Assessing MMOD Impacts on Seal Performance
by
Henry C. de Groh III, C. Daniels*, P. Dunlap, B. Steinetz

Abstract

The elastomer seal needed to seal in cabin air when NASA’s Crew Exploration Vehicle is docked is exposed to space prior to docking. While open to space, the seal might be hit by orbital debris or meteoroids. The likelihood of damage of this type depends on the size of the particle. Our campaign is designed to find the smallest particle that will cause seal failure resulting in loss of mission. We will then be able to estimate environmental risks to the seal. Preliminary tests indicate seals can withstand a surprising amount of damage and still function. Collaborations with internal and external partners are in place and include seal leak testing, modeling of the space environment using a computer code known as BUMPER, and hypervelocity impact (HVI) studies at Caltech. Preliminary work at White Sands Test Facility showed a 0.5 mm diameter HVI damaged areas about 7 times that diameter, boring deep (5 mm) into elastomer specimens. BUMPER simulations indicate there is a 1 in 1440 chance of getting hit by a particle of diameter 0.08 cm for current Lunar missions; and 0.27 cm for a 10 year ISS LIDS seal area exposure.
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Outline

- **Introduction**
  - Low Impact Docking System (LIDS) and candidate elastomers;
  - The expected space environment and mission;
  - Key questions to answer.

- **Campaign Flow Chart, Phase I and Phase II**
  
- **Phase I**
  - Hypervelocity Impact testing;
  - Feasibility Testing of seal specimens and simulated damage;
  - BUMPER MMOD environment analysis.

- **Phase II**
  - Specimen manufacture, and leak testing;
  - Hypervelocity Impacts at Caltech.

- **Conclusions**
Introduction

CEV w/ elastomer Low Impact Docking System (LIDS) seal docking to ISS w/ metal flange.

Very low leakage requirements:
- CEV < 0.02 lb_m/day
- Apollo ~ 4.5 lb_m/day

LIDS primary seal
Seal Leakage to be < 2.5 x 10^{-3} lb_m/day (~0.001 kg/day)

Metal flange
LIDS Primary Seal: Expected space environment and mission

- **Mission Duration (and Temperature)**
  - LIDS elastomers on CEV, 3 to 5 days and Lunar missions (~230 day max);
  - LIDS metal flange on ISS, 10 years.

- **Vacuum:**
  - Total mass loss (TML) < 1 %
  - Collected volatile condensable materials (CVCM) < 0.1 %

- **Atomic Oxygen**
  - 1 year exposure = $5 \times 10^{21}$ atoms/cm$^2$ fluence, exposures planned up to $6 \times 10^{22}$ atoms/cm$^2$ = 12 years exposure

- **Ultraviolet Radiation**
  - Simultaneous Near Ultraviolet (NUV, 220-400 nm) and Vacuum Ultraviolet (VUV 115-200 nm) exposures to ~1500 ESH completed.

- **Ionizing Radiation**
  - Maximum mission dose ~ 0.6 Mrad (Si), electron particle radiation used (3 Mrad completed).

- **Micro Meteoroid and Orbital Debris (MMOD)**
  - Particle size depends on mission and risk allocation; mass on particle density.
Key Questions to Answer

1. What size MMOD particle are we likely to encounter, and
2. Will it cause a seal/mission failure?
   • “Likely” relates to risk, the line between acceptable and unacceptable being set at 1 in 1400 for CEV as a whole. For our seal, expressed as a Probability of No Impact (PNI): 0.9993 + SRA (seal risk allocation).
   • Seal failure defined as damage that leads to mission failure.

3. What size particle will cause seal/mission failure, and
4. What is the likelihood of encountering that particle?
Campaign Flow Chart

Preliminary White Sands Impacts

Testing and Specimen Feasibility Tests

Preliminary BUMPER Analysis

Leak Tests and Damage Simulation

Impacts at Caltech

Measure Leakage and Characterize Damage

Particle Causes Unacceptable Leak?

Mass_{critical}

Is PNI > 0.9993 + SRA?

BUMPER of Critical Particle

Redesign Seal

Celebrate!

Phase I

Smaller

Bigger

Phase II

Yes

No

Yes

No
Simulating the space environment’s MMOD

- Phase I: White Sands & NASA Johnson, Karen Rodriguez POC
- Phase II: California Institute of Technology & JPL
  - Marc Adams at Caltech
  - Virendra Sarohia JPL-Caltech liaison.

<table>
<thead>
<tr>
<th></th>
<th>Caltech</th>
<th>White Sands</th>
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<tbody>
<tr>
<td>Max Velocity</td>
<td>10.5 km/s ?</td>
<td>7.5 km/s</td>
</tr>
<tr>
<td>Particle Size</td>
<td>~0.1 to 2.0 mm</td>
<td>~0.05 to 3.6 mm</td>
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<tr>
<td>Success Rate</td>
<td>~99%</td>
<td>80 to 65 %</td>
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<tr>
<td>Number of Particles per shot</td>
<td>1 to 6</td>
<td>1</td>
</tr>
<tr>
<td>Analysis Support</td>
<td>Extensive</td>
<td>Good</td>
</tr>
</tbody>
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Phase I Hypervelocity Testing at White Sands

Simulating the space environment’s MMOD

Six test specimens:

- Parker S0383-70
- Kirkhill ELA-SA-401
- S0383-70 covered with 0.003 inch thick SS shim (proprietary)
- S0383-70 with 0.080 inch thick S0383-70 shroud, 0.09” stand-off (proprietary)
- Ceramic SiC 0.125 inch thick
- SS plate (0.125 inch thick)

Impacted with 0.5 mm stainless steel particle at 7.5 km/sec

Elastomer samples were glued onto 3"x3"x1/8" thick Al 7075 plates.
Results, Phase I

Hypervelocity Impacts in Sheet (White Sands)

Parker S0383-70

Kirkhill ELA-SA-401

Projectile: SS, 0.5 mm, 7.5 km/s
Results, Phase I

Hypervelocity Impact on Stainless Steel (White Sands)

Stainless Steel Target

Particle Size

Projectile: SS, 0.5 mm, 7.5 km/s
Phase I Feasibility Testing

Leak Testing & Specimen Feasibility

Practice cut seals

Hand damaged seal

Feasibility specimen in Retro-fitted SSFF
Small Scale Flow Fixture (SSFF), Phase I leak testing

SSFF was retro-fitted to test feasibility of impact specimens and test procedures

- Normally used to quantify leakage past 2-309 size o-rings.
- Test conditions
  - 25% O-ring compression
  - Seal against flat plate
  - $P_{\text{HIGH}} = 14.7 \text{ psia}$
  - $P_{\text{LOW}} = 0.0 \text{ psia}$
- Specimen are connected to a leak decay system to accurately quantify leakage rate.
Phase I Seal leakage and damage assessment

Sculpted damage in Esterline washer style o-ring

Increasing Damage
Phase I Leakage Results

Leakage of as received and damaged washer style seals.

Leakage, kg air/day

0.0E+00
1.0E-03
2.0E-04
3.0E-04
4.0E-04
5.0E-04
6.0E-04
7.0E-04
8.0E-04
9.0E-04
1.0E-03
1.1E-03
1.2E-03
1.3E-03
1.4E-03

Esterline No damage
Damage width ~ 2mm
Damage width ~ 3mm
Damage width ~ 4mm
Damage width ~ 6mm
Parker-50 Over Exposed

Damage width ~ 2mm
Damage width ~ 3mm
Damage width ~ 4mm
Damage width ~ 6mm
Phase I, BUMPER analysis

What is BUMPER?

Mission profile

Meteoroid Eng. Model (MEM)

Orbital Debris Eng. Model (ORDEM 2000)

Material Properties

BUMPER Code

Risk analysis which includes Probability of No Penetration, PNP
Phase I BUMPER modeling inputs

- Area calculations, inner seal, outer seal, metal ring, whole area.
- CEV nose, inner seal, outer seal, and metal ring areas;
- Altitude – 400 km for LEO, 192,200 km for Lunar;
- Orbit inclination – 51.65°;
- Year exposure starts – 2014;
- Time in space
  - CEV approach to ISS, 3 days;
  - Lunar mission, 228 days;
  - ISS node 2 ram for 10 years.
- Impact angle cut off – 89°;
- Density – 1.15 g/cc +/- 0.05 g/cc (0.0415 lb/in³)
- Yield Strength – Tensile Strength = UTS = 1050 psi
- Speed of sound in silicone rubber = 3280 ft/s
- Brinnell Hardness (BH)
  - Parker 70 durometer Shore A ~ 15 BH;
  - Esterline 38 durometer Shore A ~ 9 BH.
Phase I Results, BUMPER analysis for a Lunar mission

Probability of an impact near the LIDS seals during a lunar mission

3 days LEO + 228 days Lunar

![Graph showing probability of no impact vs. projectile diameter.](image)
BUMPER analysis of LIDS seal for a lunar mission

BUMPER analysis showing the current 0.9993 risk specification.

3 Days LEO + 228 Days Lunar

- The graph shows the probability of no impact against projectile diameter in cm for a combined 3 days in LEO and 228 days on the lunar mission.
- The risk specification is marked with a dashed line at 0.9993.
Impact Particle Density Selection

BUMPER size → Density → Particle mass

0.08 cm → Al, 2.7 g/cm³ → 0.72 mg

Nylon 66 = 1.14
Basalt ~ 2.5
Pyroxene, augite ~ 3.4
Borosilicate glass ~ 2.4
Quartz = 2.6
Paint ~ 1.3
BUMPERS analysis for ISS’s node 2, ram flight mode

Phase I results for the LIDS flange on ISS

10 years in LEO

Prob. of No Impact

Projectile size, cm

0.9970
0.9975
0.9980
0.9985
0.9990
0.9995
1.0000

0.15 0.20 0.25 0.30
Phase II, Impact Specimen Flow Fixture and Seal Specimens

ISFF Plates

Shims for 25% compression

6” Al Plate

Nested washer style o-rings
Phase II Hypervelocity Impacts

Small Particle Hypervelocity Impact Range at Caltech
Conclusions/Summary

- Our campaign is designed to find the smallest particle that will cause seal failure resulting in loss of mission. We will then be able to estimate environmental MMOD risk.

- Preliminary tests indicate seals can withstand a surprising amount of damage and still function.

- Collaborations with internal and external partners are in place and proceeding (Seal testing, BUMPER, and HVI at Caltech).

- White Sands work showed a 0.5 mm diameter HVI damaged areas about 7 times that diameter, boring deep (5 mm) into elastomer specimens.

- BUMPER simulations indicate PNI = 0.9993 for $d_L = 0.08$ cm for current Lunar missions; and PNI = 0.9993 for $d_{ISS} = 0.27$ cm for a 10 year ISS LIDS seal area exposure.