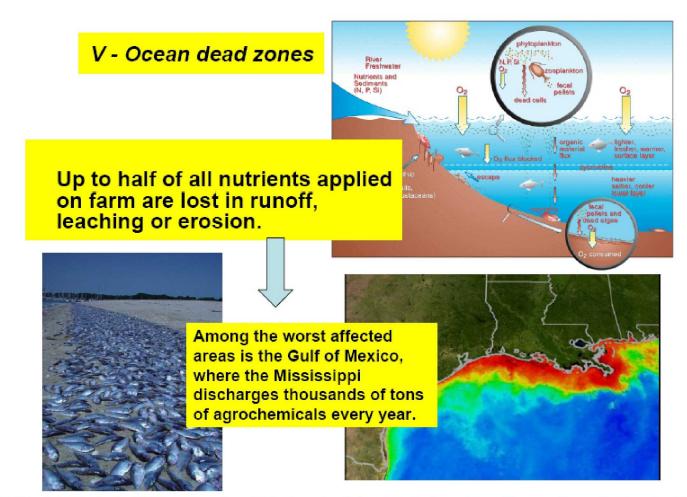


there is a loss of about 5-10 million ha arable land a year.

Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy



### Nutrient Runoff and Ocean/Bay Dead Zones (hypoxic)



Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy

### FOIL FACE SEAL TESTING

John Munson Rolls-Royce Indianapolis, Indiana



### **Foil Face Seal Testing**

John Munson Rolls-Royce - Indianapolis, IN

### Seal Development Strategy

- Foil thrust bearing provides a compliant primary (stationary) seal ring
  - Gas film stiffness is greater than primary ring structural stiffness - accommodates the out-of-flat distortion
  - Provides greater tolerance to wear and contamination in the air stream - no fine geometry or small holes needed
- Combining foil thrust bearing technology with face seal architecture - secondary seal accommodates axial excursion and some angular misalignment
- Foil bearing need only support itself axially, modest load capacity required
- An extension of existing technology



In the seal literature you can find many attempts by various researchers to adapt film riding seals to the gas turbine engine. None have been successful, potential distortion of the sealing faces is the primary reason. There is a film riding device that does accommodate distortion and is in service in aircraft applications, namely the foil bearing. More specifically a foil thrust bearing. These are not intended to be seals, and they do not accommodate large axial movement between shaft & static structure.

By combining the 2 a unique type of face seal has been created. It functions like a normal face seal. The foil thrust bearing replaces the normal primary sealing surface. The compliance of the foil bearing allows the foils to track distortion of the mating seal ring.

The foil seal has several perceived advantages over existing hydrodynamic designs, enumerated in the chart. Materials and design methodology needed for this application already exist. Also the load capacity requirements for the foil bearing are low since it only needs to support itself and overcome friction forces at the anti-rotation keys.

**Face Seal Test Results** 

Seal lift-off

- Inversely proportional to square root of load
- Protective coatings required for foils
- Radial coning allowable coning only limited by the amount of clearance provided by bump foils
- Circumferential out of flatness
  - Up to 0.009 in./4 wavelengths static side out-of-flat
  - Also rotating mating ring machined out-of-flat:
    - Max requirement 0.008 in. ~>16" seal
    - Scaled for >4.5 in. seal 0.003 in. preserves wave aspect ratio
    - 1, 3, & 5 wavelengths successfully tested

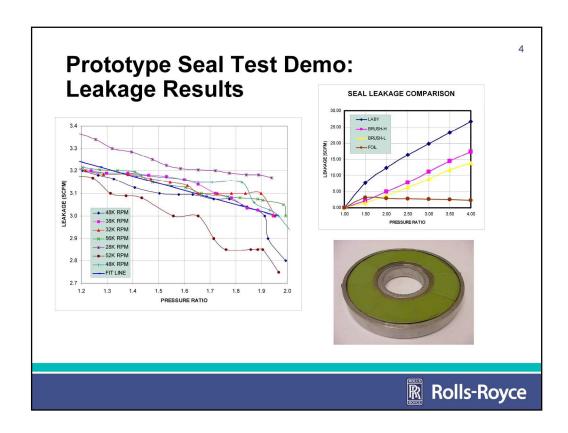


3

Lift-off testing was done to establish where would we expect an engine seal to go from contacting to non-contacting. Extrapolation of the test results indicates that this should occur between 1500 and 2000 RPM. While this is well below the engine operating range, it implies that some form of protective coating is required for the foils.

The seal was tested with up to 3° of coning built into the mating ring. The test results seem to suggest that the only limit to how much coning the seal can accommodate is a function of the clearance built into the bump foil. No difference in operation was noted between coned and non-coned mating ring tests.

We also presented results wherein the static structure was made out-of-flat circumferentially. The seal easily accommodated 0.009" of distortion. These results were supplemented with additional testing wherein the rotating sealing surface was manufactured circumferentially out-of-flat (OOF). The goal 0.008" OOF requirement was scaled for these tests to preserve the aspect ratio of the "wave." A maximum of 0.003" OOF was used for the 3 and 5 wavelength tests. With 5 waves the OOF is equivalent to 0.009" OOF with a 16" diameter seal. The seal also accommodated this distortion, although with 5 waves, 0.003" OOF load capacity was reduced by approximately 30%.



The proof-of-concept seal was also used to characterize expected seal leakage so that this seal could be compared with other types of seals, e.g. labyrinth or brush, used in secondary flow path applications. Tests were run with a variety of axial loads and differential pressures applied. The tests were conducted at several different speeds, as well. As the figure indicates, no clear effect of speed on leakage was observed. A general leakage curve was fitted to the test data. This curve was used to compare foil seal leakage to other seals. This result is shown in the figure at top right. At very low differential pressures the seal s all give similar performance. At higher differential pressures the foil seal is clearly superior.

**Present Requirements** 

- Large diameter seals, up to 36" diameter
  - Require large axial motion capability ±0.2"
  - Up to 1200°F
  - <100 psid</p>
  - 1000 ft/sec
- Prototype seal test article ~1/7 required size
- Current test article ~1/2 size
  - Fits in available test rig
  - Large enough to develop full speed, pressure, temp test conditions
  - Test for any size effects as technology gets scaled up



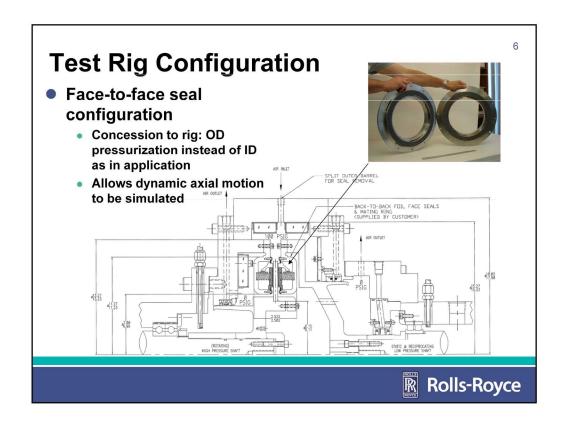
5

In terms of cost versus benefit it has always been clear that there are only certain engine sealing locations where the foil type face seal is best suited. These are "high-value" sealing locations within engines such as rotor thrust balance and/or turbine rim seals. As encouraging as the proof-of-concept testing was, it is a long way from the small 4.5" OD demo seal to the up to 36" diameter seals that will be required for the applications under consideration.

As the slide shows, temperatures and speeds tend to be high but differential pressures modest relative to all other seal industry applications. Some of the applications under consideration will also need to accommodate large axial excursions. Radial excursions are also equally large. These have not been shown because they can be easily accommodated by ensuring the mating ring face is always large enough so that the primary sealing face stays completely in contact with the mating ring. For a conventional spiral groove type film riding face seal these excursions would be more concerning as they would have led to unsymmetrical lift forces.

Present plans are to test an approximately half size seal. This size was selected because:

- It provides a means to check for effect of size on seal performance
- To allow supplier supply chain development for large parts
- Test rig size limitations versus the type of testing desired



The ability to simulate the expected axial excursions while the seal was rotating was seen as a prime requirement for selection of a test rig. This and the envisioned size of the test parts determined the selection of the test rig. Stein Seal's dual shaft rig is being configured to run the planned test program. Two test seals are used in a face to face configuration to eliminate the large thrust imbalance load that a single seal would have imposed on the shaft.

The completed test seals are shown in the small upper right hand figure. The seals are right and left handed but otherwise identical in design.

7

# **Planned Test Program**

- Performance mapping
- Dynamic axial motion 10 sec slow transient (thermal growth)
- Distorted Mating Ring
  - (1) Coning (0.5° radial) Thermal/pressure induced (usually)
  - (2) Swash (.002" TIR) mounting errors
  - (3) Circumferential out-of-flat (.001" peak to peak)
  - (4) Combination of 2&3
- Dynamic axial <0.1 sec, fast transient (compressor surge)</li>
- Dust ingestion (10μm, .0003 Lb<sub>m</sub>/sec)
- Windmilling both directions



# PRELIMINARY TEST RESULTS OF A NON-CONTACTING FINGER SEAL ON A HERRINGBONE-GROOVED ROTOR

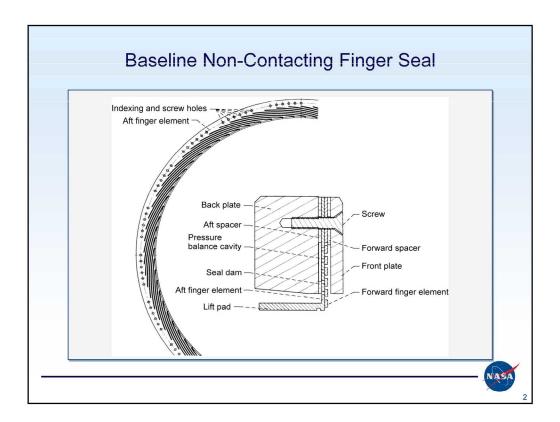
Margaret Proctor and Irebert Delgado
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio



This is nearly the same presentation I made in July 2008 at the Joint Propulsion Conference in Hartford, CT. The details of this work can be found in the NASA TM-2008-215475 and AIAA-2008-4506.

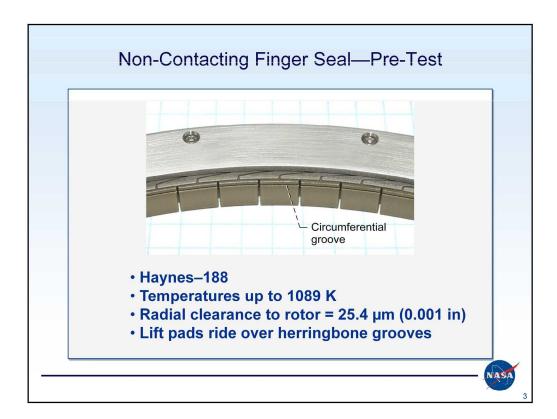
Low leakage, non-contacting finger seals have potential to reduce gas turbine engine specific fuel consumption by 2 to 3 percent and to reduce direct operating costs by increasing the time between engine overhauls.

To investigate the potential of the non-contacting finger seal and to provide data to develop a verified design methodology for it, a baseline non-contacting finger seal was designed and fabricated. Static tests and initial spin tests have been conducted. The test hardware, apparatus, procedures as well as the leakage performance, power loss, and wear results will be presented. Unexpected findings prompted exploratory bind-up tests not typical of previous test procedures.



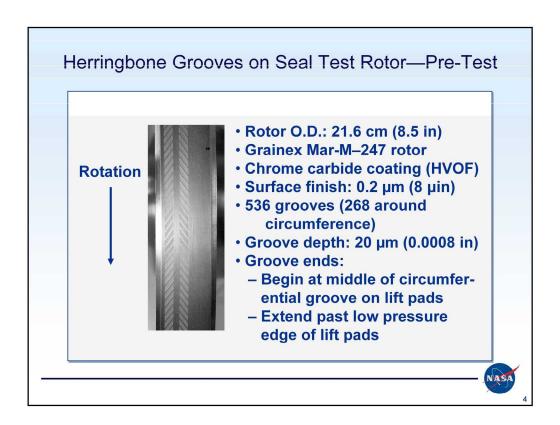
The baseline non-contacting finger seal is a NASA patented design. The primary difference between it and Gul Arora's design patented by AlliedSignal is that there are no lift pads on the high pressure fingers.

The baseline non-contacting finger seal is comprised of a back plate, aft spacer, aft (or low pressure) finger element, forward (or high pressure) finger element, forward spacer, and front plate. The components are held together with 20 flat head screws. A typical seal would have a back plate of approximately the same thickness as the front plate and would be riveted together. The thicker back plate allows use of threaded fasteners so that different finger elements can be tested without having to replace all the individual seal components. The finger elements are essentially washers made of thin sheet stock with multiple curved slots machined around the inner diameter to form the fingers. They are clocked so that the fingers of one cover the slots of the other. The aft finger element fingers have axial extensions or "lift pads" at the seal id that are concentric to the rotor. The fingers act as cantilever beams and flex in response to rotor dynamic motion and radial growth of the rotor due to centrifugal or thermal forces.

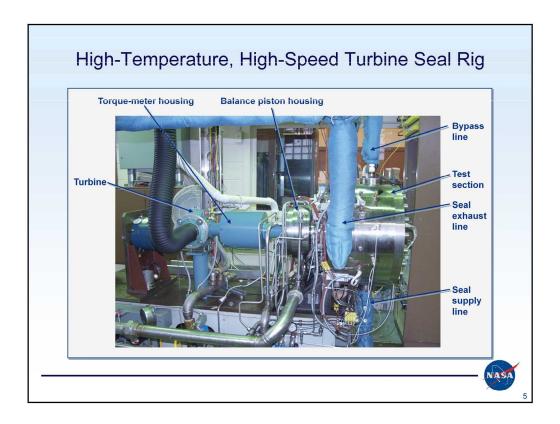


Another difference between the forward and aft fingers elements is that the high pressure fingers have a larger inner diameter to ensure they don't touch the rotor due to pressure blow down effects. Applying a pressure differential across a finger seal generates a suction force that draws the fingers towards the rotor due to the lower pressure under the finger pads. It's possible to reduce the high pressure finger element id to match the low pressure finger element id if there is sufficient friction between the two elements to keep them moving together.

The lift pads have a circumferential groove so that low pressure exists at all four edges of the lift pad.

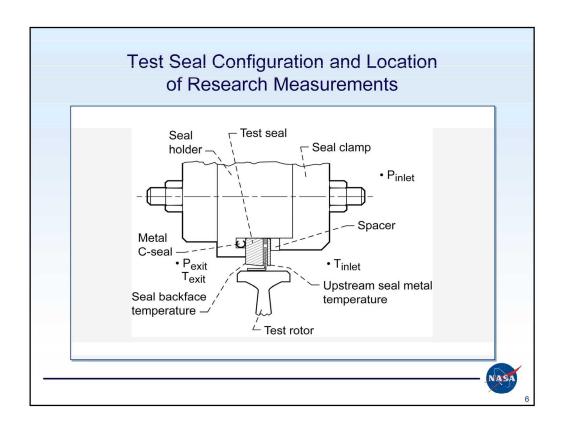


The direction of rotation causes pumping towards the center of the groove pattern.

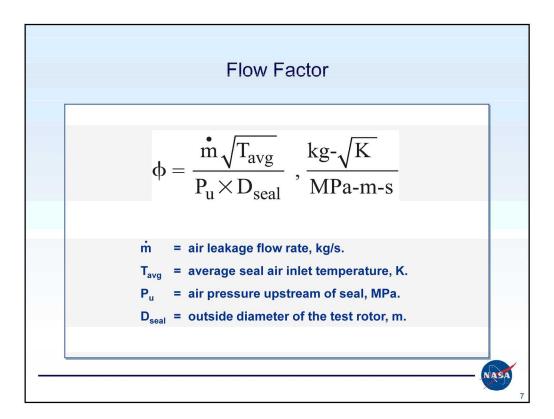


The High-Temperature, High-Speed Turbine Seal Rig is used to measure seal leakage and power loss at different speeds, pressure differentials and temperatures.

A torque meter is used to measure the seal torque. Tare torque is measured without a seal and is subtracted from the torque measured with a seal installed to determine the seal torque. Seal power loss is simply the seal torque multiplied by the speed. When a pressure differential is applied across the seal windage on the high pressure side of the test disk and balance piston increases due to the increased density of the air. Bearing torque is also increased. The additional windage and bearing torque are approximated and subtracted from the measured power loss. Hence the seal power loss presented is approximate.



The seal inlet and exit pressures and temperatures and the seal backface temperature are measured at three equally spaced locations around the circumference.



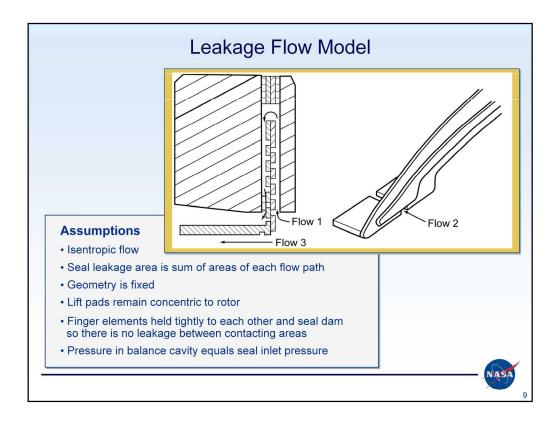
The seal leakage rate is used to compute the flow factor.

	Shaft	Inlet air	Pressure drop		
Test	speed, rpm	temperature,	across seal, kPa	Comment	
Initial static tests	0	300 533 700	0–517 kPa (or max.) – 0		
Shaft bound. Se	eal remov	ed, visually ins	spected and reinstalled.		
Bind-up tests Part 1 Part 2	0	300 K	69, 138, 207, 276, 345, 414, 483 0-276 in 13.8 increments, 483, 552, 576	Can shaft turn by hand at 0 kPa at test pressure	
Seal removed for	or visual	inspection. Dep	posits on seal sampled. Seal ultrasonically	cleaned and reinstalled.	
Repeat Static Tests	0	300 533 700	0 – max. – 0, 3 cycles		
Shaft bound. Se	eal remov	ed, visually ins	spected, and reinstalled.		
Spin Test 1	0 300 K 13.8 5,000 13.8, 34, 69, 103, 138,103, 69, 34, 13.8 0 13.8 0		25 min at 5000 rpm		
Seal removed, v	visually ir	nspected, and r	reinstalled.		
Spin Test 2	0 0 5,000	300 K	0 - max 0, 1 cycle 13.8 13.8, 34, 69, 103, 138, 172, 206, 241, 206, 172, 138, 103, 69, 34, 13.8	68 min at 5000 rpm	

# Self explanatory.

The seal bound up the shaft at pressure differentials of 276 KPa (40 psid) and higher.

The shaft was found bound by seal after the repeat static test and rig was cooled down. This can be explained. The pressure differential used during cool down was 345 KPa, which is higher than the pressure at which the seal binds the shaft. Since the clearance increases with temperature and the pressure locked the seal onto the shaft, when the rig cooled down it trapped the seal in the locked position.

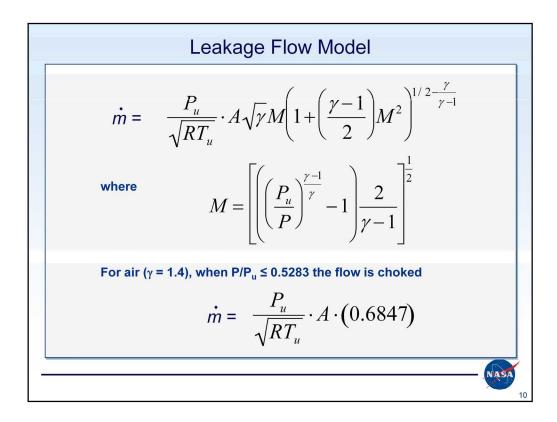


A simple leakage model was used to predict the seal leakage rate.

The model assumes there are three flow paths through the seal as shown.

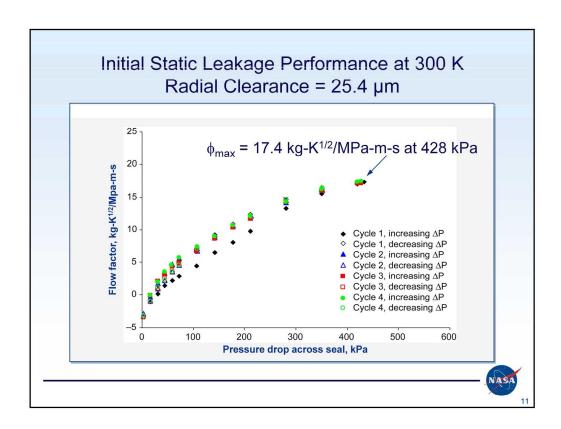
The sum of these three areas equals the seal leakage area.

The assumption that the pressure in the balance cavity equals the seal inlet pressure is good because the flow area of the finger slots at the seal dam is 11 times smaller than the area of the flow restrictions upstream of it. This means the finger slots control the leakage rate in that flow path.

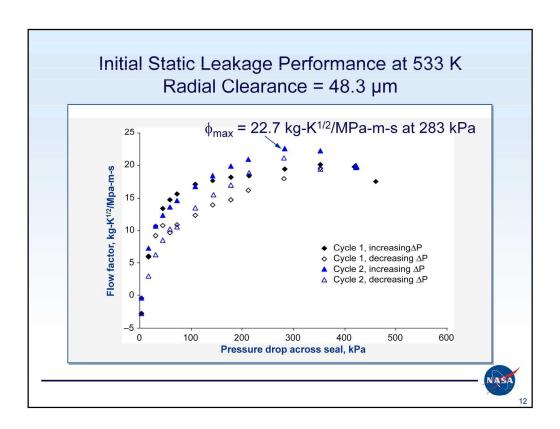


The leakage rate is predicted using the isentropic flow equation.

A discharge coefficient of 0.65, which is typical of orifices, can be applied to account for inlet and exit losses.



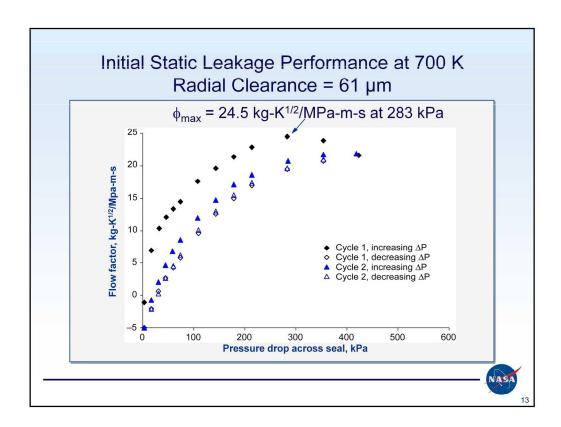
The maximum flow factor of approximately 17.4 kg- $K^{1/2}$ /MPa-m-s occurred at approximately 428 kPa across the seal. The data show little hysteresis after the first cycle of increasing pressure differential.



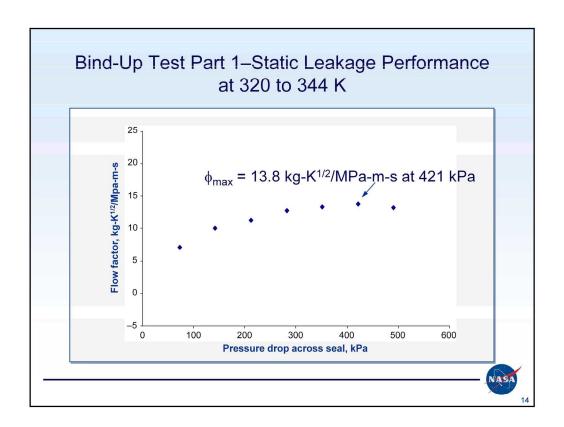
The seal exhibits more hysteresis than at room temperature.

The maximum flow factor occurred at 283 kPa and was 22.7 kg- $K^{1/2}$ /MPa-m-s.

This higher flow factor can be attributed to an increase in radial clearance due to the difference in the coefficients of thermal expansion for the seal and rotor materials. At room temperature the radial clearance is  $25.4 \mu m$ . Assuming that both the seal and rotor are at 533 K the radial clearance increases to  $48.3 \mu m$ , nearly double the build clearance.



This is the initial static leakage performance at 700 K. At this temperature the radial clearance grows to 61  $\mu m$ . The maximum flow factor occurred at 283 kPa and is 24.5 kg- $K^{1/2}/MPa$ -m-s.

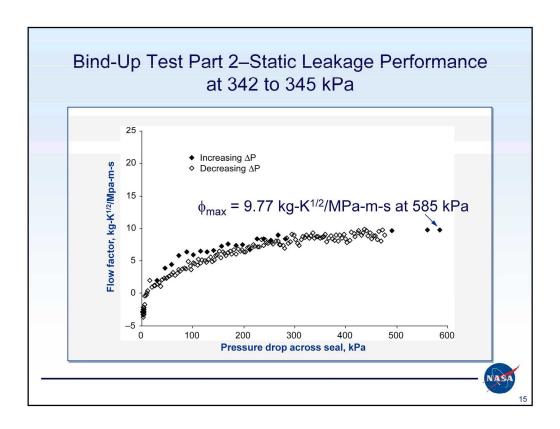


This is the static leakage performance in the Bind-Up test part 1.

The inlet air temperature steadily increased from 320 to 344 K due to residual heat in the insulated piping between the air heater and test rig.

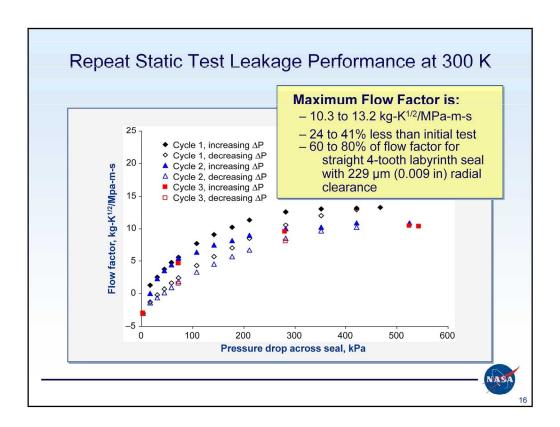
The maximum flow factor of 13.8 kg- $K^{1/2}$ /MPa-m-s at 421 kPa is less than the initial static test.

Recall that the shaft is turned by hand at 0 kPa between each data point. Rotation assists in moving the seal into its optimum position.



In part 2 of the Bind-Up test the inlet air temperature was 342 to 345 K.

The maximum flow factor was  $9.77 \text{ kg-K}^{1/2}/\text{MPa-m-s}$  at 585 kPa and is lower than the flow factor in part 1 of the bind-up test. Recall that in part 2 of the bind-up test that the shaft is rotated by hand at every pressure differential test point up to 276 kPa. This result further demonstrates the importance of shaft rotation to obtaining the optimum seal position.



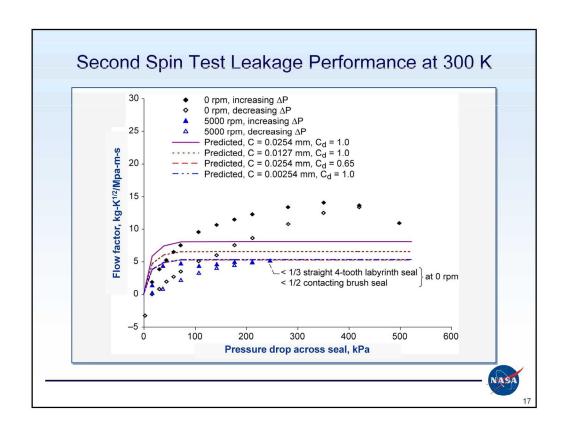
# Self-explanatory.

Unlike the initial static test at 300 K, there is quite a bit of hysteresis.

In all cycles the flow factor is lower for decreasing pressure differential than for increasing differential.

Since there are no temperature changes, the hysteresis is most likely due to internal friction forces within the seal. As pressure differential increases, the fingers toward the rotor due to the pressure blow down effect. It is surmised that friction forces hold the fingers at the smaller clearance as pressure differential decreases resulting in a lower flow factor. Reducing the pressure differential to zero releases the fingers.

The repeat static tests at 533 and 700K had similar hysteresis and 10 to 20 percent lower maximum flow factors than the initial static tests.



This is the leakage performance of the non-contacting finger seal just prior to and during the second spin test at 5000 rpm.

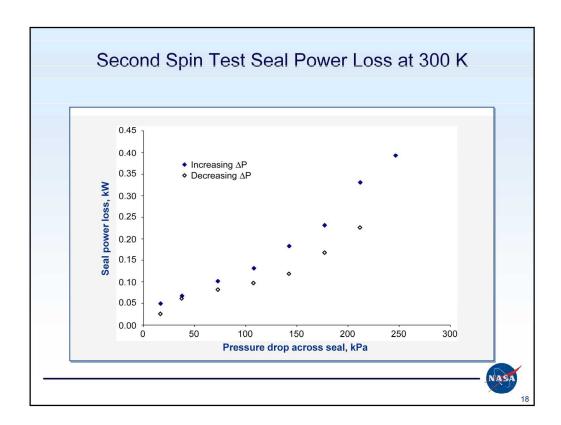
Predicted flow factors are in reasonable agreement with the data.

Hysteresis is present in both the static and second spin test data.

The flow factor with shaft rotation at 5000 rpm is substantially less than the static flow factor; approximately half at 241 kPa where it begins to level out.

The measured flow factor at 241 kPa was 5.2 kg-K<sup>1/2</sup>/MPa-m-s. This is less than on third of the measured flow factor of a straight four-tooth labyrinth seal and les than on half the flow factor of a contacting brush seal at static conditions previously reported.

The measured flow factor for this non-contacting finger seal is similar to that measured for a contacting finger seal at 186 m/s 700 K, and 276 kPa of 3 to 6 kg-K<sup>1/2</sup>/MPa-m-s.



Power loss at 5000 rpm and 300 K increases as a function of pressure drop across the seal.

The maximum power loss at 5000 rpm is approximately 0.4 kW at 247 kPa.

The seal exhibits some hysteresis. Seal power loss for decreasing pressure differentials is approximately 30 percent less than for increasing pressure differentials.

The hysteresis in power loss corresponds to the hysteresis in flow factor data.

This makes sense since lower flow factors indicate smaller clearances. Power loss decreases as radial clearance decreases.

Although a direct comparison can not yet be made, it is observed that the non-contacting seal power loss is of the same order of magnitude as that for the contacting brush and finger seals.

# Wear Results After Initial Spin Tests

### Seal

- · Visual inspection finds seal in good condition.
- · No significant change in weight.
- · Light burnishing on:
  - All low-pressure lift pads at I.D. near high-pressure edges.
- High-pressure fingers around the finger "toe".
- · All the fingers and lift pads are free to move.

### Rotor

- Shiny wear track of uniform axial length around entire circumference has no perceptible depth by touch.
- · Grooves were clean and free of debris.
- Burnishing is result of brief contact during start and stop of shaft rotation.
- There was no rapid or substantial rise in seal exit or back face temperature.

Non-contacting operation was achieved.



19

Self explanatory.

# **Conclusions**

The Non-Contacting Finger Seal promises low leakage and long life capability.

- 1. No measurable wear after 93 minutes of rotation at 300 K and 5000 rpm.
- 2. Non-contacting operation was achieved at 5000 rpm and 14 to 241 kPa.
- 3. The measured flow factor at 5000 rpm and 241 kPa was
  - <1/3 of the measured flow factor of a straight 4-tooth labyrinth seal and <1/2 of the measured flow factor of a contacting brush seal at static conditions.
- 4. Rotation is required to properly seat the seal and results in lower flow factors.
- 5. Non-contacting finger seal power loss is the same order of magnitude as brush and finger seals.

The simplified flow model is in reasonable agreement with data once flow chokes.

Further testing and analysis is needed to

- understand the nuances of this particular non-contacting finger seal design
- develop useful design methodologies and predictive tools.

Fluid-structural modeling is needed to

- understand bind-up observed at 276 kPa
- · determine design modifications to achieve higher pressure capability.



20

Self explanatory.

## LOW-TORQUE SEAL DEVELOPMENT

Scott Lattime and Richard Borowski The Timken Co. Canton, Ohio



# **Low-Torque Seal Development**

Scott B. Lattime Richard Borowski The Timken Co., Canton, Ohio

November 18, 2008

### Overview

- Due to increasing energy costs, many industries are paying more and more attention to the energy required to keep their equipment moving. The torque required to overcome the drag produced by contacting lip seals that are found in a variety of rotating equipment can significantly add to the total operating costs of that equipment.
- The Timken Co. is constantly working on innovations that manage friction via development in the areas of bearings, seals, coatings, and lubricants.
- Two examples of such work are presented in the area of seal development where Timken has been working on
  - Engineered surfaces for enhanced performance of contacting lip seals
  - 2) The development of a non-contacting seal for rail applications.

,

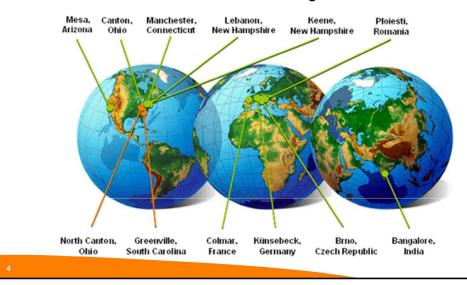
# **Company Overview**

The Timken Company is a leading global provider of highly engineered bearings, power transmission solutions and high-quality alloy steels. We serve a wide range of industries through our **Bearings and Power Transmission Group** business segments — Aerospace and Defense, Process Industries and Mobile Industries — and our **Steel Group**.



Major products and services include: Friction Management Bearings, surface engineering, lubricant and seal development; Power Transmission and Electronic Controls – innovative gear assemblies (flex-pin), electric drive motors, sensor products; Steel - specialty steels and precision steel components, Aerospace components and services (brgs, helicopter transmissions and rotorhead assemblies; Bearing maintenance tools, Condition monitoring systems and services, Engineering and technical services, Repair and refurbishing services

- Established in 1899
- Total number of associates worldwide: 25,000
- 62 plants and 104 sales offices, 12 technology centers
- Listed on the New York Stock Exchange since 1922



# **Motivation: Torque Reduction = Energy Savings**

**Process Industries** (electric motors, pumps, gearboxes, windmills)

- Small bore lip seals (< 3") can account for 4 in-lb of torque.</p>
  - 4 in-lb = 170 W (3600 rpm) = 496 kW/yr (8 hr/day)
- Large bore lip seals (>62") can account for torque > 400 ft-lb
  - 400 ft-lb = 1 kW (20 rpm) = 2900 kW/yr (8hr/day)

**<u>Automotive Industries</u>** (wheel end applications)

~0.01% mpg = 1 in-lb (per wheel)

**Rail Industries** (major car owners)

~0.1% fuel savings = 1 in-lb (per wheel)

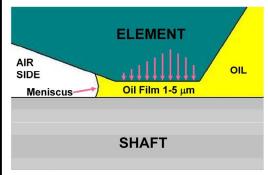
# **Background**

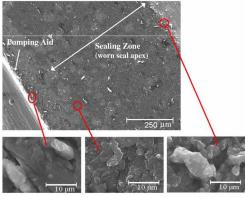
- Elastomer lip seals have been in use since the 1930's. They offer low-cost sealing solutions to power, process, transportation industries.
- Properly designed elastomer lip seals operate under full fluid film lubrication due mainly to the hydrodynamic action microasperities which are formed on the elastomer surface during break-in (Jagger '57, Jagger & Walker '66).
- Surface micro-features have been developed to enhance bearing and seal performance (Otto '74, McNickle & Etsion '01, Yu et al. '02, Stephens '04, Lou '04).

# Retention The primary purpose is to retain lubricant in the assembly (prevents lubricant leakage) The sealing lip should be positioned toward the lubricant Exclusion The primary purpose is to exclude contamination (prevents contaminant ingress) The sealing lip should be facing the contamination

# **Sealing Mechanism**

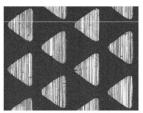
- Micro-asperities in the elastomer surface retain fluid and deform under shear stress functioning like tiny viscous pumps
- The generated pressure distribution across sealing zone provides load support as well as reverse pumping



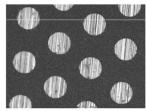


# **Surface Texture Geometries**

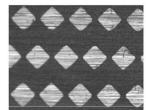
- Cavity geometries chosen due to ease of manufacturing and wear considerations
- Manufacturing Processes UV-photolithography Roll-forming
- Over 20 different texture sizes/orientations have been tested



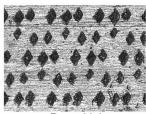
Triangular



Circular

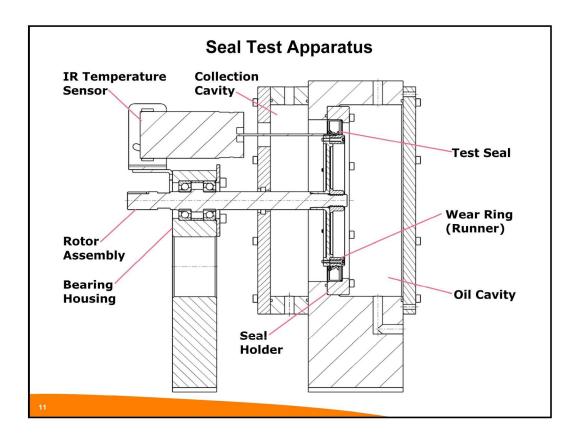


Diamond

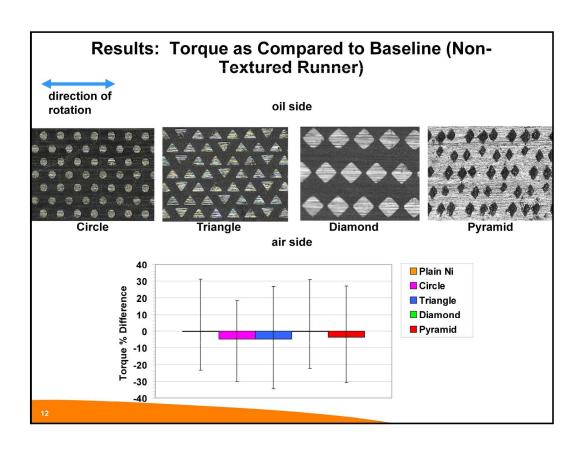


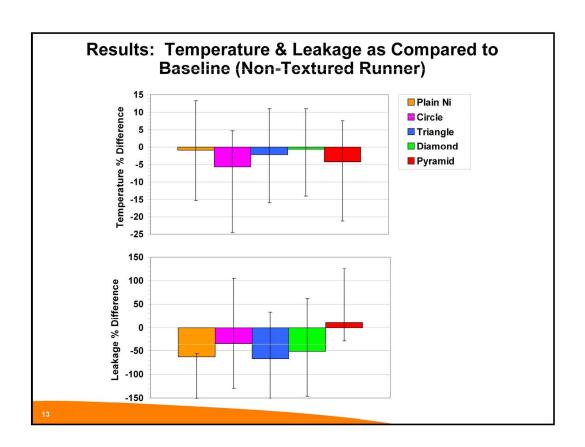
Pyramida

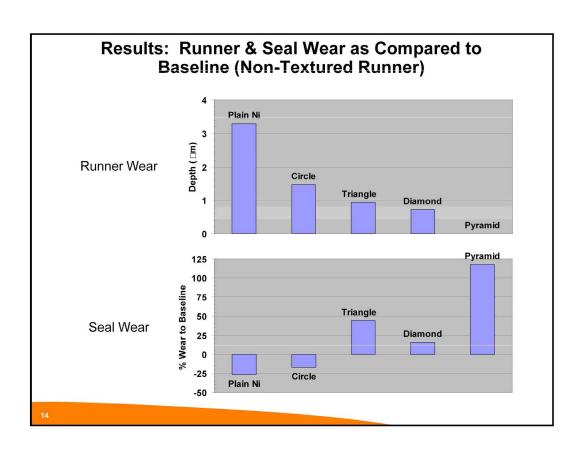
10



Test were performed with 20W-50 oil at 750 rpm over 24 hr.







### **Conclusions**

- Feasibility of enhancing lip seal performance due to the application of manufactured micro-features on the running surface was experimentally proven.
- Although there was a large amount of scatter to the data, the trends show the textured running surfaces exhibited a reduction in operating torque and temperature of up to 5% and over 50% reduction in leakage as compared to non-textured surfaces.
- Wear of the cavity-textured running surfaces was less than 25% of the cavity depth and seems unlikely to have a large influence on the performance results.
- The circular cavities exhibited the best overall performance on lowering seal torque and temperature with the least amount of seal wear. However it is unclear at this point what effect the Ni plating itself has on the performance (e.g. solid lubricant).

### **Future Work**

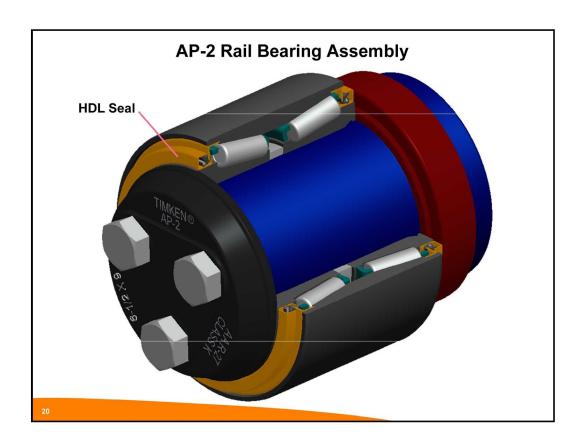
- The effects of the Ni plating must be ruled out by manufacturing texture geometries on the native metal (e.g., laser machining).
- Due to the variability of the results, larger sample sizes should be used to gain statistical confidence.
- Development and evaluation of textured elastomer on plain running surface (textured molds) should be investigated as a lower cost alternative.
- Characterize the long-term effects of micro-features on seal life with much longer test runs (100's of hours) as well as on the elastomer micro-asperities.

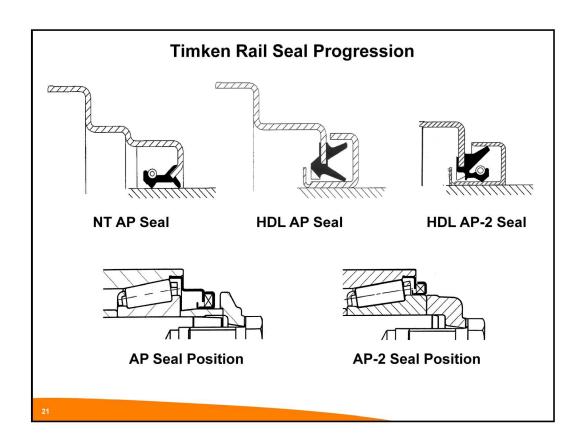
EcoTurn Seal:
Development of a Non-contacting
Seal for Rail Applications

## Timken History of Railroad Innovation

<ul><li>1923</li></ul>	FIRST RAILROAD APPLICATION
<b>1930</b>	TIMKEN FOUR ACES LOCOMOTIVE
<ul><li>1954</li></ul>	TIMKEN "AP" BEARING
<ul><li>1968</li></ul>	FIRST FITTED BACKING RING
<ul><li>1972</li></ul>	NFL BEARING CONCEPT INTRODUCED
<b>1988</b>	TIMKEN HDL™ SEAL
<ul><li>1994</li></ul>	TIMKEN "AP-2" BEARING
<b>2008</b>	TIMKEN ECOTURN™ SEAL



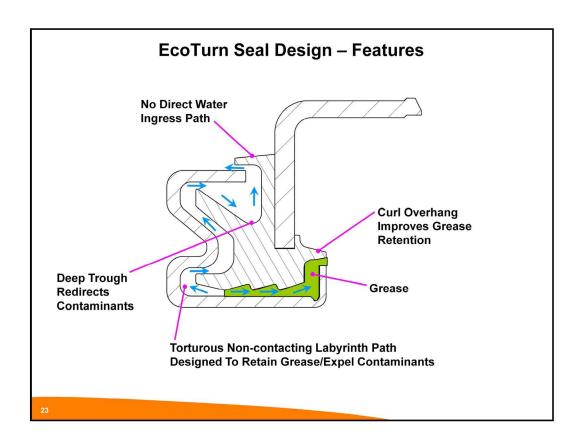




### **Design Criteria**

"THE SEAL PERFORMANCE MUST EXCEED THAT OF THE CURRENT HDL SEAL DESIGN"

- REDUCED GREASE WEEPAGE
- "ZERO" TORQUE
- IMPROVED WATER/CONTAMINANT EXCLUSION
- INCREASED ROBUSTNESS
- COST
- IP RETENTION
- FIT BOTH "AP" AND "AP-2"



## **Seal Laboratory – Test Capabilities**



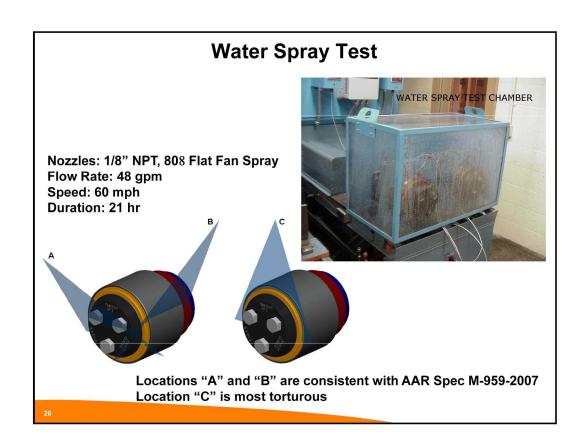


- PERFORMANCE
- TORQUE
- VIBRATION
- SLURRY INGRESS
- DUST INGRESS
- WATER SPRAY
- WATER SUBMERSION
- HIGH/LOW TEMPERATURE
- LIFE

2/

		AAR	R Quali	fication 1	<b>Testin</b>	g Summa	ry	
	M-959 Sec.	Test	M-959 Limits		Results			
			Grease Purge	Contaminate Ingress	Grease Purge	Contaminate Ingress	Pass/ Fail	Status
	4.3.1	Elevated Temperature	10g Per seal	N/A	0g	N/A	Pass	Complete
	4.3.2	Low Temperature		amage or ssive wear	No damage or wear observed		Pass	Complete
	4.3.3	Dust Ingress	N/A	1%	N/A	0.1%	Pass	Complete
	4.3.4	Water Spray	N/A	0.5% free water	N/A	0% free water	Pass	Complete
	4.3.5	Vibration	10%	N/A	0%	N/A	Pass	Complete
	4.3.6	Accelerated Life	10%	N/A	1.1%	N/A	Pass	1 of 2 sets complete
	4.1.4	Seal Torque	34	l in-lbf	1.25 in-lbf		Pass	Complete

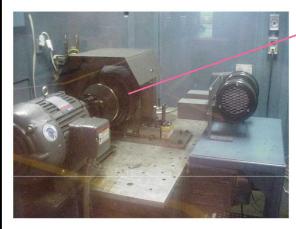
Accelerated Life test: 34,400 lb, 60 mph, 250,000 mi

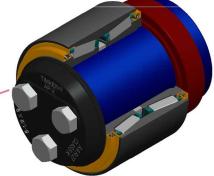


### **Vibration Test**

Displacement: 1/16" peak to peak in the vertical plane through axle

Frequency: 38 Hz
Cycle: 21 hr running, 3 hr down
Speed: 60 mph
Duration: 4 Days



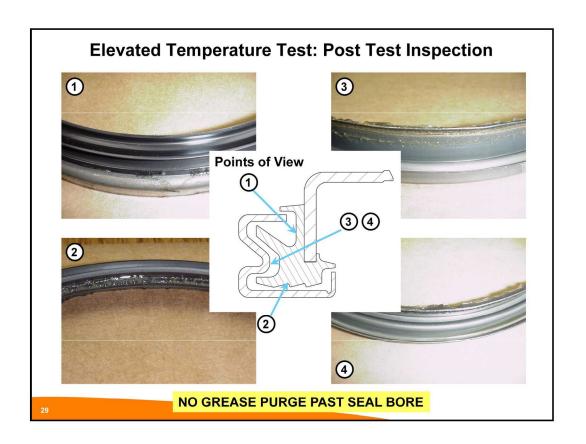


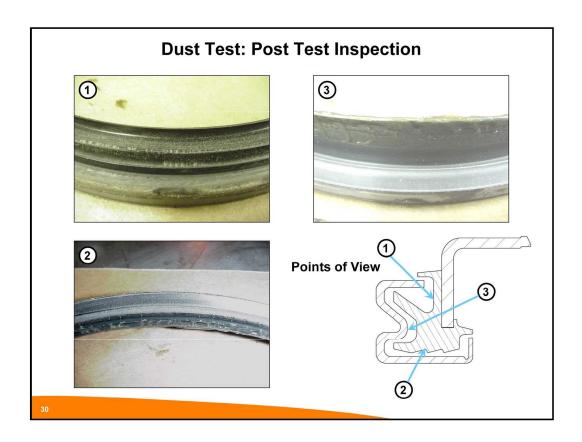
### **Dust Test**

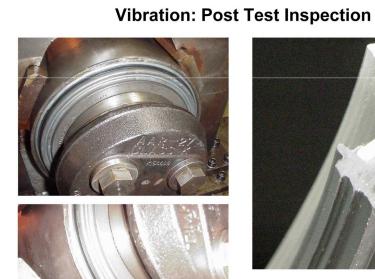
**Closely Fitted Canister (0.5" Radial Clearance)** 

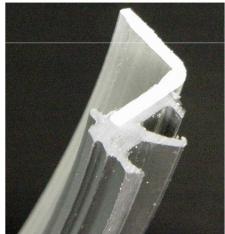
Dust Fill: 15% Speed: 500 rpm Duration: 100 hr



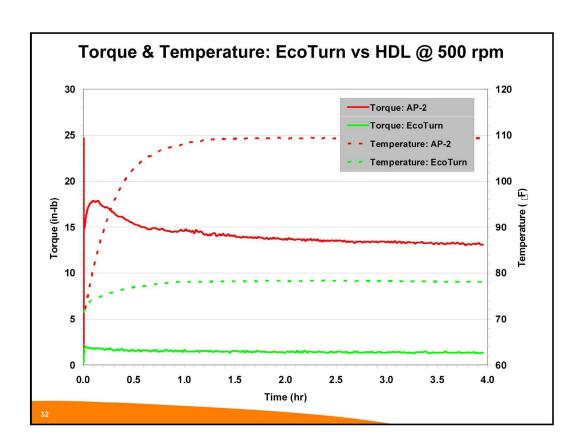








NO GREASE PURGE THROUGH SEAL NO WEAR OF SEAL LIP



## **Field Testing**

- Currently have 80 seals on a captured line since July of '08
- Bearings have been visually inspected twice (most recent 09/04/08) showing no signs of seepage.



### **Conclusions**

- The EcoTurn Class K production prototypes have passed all AAR qualification tests and received conditional approval.
- The accelerated life test on the second set of seals is in progress. Due to the performance of the first set, no problems are expected.
- The seal has demonstrated superior performance over the HDL seal in the test lab with virtually zero torque and excellent contaminant exclusion and grease retention.

#### AN OVERVIEW OF NON-METALLIC BRUSH SEAL TECHNOLOGY

Eric J. Ruggiero GE Global Research Niskayuna, New York

# An Overview of Non-Metallic Brush Seal Technology

Eric J. Ruggiero, Ph.D.
GE Global Research
Niskayuna, New York
ruggiero@research.ge.com

NASA Seal / Secondary Air System Research Symposium

John H. Glenn Research Center
Cleveland, Ohio



November 18, 2008

Abstract: Non-metallic brush seals are ultra-low flow sealing elements ideal for low pressure differentials (<30 psid) and low temperature (typically <300 degF) applications. The compliant bristle pack of a non-metallic brush seal is advantageous in terms of sealing capability during transients. However, if not designed properly, the bristle pack compliance can be detrimental to the performance of the seal. GE GLobal Research has investigated the stiffness and heat generation properties of non-metallic brush seals made from Kevlar and Carbon Fiber. The presentation will review the progress made on the design points of the seals, as well as highlight some current commercial applications of the technology.

--Eric J. Ruggiero, Ph.D. GE Global Research One Research Circle (K1-3B17) Niskayuna, New York 12309 (518)-387-4279 ruggiero@research.ge.com

## Why non-metallic brush seals?

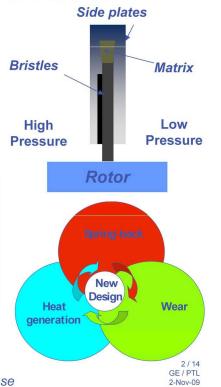
Excellent sealing (< 0.002" effective clearance)

Wear particulate benign in bearing environment

Good oil preclusion properties

Compliant bristle pack

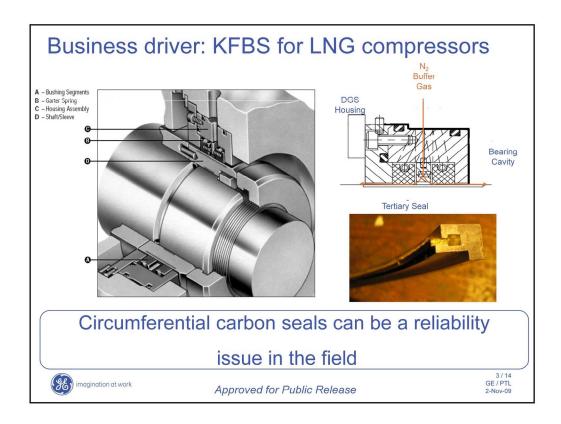
- No rotor scoring or marking
- Source of heat generation
- Wear debris caused by stiffness



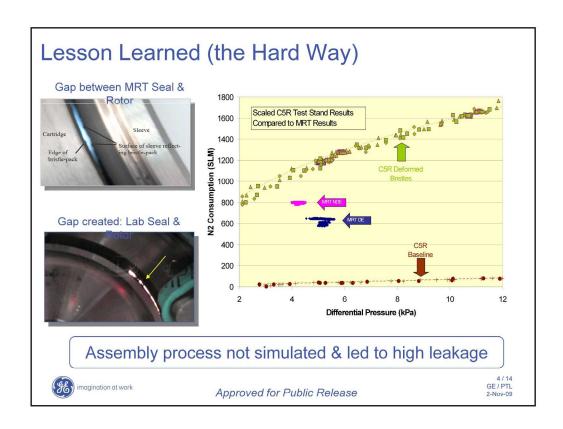


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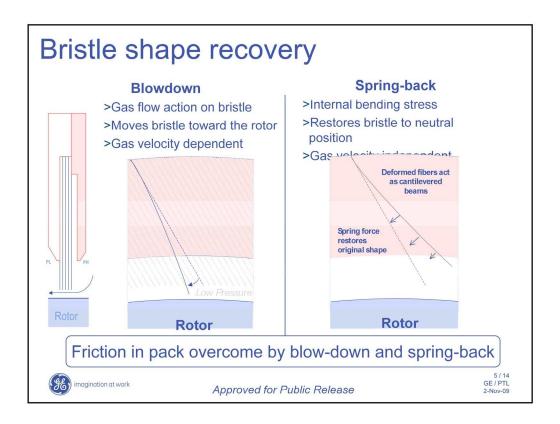




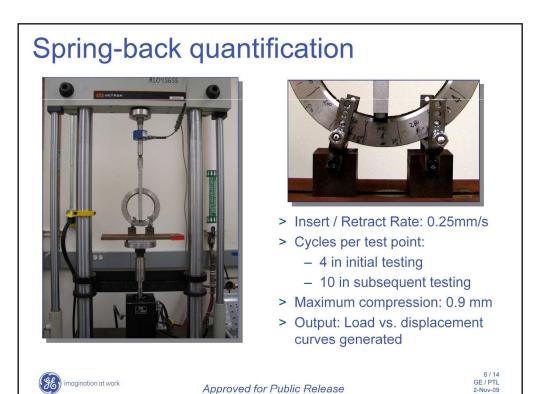
GE Oil & Gas was not the primary business driver in the initial development of non-metallic brush seals. However, GE O&G was the first to heavily invest in the technology development to ensure a robust seal design.



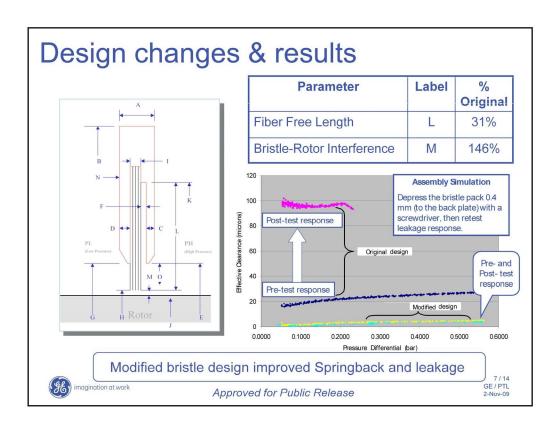
Early 2007 field trial had high leakage. RCA following the field trial failure revealed that the bristle pack was poorly designed—it was too soft from a stiffness perspective. The assembly process of getting the seals onto the rotor was never simulated in the subscale testing, thus never identified as a potential issue prior to field testing.



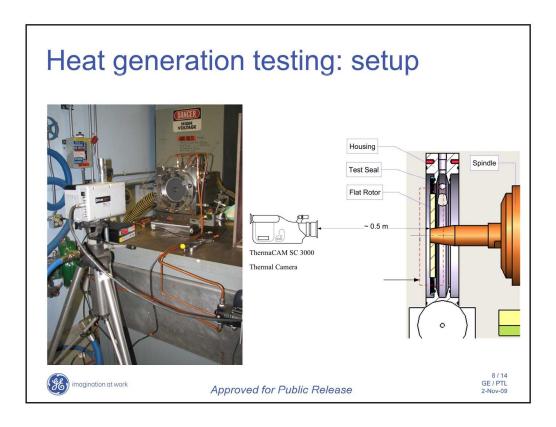
There are two main factors that affect bristle pack recoverability: blow-down and spring-back. The focus of this research is on spring-back, as it is a property inherent to the seal design and not a function of differential pressure.



Spring-back test setup at GE GR in Niskayuna, NY.



Identified design changes to improve the stiffness of the bristle pack led to a successful second attempt both in the subscale and in a field trial.



Heat generation testing setup at GE GR, Niskayuna, NY.

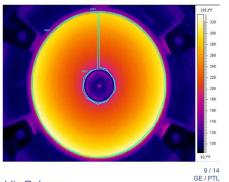
## Heat generation test procedure

- 1. Set rotor speed
- 2. Monitor average temperature at inner 1" diameter of rotor
- 3. Record thermal gradient throughout rotor once steady-state conditions are met
- 4. Increase rotor speed

### **Test Conditions:**

> 7, 33, 67, and 100% rpm

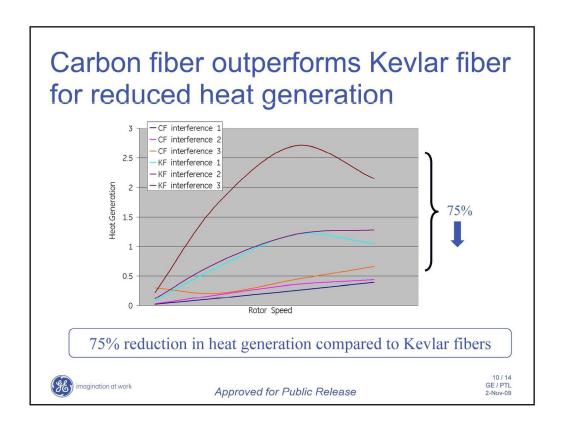
> Clearance, L-L, and Int





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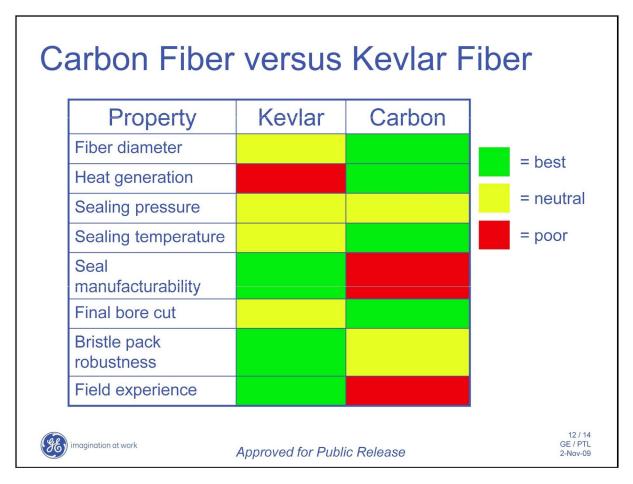




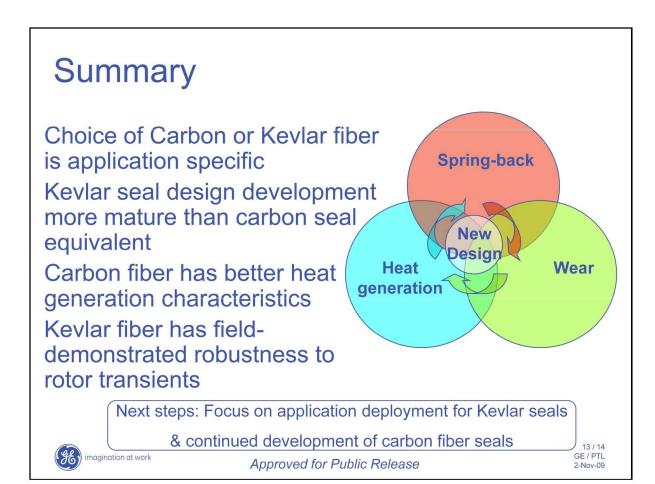
Seal designs were similar for both carbon and kevlar fiber.



Wear testing setup at GE GR in Niskayuna, NY.



This table compares the identified property in the leftmost column between both the kevlar and carbon seal designs. Since it is comparing just these two seals, each row compares the stated property, where one seal is usually identified as being better or worse than the other.



## References

- •Ruggiero, Eric J., Mehmet Demiroglu, Jason Allen, and Mark Lusted. "Heat Generation Characteristics of a Kevlar Fiber Brush Seal," *AIAA Joint Propulsion Conference*, July 8 11, 2007, Cincinnati, OH.
- •Ruggiero, Eric J., Jason Allen, and Mark Lusted. "Heat Generation Characteristics of a Carbon Fiber Brush Seal," *AIAA Joint Propulsion Conference*, July 21-23, 2008, Cincinnati, OH.
- •Ruggiero, Eric J., Paolo Susini, and Mark Lusted. "Kevlar Fiber Brush Seals for LNG Compressors," *AIAA Joint Propulsion Conference*, July 21-23, 2008, Cincinnati, OH

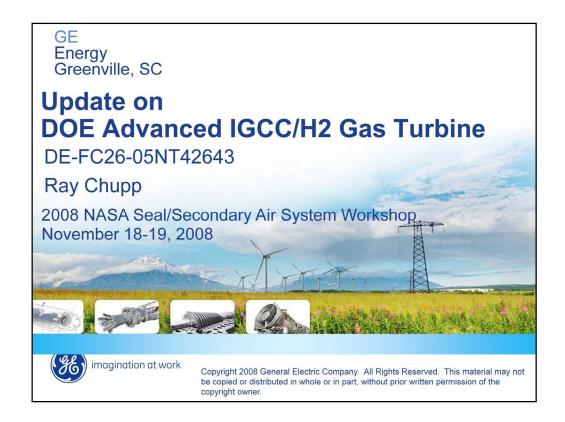


Approved for Public Release

14 / 14 GE / PTL 2-Nov-09

### UPDATE ON DOE ADVANCED IGCC/H2 GAS TURBINE

Ray Chupp GE Energy Greenville, South Carolina



## GE Energy

## Update on DOE Advanced IGCC/H2 Gas Turbine

DE-FC26-05NT42643

Ray Chupp

## 2008 NASA Seal/Secondary Air System Workshop November 18-19, 2008

- 1. This material is based upon work supported by the Department of Energy under Award Number DE-FC26-05NT42643
- 2. This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



## **Acknowledgements**

GE would like to extend a special thanks to the US Department of Energy National Energy Technology Laboratory and the following individuals for their past and continued support on the DOE/GE "Advanced IGCC/Hydrogen Gas Turbine Development Program"

## **Rich Dennis**

Turbine Technology Manager
Office of Fossil Energy
U.S. Department of Energy
National Energy Technology Laboratory



## Ron Harp

Project Manager
Power Systems Division
U.S. Department of Energy
National Energy Technology Laboratory





# **IGCC - H<sub>2</sub> Gas Turbine Landscape**

## **Objective**

**Approach** 

Capability

Cleaner Energy from Coal

via

IGCC with Carbon Capture

## Today

**GE** existing products:

7FB-H2

- · High-H2 GT fleet
- · Successful operation
- Diffusion flame
- Diluent for NOx



### **Future**

**Technology Advances** 

- Reduced NOx (2ppm)
- Increased Performance (+3-5pts)
- DOE Program Increased Output
  - Reduced Cost

Combustion v

**Turbine** 

**Materials Systems** 

### **Program Timeline**

2010 2011 2013 - TBD 2006 Phase III (Not Yet Awarded) Phase I (CPT) Phase II (Awarded, In Progress) Concept Design **Detailed Design & Component Validation Test** Final Design & Field Evaluation

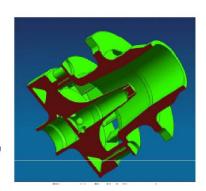


## **Combustion Technology:**

Modeling
Subscale testing
Limited full scale, multi nozzle testing

Phase I... focus on fundamentals

- 'Chemistry' evaluation fuels, mixing, residence time, EGR
- Benchmark existing NG designs on high H2 fuels
- Evaluate 1<sup>st</sup> Gen prototypes (based on traditional designs)
- Evaluate 2<sup>nd</sup> Gen prototypes (more 'out-of-the-box'
   designed specifically for high H2)



## Phase I Goal Complete: Select top two concepts for further evaluation in Phase II



Phase II... design optimization

- Optimize designs for resistance to flashback, flameholding, dynamics
- Obtain data to minimize risk
- Validate the technology

Status: Initial full can/larger scale testing of down selected concepts providing promising results, continuing to drive down emissions and extend operability



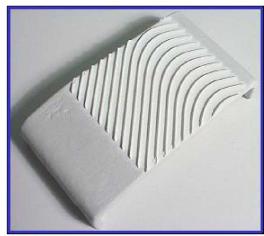
## **Materials Technology:**

Phase I... characterization and development

- Characterizing the environment
- Identification of candidate material/coating systems
- Development of screening tests for material systems (corrosion, erosion, impact)
- CMC/EBC development



### Phase I Goal Complete: Screened list of candidate material systems for Phase II





Phase II... enabling turbine technology improvements

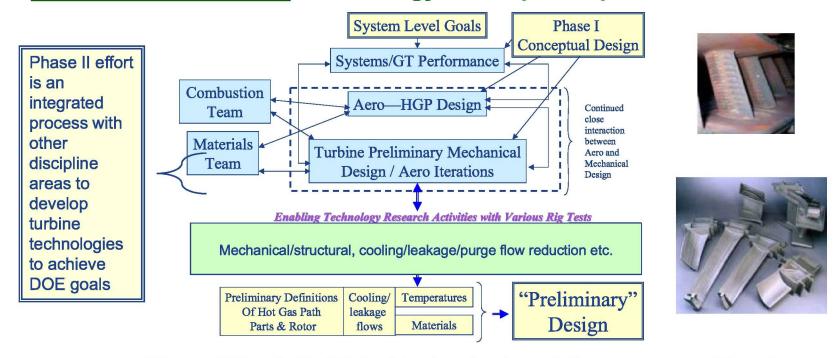
- Validation of material systems at component level
- Field testing of components where applicable

**Status:** Interim down select completed with significant capability improvements, line of sight to program targets

## **Turbine Technology:**

Phase I... identifying turbine technology improvements

## Phase I Goal Complete: Technology development plan for Phase II



## **Phase II Goal**: Validated technologies at the component level



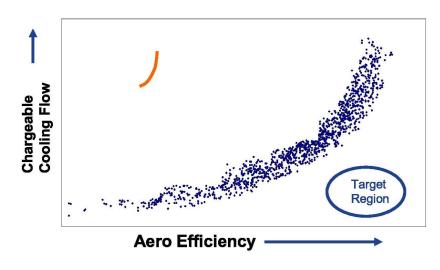
# **Turbine - Aerodynamics**

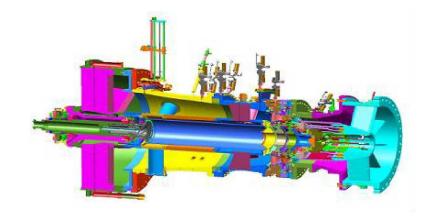
## **Advanced Design**

- work splits, reaction, and airfoil counts.
- 3-D Aero & Endwall Contouring

## **Turbine Rig Testing**

Learning, Validation







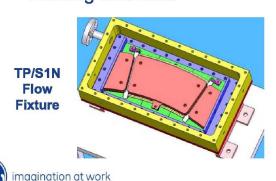
## **Turbine - Mechanical**

## **Turbine Goal:**

Higher component efficiency with higher flow rates

## **Turbine Efforts Launched:**

- Conceptual design studies on different turbine concepts – aerodynamic and mechanical
- Advanced technology development to <u>reduce</u> <u>parasitic leakages</u>
  - Transition Piece/Stage 1 nozzle seal
  - Turbine interstage beneath nozzle
- Advanced technology dev. to address turbine blade durability
  - Damping effect on aeromechanics
  - Fretting and wear





Fretting & Wear Test





6

# **Turbine – Heat Transfer/Sealing Plans**

### Cooling Flow Reduction:

- Focus on <u>improving turbine hot gas path part cooling</u> <u>efficiency</u>
- Applicable to current metallic turbine components and synergistic with advance materials
- Address challenges of IGCC/hydrogen fuel environment (for example, possible cooling hole plugging)

### Leakage Flow Reduction:

- Focus on <u>decreasing turbine parasitic leakages</u>, i.e. between static-to-static, static-to-rotating, and rotating-to-rotating turbine parts
- Develop improved seal designs in a variety of important areas

### • Purge Flow Reduction:

- Focus on <u>decreasing required flows</u> to keep rotor disk cavities within temperature limits
- Develop improved sealing at the cavity rims and modified flow geometries to minimize hot gas ingestion and aerodynamic impact









## Cooling—Advanced Film Cooling

Diffuser and Chevron shaped film cooling hole geometries\*

Shaped "Baseline" Chevron 1 "Flat"

Chevron 2 "Tent"

Chevron 3 "Arcuate"

**Example geometries for shallow** trench film cooling\*









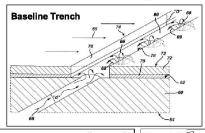


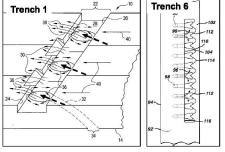
- 0.66 mm diameter · 30-deg to surface tangent
- · 20-deg lateral diffuser
- 10-deg laidback

· 0.46 mm diameter "chevron" edge troughs

Results to date show:

- Some hole/trench configurations provide up to 20% higher average film effectiveness than diffuser shaped holes.
- Aerodynamic mixing losses were also measured





### **Blowing Ratio or Pressure Ratio**

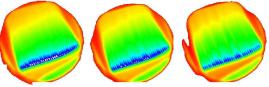
Low **Moderate** High

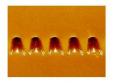




**Shaped Holes** 

**Chevron Holes** 



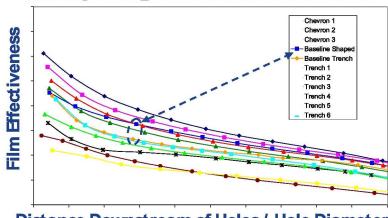


Full-surface film effectiveness data for diffuser shaped holes and chevron holes.



\* Hole shapes based on US patents: 7,328,580, 6,234,755, 6,234,755, and 2008/0057271A1.

### Laterally averaged film effectiveness curves



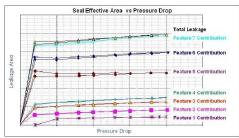
Distance Downstream of Holes / Hole Diameter

2008 NASA Seal/Secondary Air System Workshop, No. 18, 2008, Ohio Aerospace Institute (OAI)—Copyright 2008 General Electric Company

## **Advanced Sealing—Four Focus Locations**

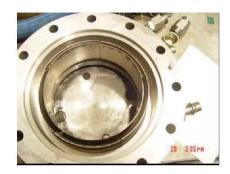
### **Transition Piece/Stage 1 Nozzle Seal**





- New flow fixture built to test engine size seals.
- Relative axial movement modeled.
- Leakage through various paths measured.
- Current and new seal designs tested to optimize seal design

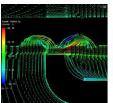
### **Turbine Interstage Seal**

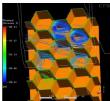


- New seal approaches investigated.
- · Initial testing on 5-in flow rig.
- Intermediate size rig being built

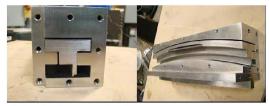
### **Angel Wing Seal**







### **High Pressure Packing Seal**



- Passive retractable brush seal design based on successful GE steam turbine retractable seals
- Testing at full pressure conditions

- Identified optimum abradable geometry/material vs. location
- Flow resistance quantified via. CFD
- Honeycomb → good flow restriction for engine radial closures
- Studying aluminizing honeycomb material to increase oxidation resistance

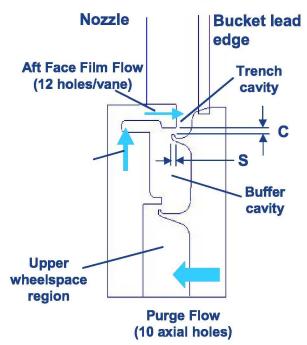


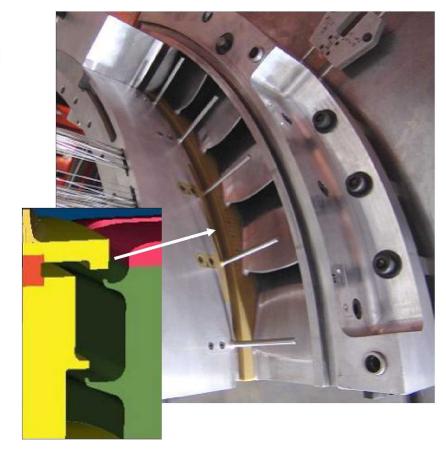


12

## Purge Flow—Transonic Annular Cascade Screening Tests

Regional static pressure distributions, Infrared surface temperature maps, trench and buffer cavity cooling effectiveness.

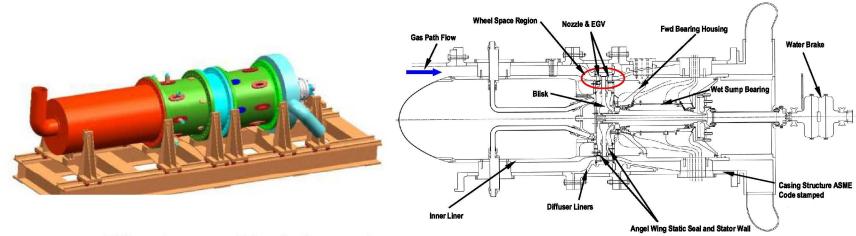




- Annular sector cascade rig run to gather data on rim seal region pressures, temperatures, and hot gas ingestion for various geometries.
- Data used to validate detailed CFD model analysis.
- Potential improved rim seal configurations being tested.



## Purge Flow—Rotating Wheelspace Rig Development



Wheelspace Rig Schematic

**Test Section Features** 

- Scaled baseline geometry with flexibility to model other engine configurations
- Features to allow testing variations.
- Rotating and static instrumentation
- · Configurations will be tested to achieve optimum designs.
- Data will be used to validate detailed CFD models with rotation.



# **Summary and Conclusions**

- 1. Strong program structured to meet DOE goals on efficiency, emissions, and capital cost
- 2. Phase I completed all milestones met and significant progress made:
  - Obtained near-entitlement NOx emissions at temperatures of interest for this program
  - Turbine technologies identified to achieve DOE goals development will expand in Phase II

## 3. Phase II Underway:

- Combustion focus narrowed to two concepts
- <u>Materials</u> focus on optimization of materials/coating systems for environment
- Heavier turbine effort on mechanical and aero aspects plus:
  - > Cooling—initially looking at advanced film cooling
  - > Sealing—focusing on four key leakage areas
  - > Purge flow—initially using a cascade rig to screen configurations & validate CFD, rotating rig being developed



#### OVERVIEW OF LIDS DOCKING SEALS DEVELOPMENT

Patrick Dunlap and Bruce Steinetz
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Christopher Daniels University of Akron Akron, Ohio

National Aeronautics and Space Administration



### Overview of LIDS Docking Seals Development

Pat Dunlap Dr. Bruce Steinetz NASA Glenn Research Center Cleveland, OH Structures & Materials Division

> Dr. Chris Daniels The University of Akron Akron, Ohio

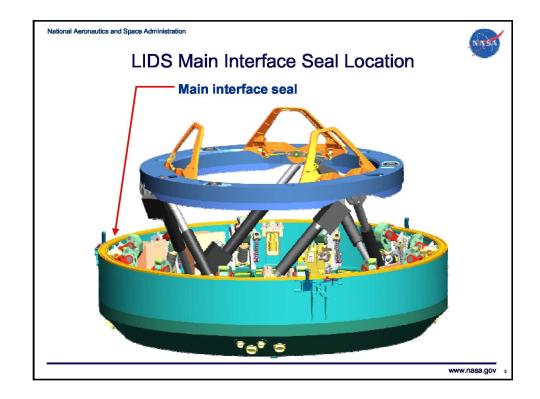
2008 NASA Seal/Secondary Air System Research Symposium November 18, 2008

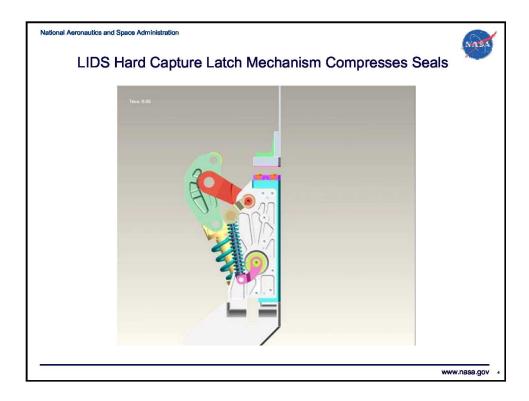


### NASA GRC LIDS Seal Development Team

- · Research staff:
  - Dr. Chris Daniels
  - Henry deGroh
  - Pat Dunlap
  - Nicholas Garafolo
  - Jay Oswald
  - Nicholas Penney
  - Ian Smith
  - Dr. Bruce Steinetz
  - Janice Wasowski
  - Marta Bastrzyk (Summer student)
  - Mason Conrad (GSRP student)
  - Sara Kline (U. of Akron co-op)

- · Design & analysis staff:
  - Joe Assion
  - Gary Drlik
  - Art Erker
  - Mike Hoychick
  - Lawrence Kren
  - Malcolm Robbie
  - Ron Storozuk
- Technicians & support staff:
  - Erhard Hartman
  - Mike Hurrell
  - Dick Tashjian
  - Joe Wisniewski
  - Dr. Bruce Banks
  - Sharon Miller
  - Deborah Waters







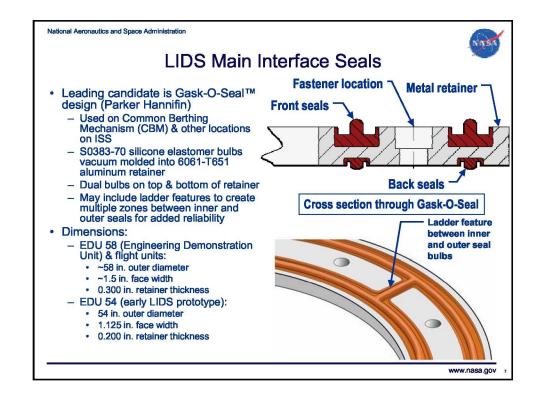
### Top Level Seal Requirements

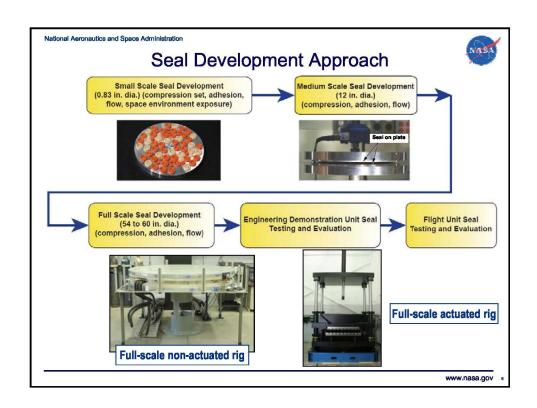
- Extremely low leak rates (≤0.0025 lbm/day) at 14.8 psia to minimize overall LIDS leakage
- Temperature ranges:
  - Operating: -30°C to +50°C (-22 °F to +122 °F)
  - Non-operating: -70°C to +100°C (-94 °F to +212 °F)
  - Ranges subject to change as additional thermal analyses and tests are performed
- Max compression loads: 140 lbf/in. (70 lbf/in. per seal bulb)
- Max load to separate seals during undocking: 300 lbf

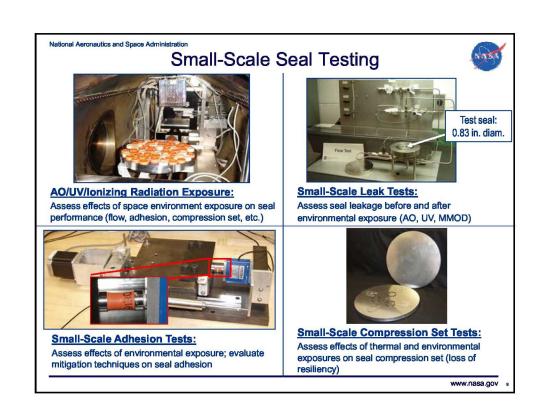


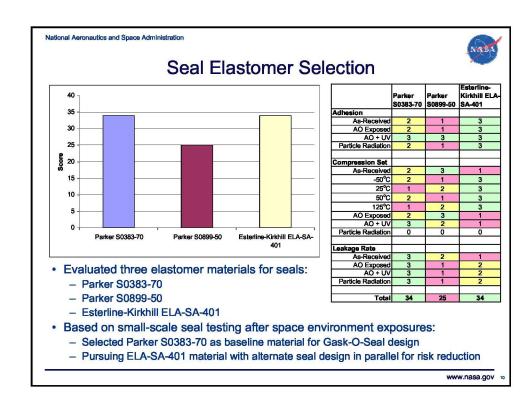
### Top Level Seal Requirements (cont.)

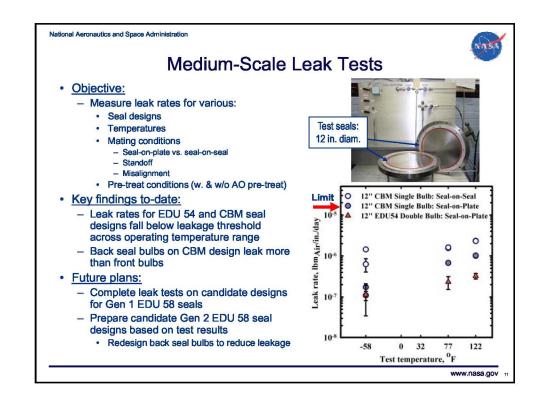
- Long mating periods (216 days) and repeated docking
- Withstand exposure to space environments (e.g., atomic oxygen (AO), UV radiation, micro-meteoroids and orbital debris (MMOD)) without excessive damage or loss of sealing ability
- Include redundant sealing features (i.e., two seals or two seal beads) and provisions to verify each seal prior to launch
- Materials must meet low outgassing requirements of total mass loss (TML) <1% and collected volatile condensable materials (CVCM) <0.10% using ASTM E595

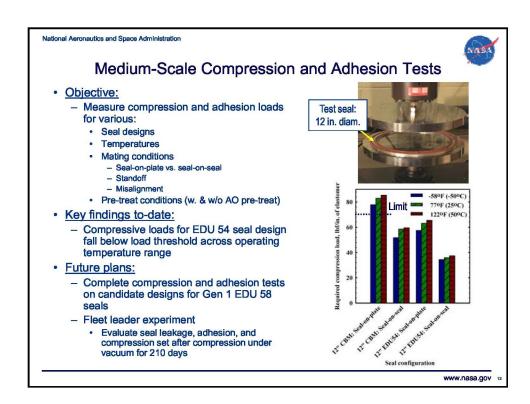


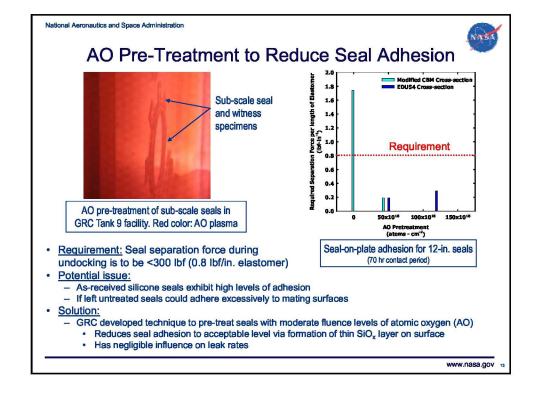












## Full-Scale Seal Testing



 Evaluate performance of candidate full-scale seals under anticipated operating conditions

#### Approach:

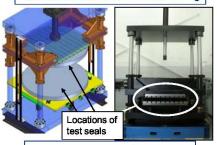
- Non-actuated test rig measures seal leak rates
- Actuated test rig measures seal leak rates and loads

#### Capabilities:

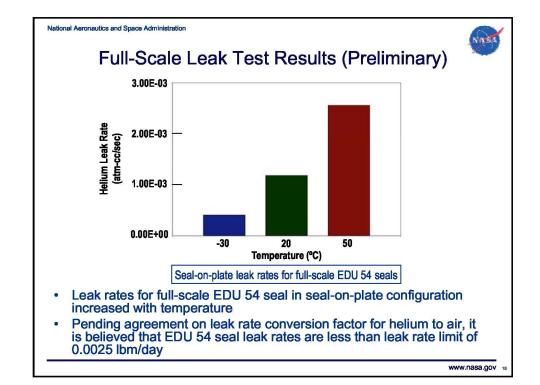
- Seal-on-plate (primary) and seal-on-seal configurations
- Seals of various designs and sizes:
  - · Diameters: 52 to 60 in.
  - · Various seal widths and thicknesses
- Temperatures: -50 to +50°C (-58 to +122°F)
- Pressure differentials across seals for:
  - · Operating conditions in space
  - · Pre-flight checkout conditions on ground
- Aligned vs. misaligned conditions
- Seal compressive & adhesive loads during docking & undocking (actuated rig only)



Full-scale non-actuated LIDS seal test rig



Full-scale actuated LIDS seal test rig





Mounted on ISS Columbus module for 9-12 mos.

To be mounted on ISS EXPRESS Logistics Carrier 2 (ELC2) for ~1 yr.

Launch to occur Oct. 2009 on STS-129



National Aeronautics and Space Administration

- MISSE 7:



### Summary

- · GRC is supporting JSC by developing LIDS main interface seals
- Seal development and testing is occurring at both sub-scale and full-scale levels
  - Small-scale tests performed to define seal materials and evaluate exposure to space environments
  - Medium-scale testing:
    - · Permits evaluation of candidate seal designs at faster pace than for fullscale seals
    - · Leak rates and loads can be scaled up to full-scale for indication of seal performance
  - Full-scale test rigs used for seal development and flight qualification tests and to assess on-orbit anomalies if needed
- GRC responsible for delivering flight hardware seals to JSC ~2013 for integration into LIDS flight units

#### DESIGN AND ANALYSIS OF MOLDED ELASTOMER SEALS

Paul Yetter and Kai Zhang Parker Hannifin San Diego, California

# 2008 NASA Seal/Secondary Air System Research Symposium

### **Design and Analysis of Molded Elastomer Seals**





Paul Yetter Sr. Product Engineer Parker Hannifin Composite Sealing Systems Division San Diego, CA Dr. Kai Zhang CAE Manager Parker Hannifin Seal Group San Diego, CA

November 18, 2008

## Gask-O-Seal™ Heritage in Space

#### Space Shuttle

Gold Plated Magnesium Fuel Cell Plates and Seals Solid Rocket Motor (SRM) Stat-O- Seals SRM Safe and Arm Igniter Seals SRM Inner and Outer Seals



#### **International Space Station**

Common Berthing Mechanism Seals
Hatch Seals
Electrical Connector Seals
Fluid Connector Thermal Isolator and Seals
Cupola Window Frame and Seal
Window Frame and Seal

#### Delta II Launch Vehicle

ISA Cover Seal

Electrical Connector Plate Seal



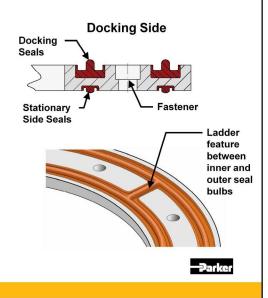
#### **International Space Station**

Intravehicular Activity Seals Hatch Stops Window Pane Bumper Columbus Module Seal Mini Pressurized Logistics Module Seal



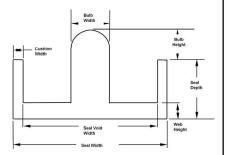
# LIDS Seal Construction and Functional Requirements

- Elastomer: Parker compound S0383-70 vacuum molded and bonded to 6061-T651 aluminum retainer.
  - Materials meet low out gassing requirements for Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM)
- Dual seal bulbs on top and bottom to meet redundancy requirement.
- Ladder features divide annulus between inner and outer seals into multiple zones for added reliability.



# LIDS Seal Construction and Functional Requirements

- Seals must withstand exposure to space environments without excessive damage or loss of sealing ability:
  - Atomic oxygen (AO)
  - Ionizing and ultraviolet (UV) radiation
  - Possible impacts from micrometeoroids and orbital debris (MMOD)
  - Vacuum conditions
  - Thermal cycling
- Temperature:
  - Operating: -50°C to +50°C (-58°F to +122°F)
  - Non-operating: -100°C to +100°C (-148°F to 212°F)
- Exhibit extremely low leakage rates (≤0.0025 lbm/day) at pressure of 14.8 psia to minimize overall LIDS leakage.
- Long mating periods (216 days) and repeated docking.
- Max compressive load < 70 lbs/linear inch/seal bead.</li>
- Max separation load < 300 lbs total.





## **FEA in Parker Seal Group**

- Parker Seal Has Been Using FEA for Optimizing Seal Designs for 18 Years
- Nonlinear FEA Software, Marc, is Deployed in All N.A. and European Divisions
- Software Ansys is Used in Asian Division



## Major Issues in Sealing FEA

## 1. Modeling of Materials

- Rubber Compounds Are Complex Composite, and Exhibit Thermo-Visco-Elastic Behavior
- Hyperelastic Model is Widely Used in Seal Industry, but Its Limitation is Often Ignored
- Viscoelastic Model is Rarely Used, and Should Get More Research and Application.

### 2. Test and Characterization of Materials

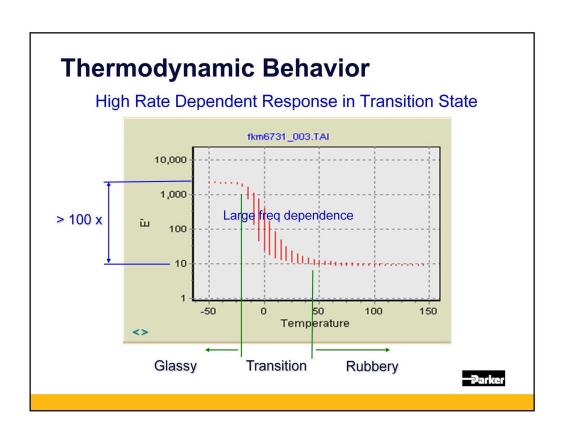
- Which Testing Modes Are Best for Hyperelastic Modeling is Debatable
- Testing at High and Low Temperature is Challenging

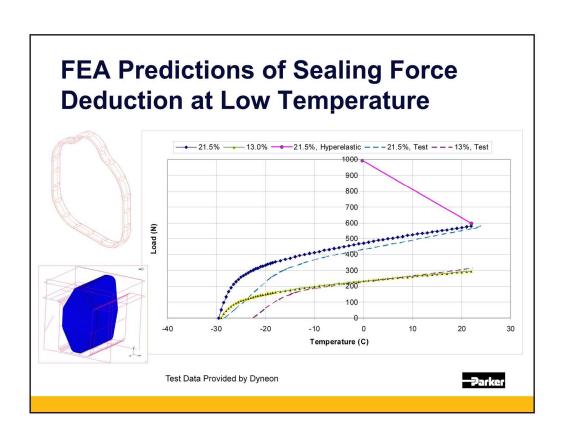


## **Hyperelastic Model**

- Capable of Capturing Nonlinear Elastic Response of Rubber Compounds in Thermodynamic Equilibrium State
- Applicable to Static and Some Dynamic (Quasi-Static) Problems at Room and High Temperature
- Can't Predict Rate or Time Dependent Responses
- Be Cautious of Using it for Low Temperature Sealing Analysis







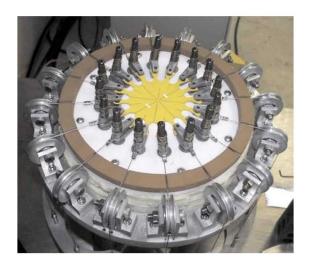
# **Testing Modes for Hyperelastic Modeling**

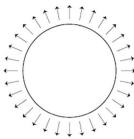
## Simple Compression or Biaxial Tension?

- Inaccuracy Due to Interfacial Friction in Simple Compression Test
- Theoretically, Equal Biaxial Tension is "Equivalent" to Simple Compression



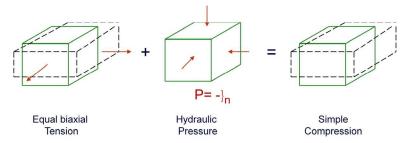
# One of Equal Biaxial Tension Devices (Developed by Axel Test Lab)







## What's the "Equivalence"?



- Derived in the Framework of Continuum Mechanics
- Assumption: Difference in Stress State Does Not Affect Mechanical Behavior of Materials

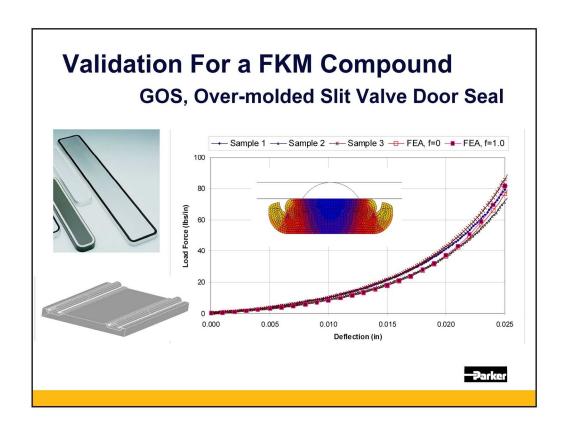
Is This Valid for Rubber Compounds with Complex Composite Structure ??



## **Practice of Parker Seal**

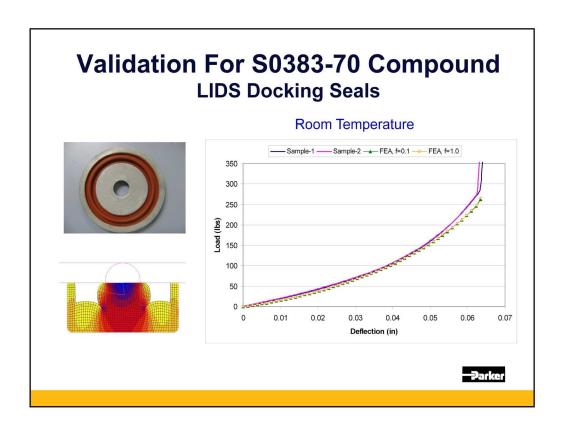
- Simple Tension and Compression Tests
- Stress vs. Strain Data of Two Tests is Combined for Curve Fitting and Generation of Hyperelastic Model Constants



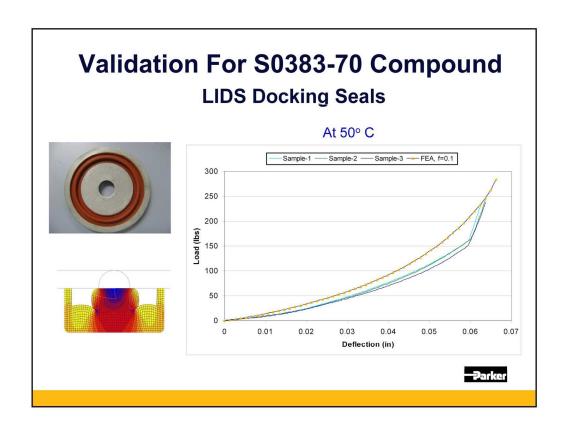


Plane strain analysis.

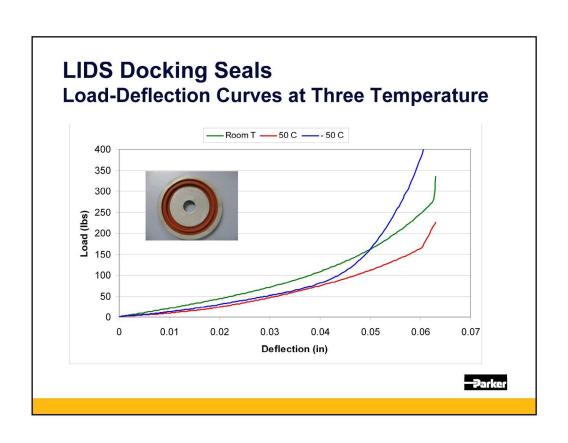
Sample are 2" long, so end effect is negligible.



Axisymmetric analysis



Axisymmetric analysis with thermal expansion. In FEA, the beat height at 50° C is about .066". However, the height of tested samples is about .060", possibly due to permanent set after previous loading.



# **FEA Simulation of Elastomers in Sealing**

### **Modeling Materials**

- Hyperelastic Model Used for Room Temperature and Higher, But Has Limitations at Predicting Response at Different Compressive Rates and at Low Temps.
- Viscoelastic Model is Rarely Used, and Needs More Research and Application.

#### **Test And Characterization of Materials**

- Better Material Characterization Using Biaxial Tension vs Simple Compression Testing Modes is Debatable.
- · Testing at High and Low Temperature is Challenging.



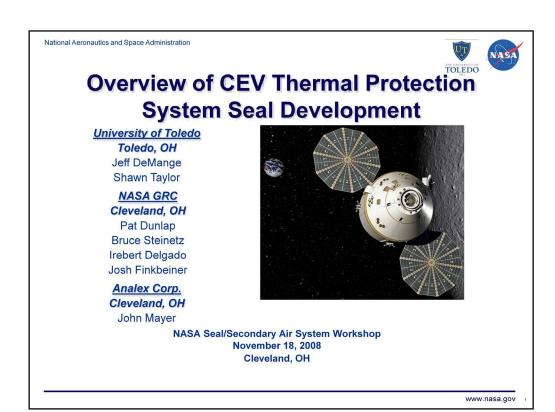


#### OVERVIEW OF CEV THERMAL PROTECTION SYSTEM SEAL DEVELOPMENT

Jeff DeMange and Shawn Taylor University of Toledo Toledo, Ohio

Patrick Dunlap, Bruce Steinetz, Irebert Delgado, and Josh Finkbeiner National Aeronautics and Space Administration Glenn Research Center Cleveland, Ohio

> John Mayer Analex Corp. Cleveland, Ohio



National Aeronautics and Space Administration

# TOLEDO



#### **Outline**

- Background
- HS-to-BS interface seal development
  - Objective and approach
  - Design
  - Testing and modeling
  - Results
- · Compression pad seal development
  - Objective and approach
  - Design
  - Testing
- Summary

www.nasa.gov

	Apollo	Orion
		200
Crew	3	3-6 LEO/ISS 4 Lunar 6 Mars
Max. Diam.	12.8 ft	16.5 ft
Height	11.4 ft	10.8 ft
Dry Weight	12,800 lbs	19,250 lbs
Volume	218 ft <sup>3</sup>	692 ft <sup>3</sup>
Seals	Silicone RTV, elastomers*	Ceramic fiber thermal barriers, elastomer seals, gaskets, foams/sponge

Apollo seals: High temp RTV (very good for sealing, good ablative properties, not much stroke), Max leakage rate ~5 lb/day, stiffer support structure → structural movements minimized

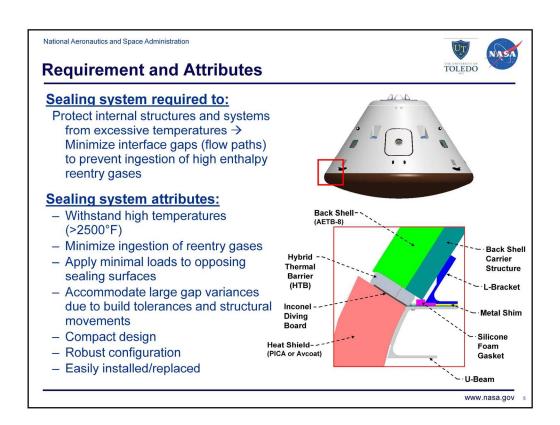
Orion seals: ~30% bigger in diameter, Because some missions may be up to 6-mo. or even longer, leakage requirements are much more stringent

National Aeronautics and Space Administration



# Heat Shield-to-Back Shell Interface Seal System

www.nasa.gov



Highlight seal design is recent

Seal is attached to Inconel diving board for easy of installation

National Aeronautics and Space Administration



### **Objective & Approach**

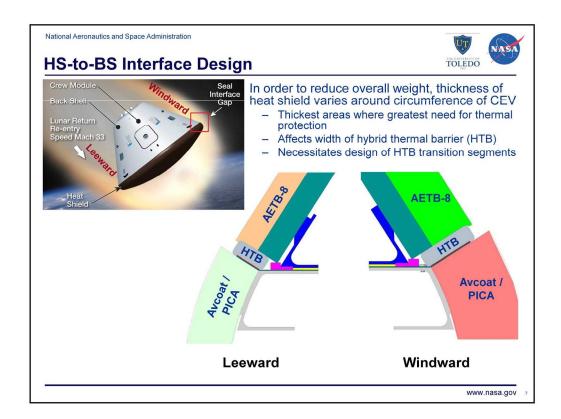
### **Objective:**

Develop required databases to support successful design and implementation of the CEV heat shield-to-back shell interface seal

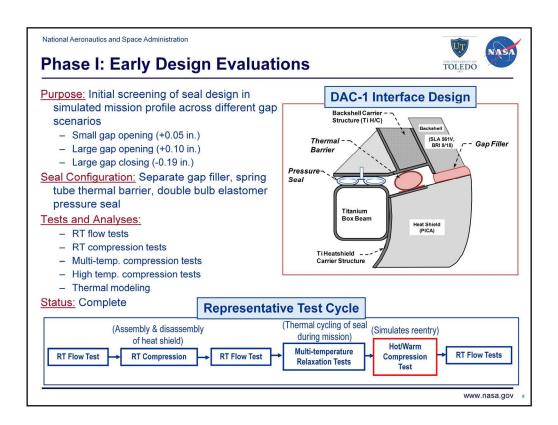
### Approach:

- Identify candidate seal designs
- Perform tests to screen and validate seal candidates
  - Coupon-level
  - Arc Jet
- Conduct thermal analyses to aid in design
- Provide recommendation to prime contractor

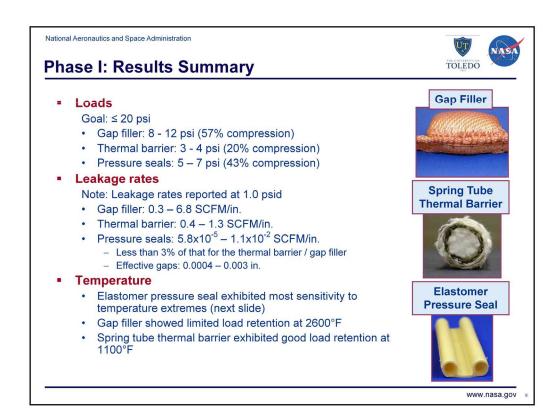
www.nasa.gov



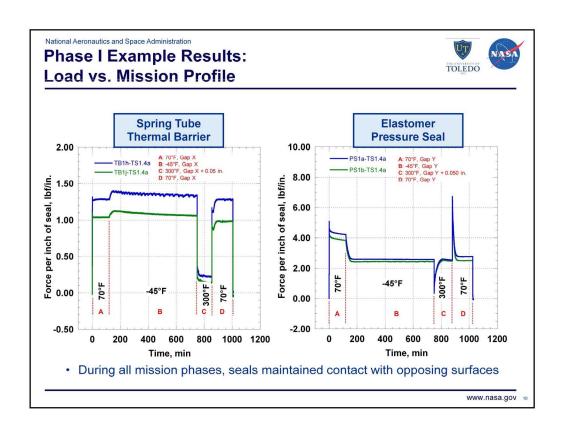
During reentry, heat distribution is non-uniform

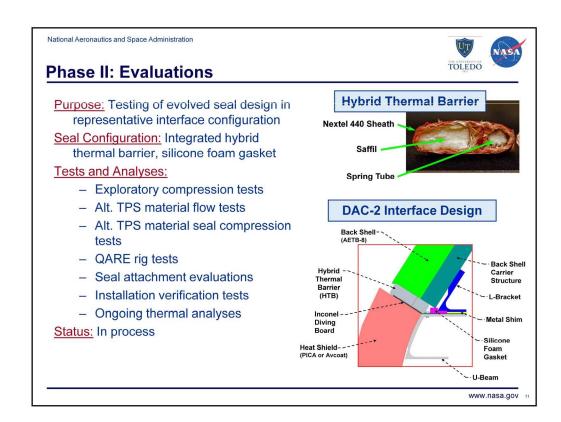


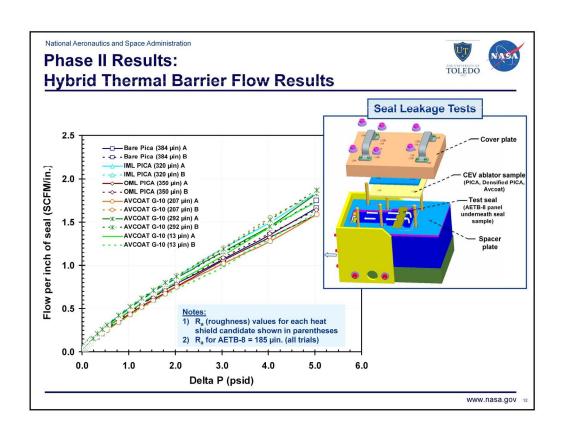
Seal design has evolved continuously since project inception

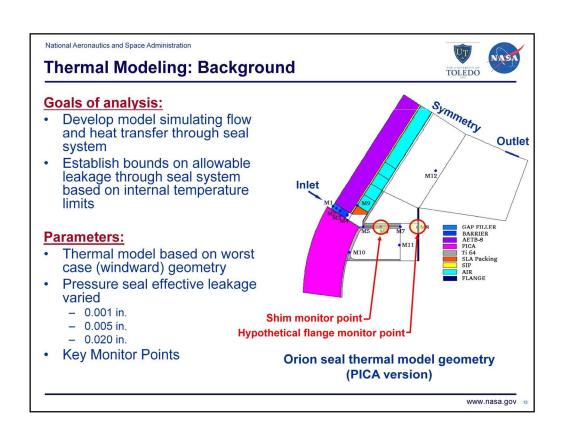


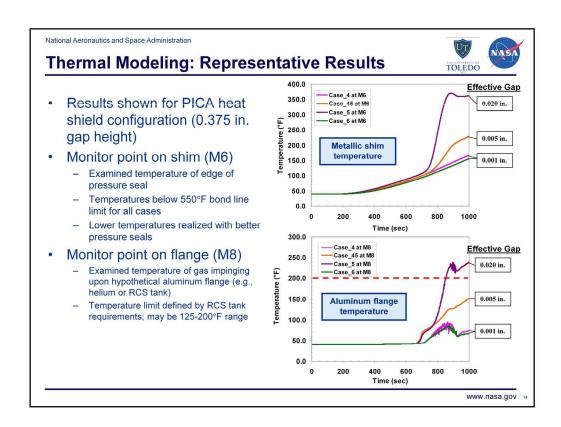
Results are applicable to next generation (HTB) seals













National Aeronautics and Space Administration





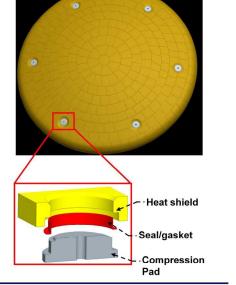
## **Compression Pad Seal Development**

#### Compression Pads (CP)

- Role: Main structural connection points between CEV and SM
- Need for seals
  - CP's are different material than heat shield
  - CP's are exposed to very high heating rates

#### **Approach & Seal Evaluations**

- Objective: Provide seal recommendation
- Seal attributes
  - Similar to HS-to-BS seal plus...
  - Ablation rate similar to HS and CP's
- Candidates: Silicone foam (or other) materials
- Preliminary testing
  - Compression test (low and high temp.)
  - Flow tests
  - System level arc jet tests



www.nasa.gov





## **Summary**

- NASA GRC supporting design, development, and implementation of numerous seal systems for the Orion CEV
  - HS-to-BS interface
  - Compression pad
- HS-to-BS Interface Seal System
  - Design has evolved as a result of changes with the CEV TPS
  - Seal system is currently under development / evaluation
    - Coupon level tests
      - Loads
      - Thermal capabilities
      - Leakage resistance
      - Bond strength tests
    - · Arc jet tests
    - · Validation test development
- Compression Pad
  - Finalizing design options
  - Evaluating material candidates

www.nasa.gov

# ULTRA-HIGH TEMPERATURE METALLIC SEAL/ENERGIZER DEVELOPMENT FOR AERO PROPULSION AND GAS TURBINE APPLICATIONS

Ken Cornett and Jesse Newman Parker Hannifin North Haven, Connecticut

Amit Datta Advanced Components & Materials Greenwich, Rhode Island



# Ultra-High Temperature Metallic Seal Program Development Team

Ken Cornett – Engineering Team Leader Advanced Products Business Unit, Parker Hannifin North Haven, CT

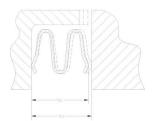
Jesse Newman – Design Engineer Advanced Products Business Unit, Parker Hannifin North Haven, CT

> Dr. Amit Datta – Consultant Advanced Components & Materials Greenwich, RI



## Program Overview

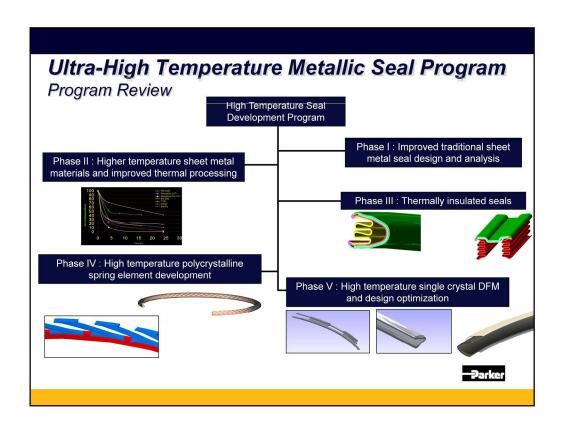
- Industry is requiring seals to operate at higher and higher temperatures.
  - Greater efficiency
  - Reduced cooling air requirements
  - Reduced emissions
- Traditional static seal designs and materials experience stress relaxation, losing their ability to maintain contact with moving flanges.
- Ultra High Temperature seal development program – Multiphase program with incremental increases in seal operating temperatures



Seal gap is created resulting from stress relaxation at elevated temperatures. The original seal height ho is reduced to he creating a gap when the flange moves away from the compressed condition.



Background of Problem



Material Comparison

### **Cast Blade Alloys Have Excellent High-Temperature Strength**

Alloy	Temperature,º F	Yield Strength,ksi	Elongation,%
Mar-M-247, Single Crystal	1600	110	8.0
CMSX-4 <sup>™</sup> , Single Crystal	1600	114	18.0
Waspaloy <sup>™</sup> , Polycrystalline	1600	60	12.0
René41 <sup>™</sup> , Polycrystalline	1600	84	11.3

<sup>•</sup> Blade alloys also have superior creep and stress rupture strength compared to cold formable superalloys. Hence, blade alloys have higher resistance to stress relaxation.

<sup>•</sup> Manufacturing Challenge - Blade alloys are only available in the cast condition (poly or single crystal)

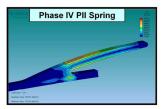


Single Crystal Spring Evolution – Phase IV

- Prototype I
  - · Solid ring machined from a polycrystalline Mar-M-247 casting
  - · Basic finger design, not optimized with FEA
  - · Opportunities for Design for Manufacturability (DFM) enhancements

#### Prototype II

- · Independent finger and support ring configuration
  - · Improved DFM and lower manufacturing cost
  - · Ability to fine tune spring load and total seal load
- FEA optimized finger configuration
- · Improved dimensional relaxation characteristics

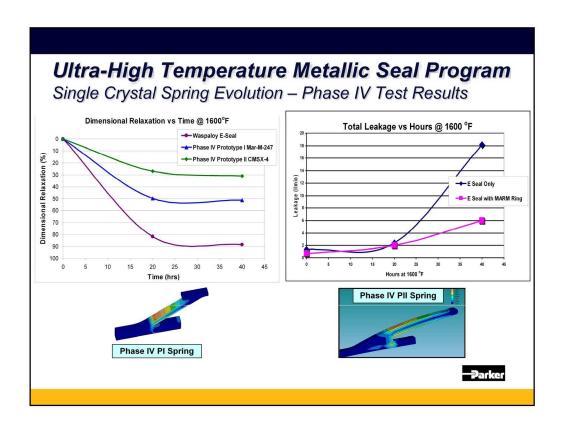




Phase IV PI Spring







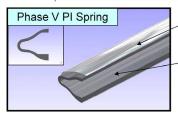
Stress relaxation testing on Phase IV prototypes showed very positive results compared to polycrystalline Waspaloy and Rene41. Follow-on leakage testing showed a strong correlation between improved stress relaxation and improved leakage results.

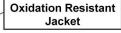
Single Crystal Spring Evolution – Phase V

- Prototype I "Wishbone"
  - Linear "V" shape machined from a single-crystal rod of CMSX-4™
  - · Secondary machining operation required to allow parts to interlock
  - · Positive stress relaxation results
  - · Opportunities for design and manufacturability enhancements
- Prototype II "Chevron"
  - Radial "V" shapes cast in both Mar-M-247 and CMSX-4<sup>™</sup> using a prototype SLA mold
  - Cast part thickness held to .020"
  - Optimized profile for reduced stress and simplified assembly (eliminated need for secondary machining operation)

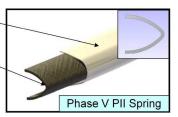






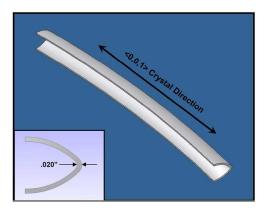


Single-Crystal Mar-M-247 or CMSX-4<sup>™</sup> Spring



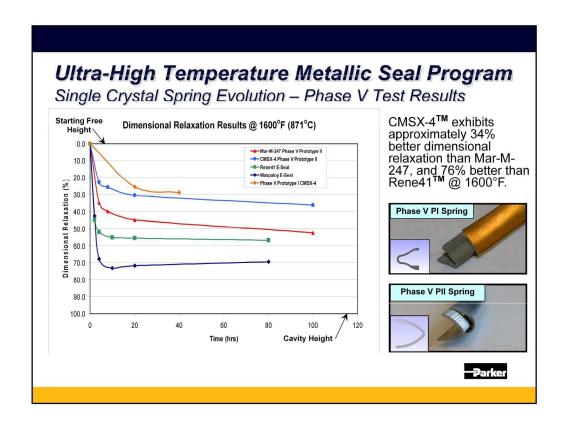


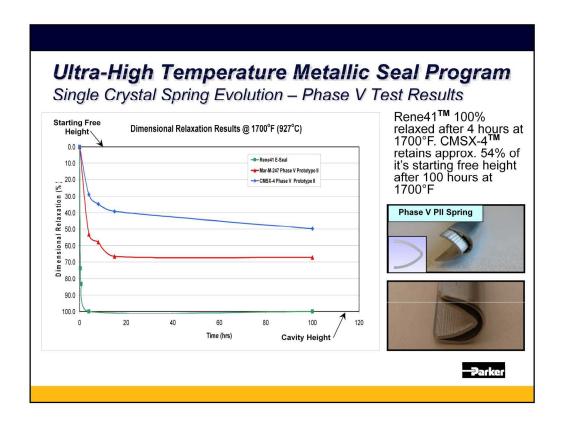
Single Crystal Spring Evolution - Phase V



- V-Spring is cast with <0,0,1> crystal orientation approximately along the circumference of the part
- This orientation improves the stress relaxation properties of the part, and maximizes the range of elastic compression







## Single Crystal Spring Evolution - Phase V Summary

- DFM has been the primary program goal since 2006
  - Convert the fundamental concept into a commercially / economically viable design while retaining stress relaxation gains
  - Through FEA analysis and DOE an improved design configuration was developed
- Modular manufacturing approach was developed
  - Standard V-Spring configuration nests within a relatively thin, oxidization resistant sheet metal jacket (Haynes® 214®, Haynes® 230®, PM2000, etc.)
  - · Jacket serves as primary pressure barrier and structural support
  - · V-Springs are brazed into position using standard techniques
- Standard V-Spring configuration allows for cost effective linear seals and hoop seals
  - · V-Springs are cast near net shape to keep manufacturing costs low
  - Cast as a single crystal material with [0,0,1] crystal orientation along the part circumference
  - By joining multiple V-Springs, any diameter seal can be cost effectively produced



### Conclusions & Future Work

- Single-crystal blade alloys can be cast in thin sections (.020") for use as high-temperature energizers for static metal seals
- Single-crystal CMSX-4<sup>™</sup> V-Springs have significantly better stress relaxation resistance than single-crystal Mar-M-247 and polycrystalline Rene41<sup>™</sup>
- The Ultra-High Temperature seal program has successfully progressed and developed a commercially viable, high temperature static seal solution.

#### Moving forward

- · Continue long-term stress relaxation testing (up to 200 hrs)
- · Perform comparative leak testing of latest prototypes
- · Perform testing at 1800°F and above

#### Future activities

- · Finalize details of manufacturing process
- Develop a product-specific, technical performance data sheet
- Identify a launch customer / application and build first production pieces for on-engine testing



# Ultra-High Temperature Metallic Seal Program Questions?

Ken Cornett – Engineering Team Leader
Advanced Products Business Unit, Parker Hannifin – North Haven, CT
<a href="mailto:kwcornett@parker.com">kwcornett@parker.com</a>
203-985-3177

Jesse Newman – Design Engineer
Advanced Products Business Unit, Parker Hannifin – North Haven, CT
<u>jesse.newman@parker.com</u> 203-985-3120

Greg More – Engineering/Sales Manager
Advanced Products Business Unit, Parker Hannifin – North Haven, CT
dgmore@parker.com 203-985-3141



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Last	First	Company	City	ST	Zip	Phone	Email
Albers	Joseph	GE Aircraft Engines	Cincinnati		45215	513.243.5772	joseph.albers@ae.ge.com
Ambarday	Veena	NASA JSC, Jacobs Technology	Houston		77058	713.248.8383	Veena.Ambardav@escg.jacobs.com
Baumeister	Joseph	NASA Glenn Research Center	Cleveland		44135-3191	216,433,2179	joseph.f.baumeister@nasa.gov
Boatright	Leslie	NASA Kennedy Space Center	Kennedy Space Center	FL	32899	321.861.3611	Leslie.J.Boatright@nasa.gov
Bond	Bruce	Jackson Bond Enterprises, LLC	Rochester		03867	603.742.2350	bruce.bond@jacksonbondllc.com
Buyukisik	Osman	GE Aviation	Cincinnati		45215	513.243.6276	osman.buyukisik@ge.com
Carr	Paige	Lockheed Martin Mission Services	Houston		77258	281.333.6049	paige.p.carr@lmco.com
Chehab	Abdullatif "Ed"	Siemens Energy Sector	Orlando	FL	32826	407.736.7215	ed.chehab@siemens.com
Chupp	Ray	GE Energy	Greenville		29615	864.254.5320	raymond.chupp@ge.com
Conrad	Mason	NASA GRC - CWRU	Cleveland		44135	727.643.4278	rayorialoriapp@golooni
Cornett	Kenneth	Parker Hannifin	North Haven	CT		203.985.3177	kwcomett@parker.com
Daniels	Chris	NASA GRC -Univ. of Akron	Cleveland		44135	216.433.6714	christopher.c.daniels@grc.nasa.gov
Datta	Amit	Advanced Components & Materials Inc.	E. Greenwich	RI	02818	401.885.5064	ADatta@worldnet.att.net
deGroh	Henry	NASA Glenn Research Center	Cleveland		44135	216.433.5025	Henry.C.Degroh@nasa.gov
Delgado	Irebert	NASA GRC - U.S. Army	Cleveland		44135	216.433.3935	irebert.r.delgado@nasa.gov
DeMange	Jeffrey J.	NASA Glenn Research Center	Cleveland		44135	216.433.3568	Jeffrey.J.Demange@nasa.gov
Drlik	Gary	NASA GRC - Analex Corp.	Cleveland		44135	216.433.6301	gary.j.drlik@nasa.gov
Dunlap	Patrick	NASA Glenn Research Center	Cleveland		44135	216,433,3017	patrick.h.dunlap@nasa.gov
Erker	Art	NASA GRC - Analex Corp.	Cleveland		44135	216.433.2911	arthur.h.erker@nasa.gov
Favenesi	Bill	Garlock Helicoflex	Columbia		29209	803.695.3527	bill.favenesi@garlock.com
Finkbeiner	Joshua	NASA Glenn Research Center	Cleveland		44135	216,433,6080	joshua.r.finkbeiner@nasa.gov
Garafolo	Nicholas	NASA GRC - U. of Akron	Cleveland		44135	216.433.6021	Nicholas.G.Garafolo@nasa.gov
Gravereaux		Jetseal, Inc.	Spokane		99202	509.467.9133	sgravereaux@jetseal.com
Grondahl	Clayton	CMG Tech, LLC	Rexford		12148	518.371.5050	cmgtech@earthlink.net
Harrison	Doug	Lockheed Martin Misson Services	Houston		77258	281.333.6170	doug.harrison@lmco.com
Hendricks	Robert C.	NASA Glenn Research Center	Cleveland		44135	216.977.7507	robert.c.hendricks@nasa.gov
Jelgerhuis	Elmer	Aero Systems Engineering	St. Paul		55107	651.220.1269	ejelgerhuis@aerosysengr.com
Johnson	Frank	Polymer Concepts Technologies, Inc	Broadview Hts		44147	440.717.0852	frankjohnson@polymerconcepts.com
Kim	Sura	CFD Research Corp.	Huntsville	AL	35805	256.726.4846	sxk@cfdrc.com
Klamar	Joseph	JGK TechnoSystems	Hudson		44236-1183	330.656.3274	igklamar@yahoo.com
Kuhn	Fred	Boeing	Fairborn		45324	937.427.1767	frederic.j.kuhn@boeing.com
Lattime	Scott	The Timken Company	Canton		44706-0930	330.471.2284	scott.lattime@timken.com
Makhobey	Mark	Car-Graph, Inc.	Tempe		85281	480.894.1356x219	mmakhobey@car-graph.com
Malhiot	Kirk	Northrup Grumman, Marine System	Sunnyvale		94088	408.735.2112	kirk.malhiot@ngc.com
Mayer	John	NASA GRC - Analex Corp.	Cleveland		44135	216,433,2734	john.j.mayer@nasa.gov
Misra	Ajay	NASA Headquarters	Washington		20024-3210	210110012701	ajay.k.misra@nasa.gov
Munson	John	Rolls Royce Corp.	Indianapolis	IN	46260	317,230,6409	John.H.Munson@Rolls-Royce.com
Newman	Jesse	Parker Hannifin Corporation	North Haven	CT	06473	203.985.3120	jesse.newman@parker.com
Pelischek	Timothy	NASA Johnson Space Center	Houston		77058	281.483.8843	timothy.e.pelischek@nasa.gov
Penney	Nicholas	NASA GRC - OAI	Cleveland	ОН		216.433.6791	nicholas.penney@nasa.gov
Pham	Hoa	Jacobs Sverdrup	Houston	TX		281.461.5298	hoa.pham@escg.jacobs.com
Proctor	Margaret	NASA Glenn Research Center	Cleveland		44135	216.977.7526	margaret.p.proctor@nasa.gov
Pugh	David	GE Aivation	Cincinnati		45215-6301	513.243.6276	david.pugh@ge.com
Rahaim	John	General Electric	Cincinnati		45215	513.243.3460	john.rahaim@ae.ge.com
Reum	Rex	Jetseal, Inc.	Spokane	WA	99202	509.467.9133	rreum@jetseal.com
Ritzert	Frank	NASA Glenn Research Center	Cleveland		44135	216,433,8199	frank.j.ritzert@nasa.gov
Ruggiero	Eric	GE Global Research Center	Niskayuna	NY		518.387.4279	ruggiero@research.ge.com
Schenk	Doug	Parker Hannifin	San Diego	CA	92154-8206	619,671,3301	dschenk@parker.com
Schweitzer	Marc	Tara Technologies, Inc.	Daytona Beach	FL	32114	408.425.8012	marc.schweitzer@taratechnologies.com
Steinetz	Bruce	NASA Glenn Research Center	Cleveland	ОН	44135	216,433,3302	bruce.m.steinetz@nasa.gov
Stevens	Mark	NASA Glenn Research Center	Cleveland		44135	216.433.2529	Mark.A.Stevens@nasa.gov
Taylor	Shawn	NASA GRC - Univ. of Toledo	Cleveland		44135	216.433.3166	shawn.c.taylor@grc.nasa.gov
Tecza	Joseph	Dresser-Rand Company	Wellsville		14895	585.596.3513	jtecza@dresser-rand.com
Valliere	Alan	Car-Graph, Inc.	Tempe		85281	480.894.1356x215	avalliere@car-graph.com
Wasowski	Janice	NASA GRC - U. of Akron	Cleveland		44135	216.433.6709	janice.l.wasowski@nasa.gov
Wong	Gordon	The Boeing Company	Huntington Beach		92647-2099	714.372.5039	gordon.f.wong@boeing.com
Yetter	Paul	Parker Hannifin	San Diego		92154-8206	619,671,3364	pyetter@parker.com
Zhang	Kai	Parker Hannifin	San Diego		92154-8206	619.671.3288	kzhang@parker.com
Zhang	Ying	Northrup Grumman, Marine System	Sunnyvale		94088	408.735.2112	ying.zhang@ngc.com
Zimmerer	Matthew	Williams International	Walled Lake	MI	48390	248.960.2742	mzimmerer@williams-int.com
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