Advanced Seal Sessions I & II

Dr. Bruce M. Steinetz, General Chair
Mr. Patrick H. Dunlap, Structural Seals Co-Chair
NASA Glenn Research Center

Dr. Neelesh Sarawate
Turbine Seals Co-Chair
GE Global Research Center

49th AIAA/ASME/SAE/ASEE
Joint Propulsion Conference, San Jose, CA
July 16, 2013
Outline

Turbine Seals
• Why work advanced seals?
  – NASA engine/propulsion technologies NASA N+3 Studies
  – Challenges
• Advanced concepts under development
  – NASA Glenn
  – GE Global Research

Spacecraft Seals
• Habitable volume seals
• Thermal Barrier seals
Turbine Seals

Aircraft Timeline

1903
1930s
1950s
2000s

DC-3
B-707
B-787
• System improvements require advances in propulsor and core technologies
• Core technologies:
  • improved internal aerodynamic
  • higher operating temperature
  • control of parasitic losses
Why Seals?

Seals provide high return on technology $ investment
• Same performance goals possible through modest investment in the technology development
  • Example: 1/5th to 1/4th cost of obtaining same performance improvements of re-designing/re-qualifying the compressor

### NASA Study Results: Expected Seal Technology Payoffs

<table>
<thead>
<tr>
<th>Seal Technology</th>
<th>Study Engine/Co.</th>
<th>System Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large diameter aspirating seals (mult. locations)</td>
<td>GE90-Transport/GE</td>
<td>−1.86% SFC −0.69% DOC + I</td>
</tr>
<tr>
<td>Interstage seals (mult. locations)</td>
<td>GE90-Transport/GE</td>
<td>−1.25% SFC −0.36% DOC + I</td>
</tr>
<tr>
<td>Film riding seals (Turbine inter-stage seals, mult. locations)</td>
<td>Regional-AE3007/Allison-RR</td>
<td>&gt; −0.9% SFC &gt; −0.89% DOC+ I</td>
</tr>
<tr>
<td>Advanced finger seals (mult. locations)</td>
<td>Regional/Honeywell</td>
<td>−1.4% SFC −0.7% DOC + I</td>
</tr>
</tbody>
</table>

### NASA Subsonic Transport System Goals
Baseline: 2005

<table>
<thead>
<tr>
<th>Target</th>
<th>Fuel Burn</th>
<th>Cruise NOx Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>N+1: 2015</td>
<td>-33%</td>
<td>-55%</td>
</tr>
<tr>
<td>N+2: 2020</td>
<td>-50%</td>
<td>-70%</td>
</tr>
<tr>
<td>N+3: 2025</td>
<td>-60%</td>
<td>-80%</td>
</tr>
</tbody>
</table>
Engine/Propulsion Technologies from NASA N+3 Studies

• High OPR, high T4 cycle
  – CMC Turbine Blades/Vanes
  – high temp disk material
  – **improved seal design**
  – intercooled compressor

• High Efficiency Small Cores
  – **mitigate efficiency decrement**
  – active clearance control
  – flow control

<table>
<thead>
<tr>
<th>Goals</th>
<th>Noise</th>
<th>Emissions (LTO)</th>
<th>Emissions (cruise)</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrics (N+3)</td>
<td>Stage 4 – 52 dB cum</td>
<td>CAEP6 – 80%</td>
<td>2005 best – 80%</td>
<td>2005 best – 60%</td>
</tr>
</tbody>
</table>
Turbine Seals: Challenges

- Minimize leakage to enable: reduced fuel consumption and emissions
- High temperatures: 1200 to 1500°F
- Minimize heat generation
- High speeds 1000 to 1500 fps
- Moderate pressure 250 psi
- Operate with little or no wear for long life >20,000 hrs
- Occupy small “footprint”
GRC Non-contacting Finger Seals

Key benefits are …

• **Avoids wearing out parts**: No contact avoids wear found in brush seals and labyrinth seals
• **Reduced flow**: <1/3 the flow of a straight tooth labyrinth seal and <1/2 the flow of a contacting brush seal
• **Comparable power loss**: Power loss is the same order of magnitude as brush and finger seals

![Labyrinth seal](image1)

![Brush seal](image2)

![Non-contacting finger seal](image3)
GE Global Research

Neelesh Sarawate
GE Global Research
GE Global Research: Advanced Sealing Synergy

GE Global Research Center
• First industrial R&D lab
• Established in 1900
• Nearly 180 research labs
• ~2,000 technologists, 2/3rd hold PhDs

Aircraft engines
• High temp & creep
• Limited space
• High speed, swirl ratio
• Seal stability

Gas turbines
• Longer life
• Field installation, assembly
• Large interference

GE Global Research
• Fundamental research
• Seal design & analysis
• Validation tests in custom rigs

Steamp turbiners
• Rotor dynamics
• Short cycles
• Low-cost
• Rub tolerant
GE Sealing & Performance Technologies

- Brush seals
- Cloth seals
- Aspirating seals
- Abradable coatings
- Non-metallic brush seals
- Retractable seals
- Compliant plate seals

ST Brush seals 1990s-2000

Cloth Seals AIAA 2001

Aspirating seals JPP 2006

Abradable coatings GT2004-53029

Shroud coated with abradable

Non-metallic brush seals AIAA-2010 GT2012-69329

Retractable seals GT2011-45756

Compliant plate seals GT2011-45756
Spacecraft Seals

Pat Dunlap
NASA Glenn Research Center
Types of Seals

• Habitable volume seals
  – Seals for hatches, windows, docking interfaces, penetrations/ feed-throughs
  – Require extremely low leak rates to ensure that astronauts have sufficient breathable air for extended missions
  – Typically made of elastomer materials

• Thermal barrier seals
  – Seals for interfaces in vehicle thermal protection systems (TPS)
  – Must withstand extreme heating during re-entry
  – Typically made of high temperature fibers, wires, or insulating materials
Potential Missions

- Asteroid retrieval mission
- Future space station (e.g., cislunar)
- Lunar/Mars outpost
Habitable Volume Seals
### Habitable Volume Seal Challenges

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low leakage</td>
<td>Near hermetic levels (~0.002 lb\textsubscript{m} air/day)</td>
</tr>
<tr>
<td>Space environments</td>
<td>Resist damaging effects of atomic oxygen, UV radiation, ionizing radiation, MMOD</td>
</tr>
<tr>
<td>Resiliency</td>
<td>Exhibit acceptable compression set vs. cycling and re-mate after long term holds</td>
</tr>
<tr>
<td>Temperature</td>
<td>Survival: -65 to +100°C (-85 to +212°F) Operational: -50 to +75°C (-58 to +167°F)</td>
</tr>
<tr>
<td>Loads</td>
<td>Low compression and adhesion loads</td>
</tr>
<tr>
<td>Androgynous docking</td>
<td>Design for seal-on-seal operation for vehicle-to-vehicle craft emergency rescue</td>
</tr>
<tr>
<td>Fault tolerance</td>
<td>Include multiple seals/bulbs for redundancy</td>
</tr>
<tr>
<td>Surface operations</td>
<td>Exhibit robust operation in presence of dust, FOD, etc.</td>
</tr>
</tbody>
</table>
NASA Docking System

- NASA implementation of the International Docking System Standard (IDSS)
- Under development as a common docking system for a variety of host vehicles
- Requires a large (~51” diameter) near hermetic seal to prevent loss of cabin air
- Operate in either of following modes:
  - Seal-on-Flange
  - Seal-on-Seal (androgynous)
Potential NDS Applications

MPCV/Orion

Space-X Dragon

Boeing CST + Bigelow BA330

Sierra-Nevada Dream Chaser
Advanced Habitat + Rover Seals

- Rover Docking Interface/Seal
- Hatch/Seal
- Suit Port Seal
Advanced Habitable Volume Seals for Space Environments

- Seals with UV-resistant coatings
- Seals with additives for UV resistance
- Seals with retractable “shrouds”
Thermal Barrier Seals
## Thermal Barrier Seal Challenges

| Temperature       | Near term missions: 2600°F with short (<1 min.) exposures to 3200°F for single heating pulse  
|                  | Far term missions: 2600°F with longer (2-3 min.) exposures to 3200°F for multiple heating pulses (e.g., Mars re-entry/return) |
| Leakagge         | Prevent excessive heat flow to underlying structures |
| Space environments | Resist damaging effects of atomic oxygen, UV radiation, ionizing radiation, MMOD |
| Resiliency       | Maintain contact with adjacent sealing surfaces; exhibit acceptable compression set vs. cycling |
| Loads            | Exhibit light loads to prevent damage to TPS tile surfaces |
| Durability       | For dynamic interfaces, tolerate scrubbing with minimal damage or loss of performance |
Advanced Thermal Barrier Seals

Use of advanced high temperature fibers

Advanced seal preloaders for improved resiliency at high temperatures
Agenda Information
10:00 am Oral Presentation: Overview of Advanced Seals Challenges and Opportunities
Bruce M. Steinetz and Patrick H. Dunlap, NASA Glenn Research Center; Neelesh Sarawate, GE Global Research Center

10:30 am Oral Presentation: Turbomachinery Sealing Technology- Survey of Past Success and Strategy for Future Development
Joel Kirk, GE Aviation

11:00 am: Design, Manufacture and Testing of Variable Bristle Diameter Brush Seals (AIAA-2013-3859)

11:30 am: A Novel Air/Oil Separator and Its Integration to a Prototype Miniature Jet Engine (AIAA-2013-3860)
Emre Tan Topal, TUSAS Engine Industries Inc; Sercan Acarer, TEI TUSAS Engine Industries Inc. /Izmir Institute of Technology; Tuna Kirgiz, TEI TUSAS Engine Industries Inc.
1:00 pm Oral Presentation: Characterizing Multi-Scale Viscoelasticity of Polymers: A Transient Sealing Perspective
   Azam Thatte, GE Global Research

1:30 pm: Transient Simulations of Rotordynamic Problems with Whirling Motion (AIAA- 2013-3914)
   Chandrasekhar Kannepalli, Vineet Ahuja, and Ashvin Hosangadi, Combustion Research and Flow Technology, Inc. (CRAFT Tech)

2:00 pm: Use of VUV Radiation to Control Elastomer Seal Adhesion (AIAA- 2013-3915)
   Henry C. de Groh III, Bernadette J. (“Sue”) Puleo, and Deborah L. Waters, NASA Glenn Research; Presented by Sue Puleo