ELASTOMERIC SEAL DEVELOPMENT FOR ADVANCED DOCKING/BERTHING SYSTEM

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Elastomeric Seal Development for  
Advanced Docking / Berthing System

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Presentation Overview

• ADBS Overview
  → Seal evaluation criteria
  → Candidate seals
  → Environments
  → Historical data
  → Elastomers

• Test Fixtures and Results
  → Compression set
  → Adhesion testing
  → Small-scale flow test
  → Full-scale flow test

• Numerical Simulation

• Summary

• Future Work
What is the ADBS?
System under development by Johnson Space Center (JSC) to:

- Provide androgynous pressurized interface permitting autonomous docking/berthing between space vehicles and structures.
- Reduce impact loads between two mating space craft.
- Become new Agency standard for docking/berthing systems.

What are the Sealing Challenges?
- Androgynous configuration requires seal-on-seal mating at the interface between systems.
- Seals must survive exposure to space environment.
Criteria for evaluating candidate seals

- Environmental and operating temperature compatibility
  - Environment: -100 to 100°C
  - Operation: -50 to 50°C

- Compatibility to vacuum environment (low outgassing)
  - Total mass loss (TML): <1%
  - Collected volatile condensable materials (CVCM): <0.1%

- Material stability when exposed to Atomic Oxygen (AO) and Ultraviolet radiation (UV)

- Compression force required to produce adequate seal
  - Less than 100 lbf / linear inch

- Leak rate
  - Less than 0.044 lbm / day

- Resistance to mechanical damage / ability to seal after damage
  - Debris
  - Micrometeoroids
### Types of Candidate Seals

Two types of seals are being considered:

<table>
<thead>
<tr>
<th></th>
<th>Elastomeric Seals</th>
<th>Metallic Seals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to form adequate seal</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Long term resistivity to space environments</td>
<td>TBD</td>
<td>Excellent</td>
</tr>
<tr>
<td>AO / UV Micrometeoroids</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Compression load required</td>
<td>TBD: initially low / expected to rise</td>
<td>TBD</td>
</tr>
<tr>
<td>Ability to perform under gapping / misalignment</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Space application experience</td>
<td>&lt;30 days on Shuttle / ISS</td>
<td>None known</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Slight expected</td>
<td>None expected</td>
</tr>
</tbody>
</table>

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### Environmental Exposures

- As the Agency standard for docking systems, the ADBS is expected to operate:
  - In low Earth orbit (LEO)
  - On Moon
  - On Mars

<table>
<thead>
<tr>
<th>Low Earth Orbit</th>
<th>Moon</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Atomic Oxygen</em></td>
<td><em>Ultraviolet radiation</em></td>
<td><em>Ultraviolet radiation</em></td>
</tr>
<tr>
<td><em>Ultraviolet radiation</em></td>
<td><em>Vacuum</em></td>
<td><em>Vacuum</em></td>
</tr>
<tr>
<td><em>Vacuum</em></td>
<td><em>Micrometeoroids</em></td>
<td><em>Micrometeoroids</em></td>
</tr>
<tr>
<td><em>Micrometeoroids</em></td>
<td><em>Dust</em></td>
<td><em>Dust</em></td>
</tr>
<tr>
<td></td>
<td><em>Temperature (-253 to 123°C)</em></td>
<td><em>Temperature (27 to -128°C)</em></td>
</tr>
</tbody>
</table>

- To determine the effects of AO and UV, elastomer samples will be tested:
  - As-received
  - After AO exposure
  - After AO + UV exposure
**Historical Data**

- Material evaluation completed for the Common Berthing Mechanism (CBM) / International Space Station (ISS)

- Fluorocarbon elastomers are unacceptable for use in environments where Atomic Oxygen (AO) and Ultraviolet radiation (UV) are present.

- Leakage from silicone elastomer seals increased linearly when exposed for up to 181 hours of AO and UV.

- Leakage increased up to 3200% for Silicone seals exposed to 181 equivalent hours.


*Note: The chart shows the leak rate (atm cc / sec He) as a function of Equivalent hours for different materials and compression levels.*
Three candidate elastomers are under consideration:
• Parker Hannifin S383-70
• Parker Hannifin S899-50
• Esterline Kirkhill TA XELA-SA-401

All three are silicone rubber. The PH S383-70 has a durometer of 70; the PH S899-50 has a durometer of 50; the EK is the softest material having a durometer of 38.
Compression Set Testing

- Determines the ability of elastomeric compounds to retain elastic properties after prolonged compression.

- Testing per ASTM Standards D395 (Test Method B) and D1414.

- Tests to be completed
  - As-received ✔
  - After exposure to AO
  - After exposure to AO + UV

Photo of the Compression Set Fixture
Compression Set Results

- O-ring specimens have been tested per ASTM Standards D395 (Test Method B) and D1414:
  - Parker-Hannifin silicone S0383-70
  - Parker-Hannifin silicone S0899-50
  - Esterline Kirkhill silicone XELA-SA-401

- The specimen were tested in the as-received condition and have not been exposed to atomic oxygen nor ultra-violet radiation.

- Test conditions:
  - 25% Compression
  - 70 hours at room temperature
  - Surfaces were unlubricated

- Compression set results (median):
  - S0383-70: $C_B = 9.7\%$
  - S0899-50: $C_B = 7.8\%$
  - XELA-SA-401: $C_B = 13.9\%$

Compression set test results of o-ring specimen (AS 568A size 309) manufactured from Parker-Hannifin S0383-70, Parker-Hannifin S0899-50, and Esterline Kirkhill XELA-SA-401 compounds.
**Adhesion Testing**

- Quantify adhesion between two elastomeric samples before and after exposure to Atomic Oxygen and Ultraviolet radiation.

- Measures compression and adhesion forces as a function of displacement at a given compression / decompression rate.
Sample Adhesion Test Results

Adhesion test results showing effects of compression / decompression rate on adhesion for XELA-SA-401.

• Adhesion increases with increased compression / decompression rate.

Adhesion test results showing effects of contact period on adhesion for XELA-SA-401.

• Adhesion increases with increased contact duration, but levels off.
Small Scale Flow Testing

- **Quantify seal performance**
  - Of 2-309 size o-rings
  - Leakage
  - Before and after exposure to AO and UV

- **Configuration**
  - Seal against flat metal plate

- **Pressure boundary conditions**
  - Internal pressure
  - External vacuum

- **Temperature conditions**
  - Room temperature

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Photo of the Small-scale Flow Fixture with sample o-ring installed.
Full Scale Flow Testing

- Quantify seal performance
  - Leakage
  - Compressive load required
  - Separation force required
- Under representative conditions
  - Full-scale (φ54") seal-on-seal configuration
  - Pressure boundary conditions
    - Internal pressure
    - External vacuum
  - Temperature conditions
    - Minimum temperature: -50C
    - Maximum temperature: 50C
    - Temperature gradients
  - Seal-to-seal alignment
    - Up to 0.050 inch axial misalignment
    - Angular misalignment (gapping)

Full-scale Flow Fixture.
Numerical Modeling

- Preliminary model of contact pressure generated as the seal interacts with its replicate
  - Model includes
    - Properties obtained using adhesion test fixture
    - Friction
    - Misalignment of seals

- Many alternate configurations can be modeled as processing is fast (<60s) for 2-D cases
  - Seal geometry
  - Axial misalignments

- Model is linear elastic, not hyperelastic
  - Does not support true incompressibility
  - Difficult to converge
  - Hyperelasticity most closely models rubber material
    - Close to ideally elastic
    - Strongly resists volume changes
    - Very compliant in shear
    - Shear response is strongly temperature dependent

- Planning to switch to hyperelastic model after obtaining needed material properties
Common Berthing Mechanism: Numerical Simulation

- **Configuration:**
  - Parker-Hannifin
  - Gask-O-Seal

- **Aligned**

- **Linear elastic model**
  - $E = 230$ psi
  - $\nu = 0.4999$
  - $\mu_s = 0.8$

\[\text{Aligned Force-Potential View}^{\text{fig:aligned}}\]
Common Berthing Mechanism: Numerical Simulation

- Configuration: Parker-Hannifin Gask-O-Seal
- Misaligned 0.025 inch
- Linear elastic model
  - $E = 230$ psi
  - $v = 0.4999$
  - $\mu_s = 0.8$
Common Berthing Mechanism: Numerical Simulation

- Configuration: Parker-Hannifin Gask-O-Seal
- Misaligned 0.050 inch
- Linear elastic model
  - $E = 230$ psi
  - $\nu = 0.4999$
  - $\mu_s = 0.8$
Summary

- Elastomeric seals are being considered for application to the Advanced Docking / Berthing System.

- Currently, three candidate elastomers are being evaluated.

- To meet the unique requirements of the ADBS, several test fixtures have been built to determine each elastomer’s:
  - Environmental and operating temperature compatibility
  - Material stability when exposed to Atomic Oxygen and Ultraviolet radiation
  - Adhesion force required to separate
  - Compression set
  - Leak rate

- These results will be compared with those from the metallic seal development to determine the final seal design.
Future Work

• Complete compression set, adhesion, and small-scale flow tests
  → Baseline
  → After Atomic Oxygen (AO) exposure
  → After AO + Ultraviolet radiation (UV) exposure

• Down-select between competing concepts and materials based on requirements.

• Perform full-scale flow tests to assess:
  → Full scale seal-on-seal leakage
  → Temperature effects
  → Effects of axial offset
  → Effects of seal-to-seal gapping (angular misalignment)

• Perform numerical simulations to predict seal leakage
  → Seal geometries
  → Misalignments