Durability Testing of Docking System Seals for Space Applications

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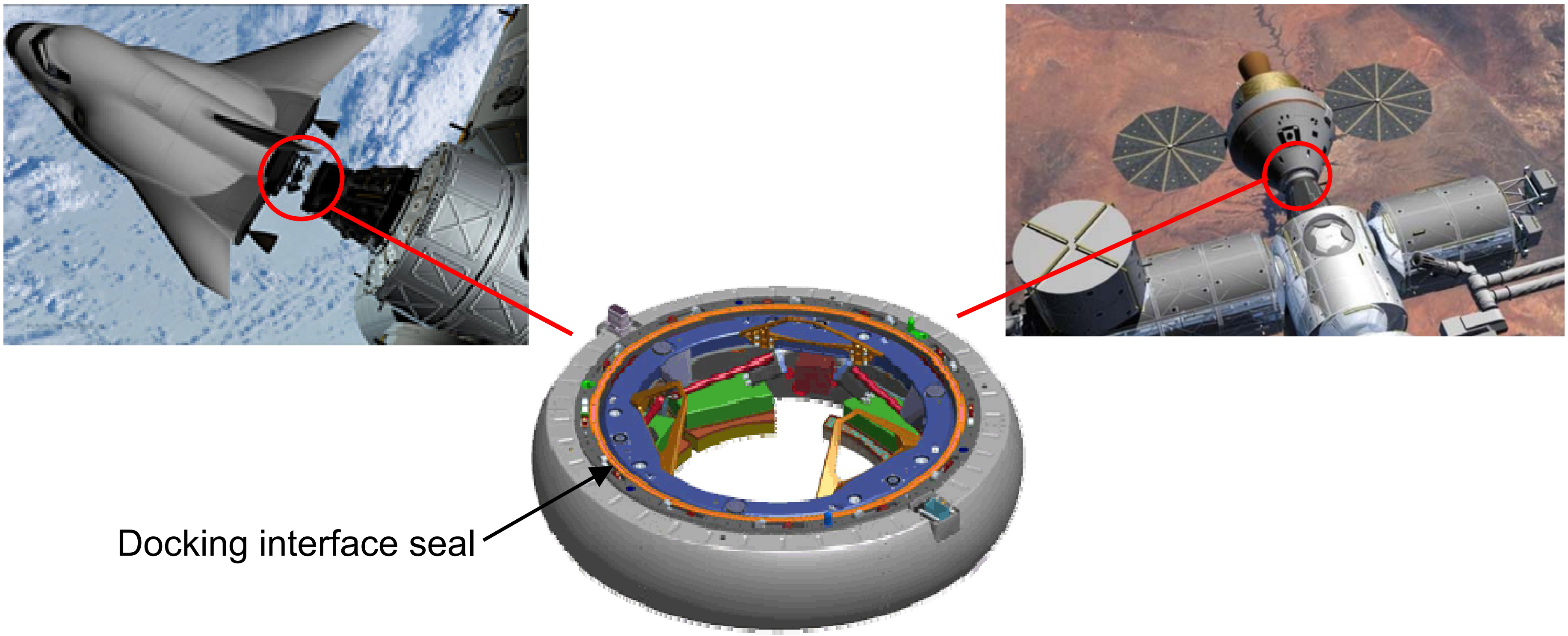
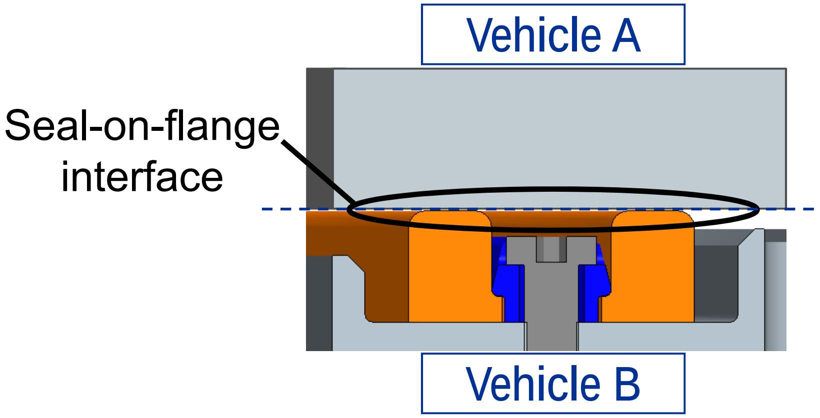
Introduction

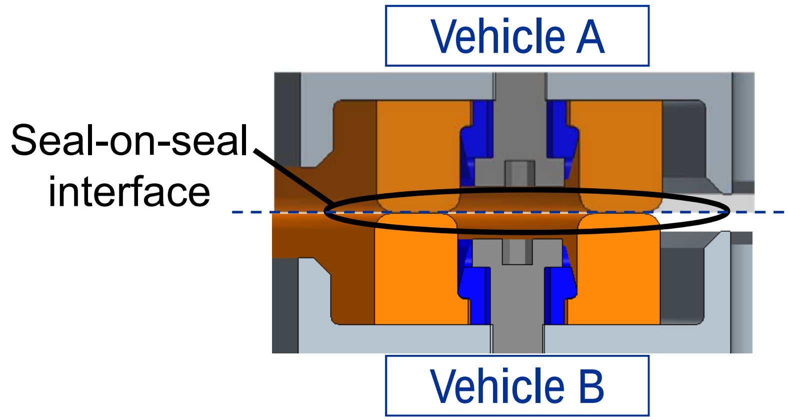


- NASA is developing advanced space-rated vacuum seals for future space exploration missions to International Space Station and beyond
- Used to seal interfaces between docked or mated vehicles and structures

Key Seal Requirements

- Large seals: Up to 50 in. (127 cm) in diameter
- Seal-on-flange or seal-on-seal mating
- Extremely low leak rates to ensure that astronauts have sufficient breathable air for extended missions
- Compression and adhesion loads must stay below prescribed thresholds
  - High adhesion loads could restrict undocking and/or damage seals

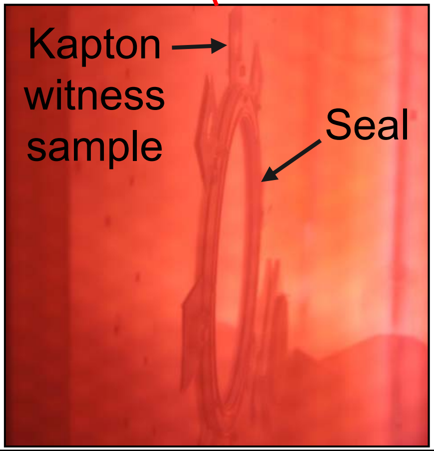




Adhesion Mitigation

- Adhesion loads for untreated silicone seals exceed capabilities of docking system separation mechanisms
- Pre-treatment of seals with low doses of atomic oxygen (AO) drastically reduces seal adhesion loads
  - Oxidizes silicone and passivates seal surfaces
  - Little effect on seal compression loads or leak rates
- Previous studies demonstrated low adhesion loads after multiple compression cycles (simulated docking and undocking)
- However, seals can also be subjected to lateral, scrubbing movements due to:
  - Mechanical alignment of docking systems after initial engagement
  - Thermal equilibration after mating has completed

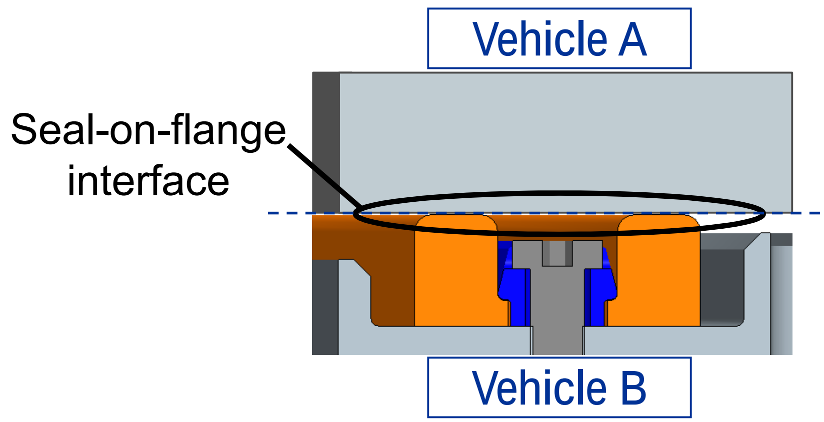
NASA GRC Tank 9 vacuum chamber facility

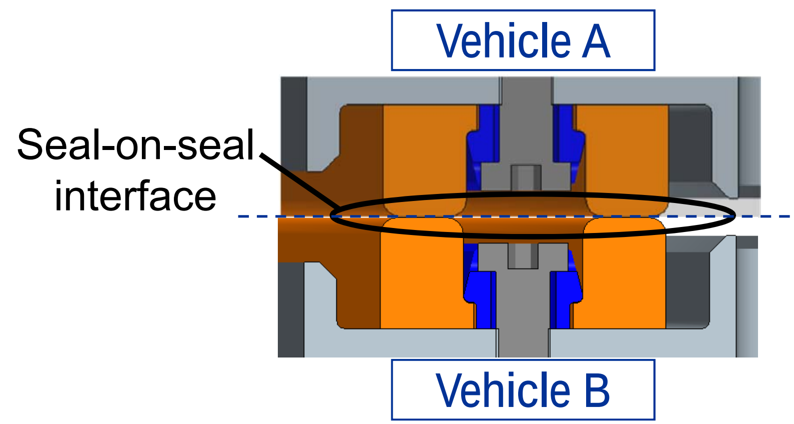


Seals being exposed to AO plasma

Goal & Approach for Study

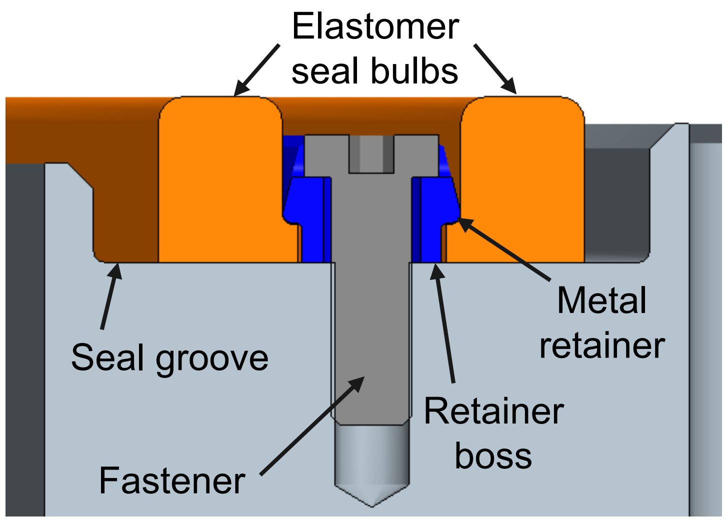
- Goal:
  - Evaluate effects of lateral scrubbing on seal performance by comparing leak rates and adhesion loads of AO pre-treated seals before and after scrubbing
- Approach:
  - Due to limited number of test specimens, performed durability (scrub) tests on seals made of two materials under anticipated worst-case conditions:
    - Seal-on-flange configuration
    - Warm operating temp. of 142°F (61°C)
    - High compression level (near full compression)
  - Performed room temperature leak tests and adhesion tests before and after durability tests to evaluate effects of scrubbing

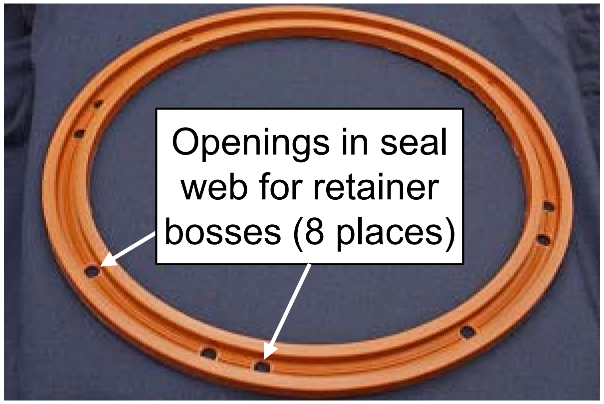




Test Specimens

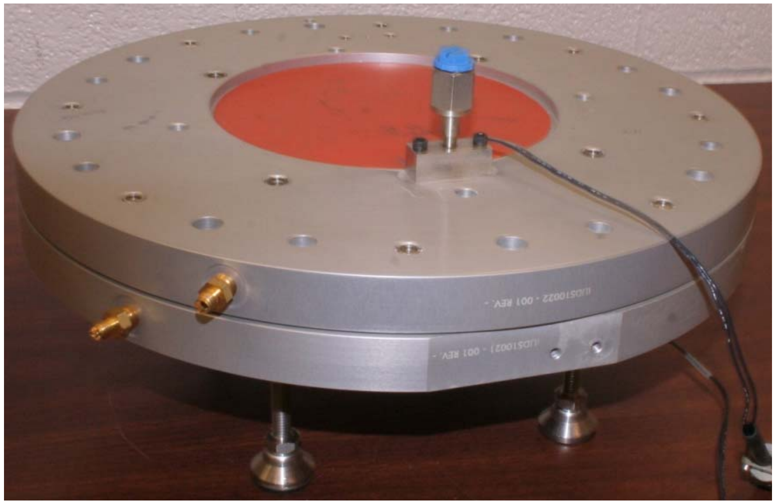
- Test specimens were subscale versions (~12 in. dia.) of candidate full-scale seal design
  - Elastomer seals made from two different silicone compounds:
    - 40 durometer material (XS3088-02)
    - 70 durometer material (S0383-70)
  - Retainers fabricated out of 6061-T651 aluminum
  - Eight #8-32 fasteners made of A286
- Test specimens were pre-treated to AO fluence level of approximately 1×10^{20} atoms/cm^2 prior to testing





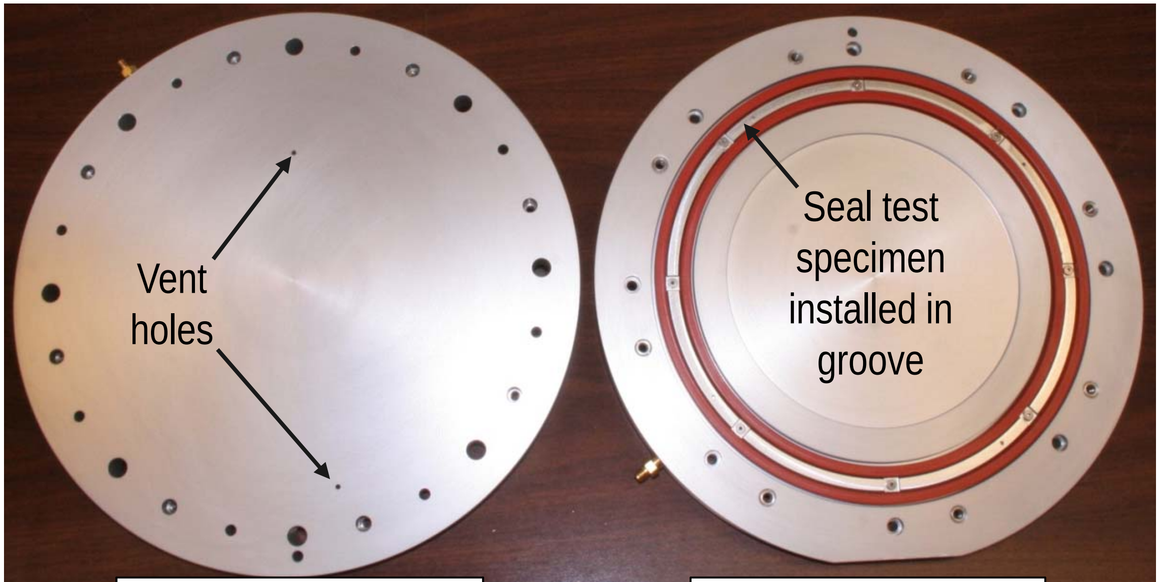
Test Sequence

- Each test specimen was subjected to same test sequence:
    1. Room temperature adhesion test
    2. Room temperature leak test
    3. Durability test at anticipated warm operating temperature of 142°F (61°C)
    4. Room temperature leak test
    5. Room temperature adhesion test
- Seal test specimen remained installed in same test fixture as it was moved from test to test to minimize handling and disturbances of seal



Seal test fixture

Test Fixture Details



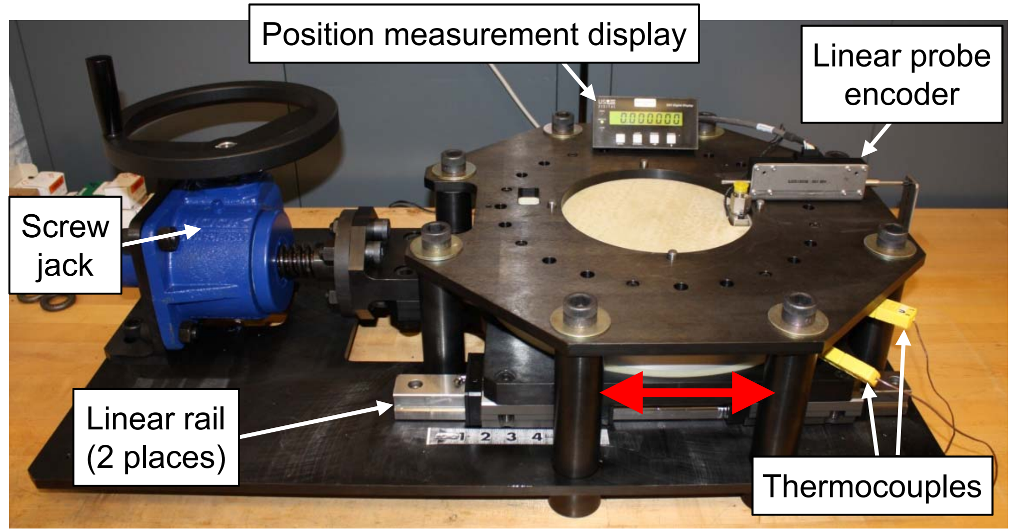
Upper test platen

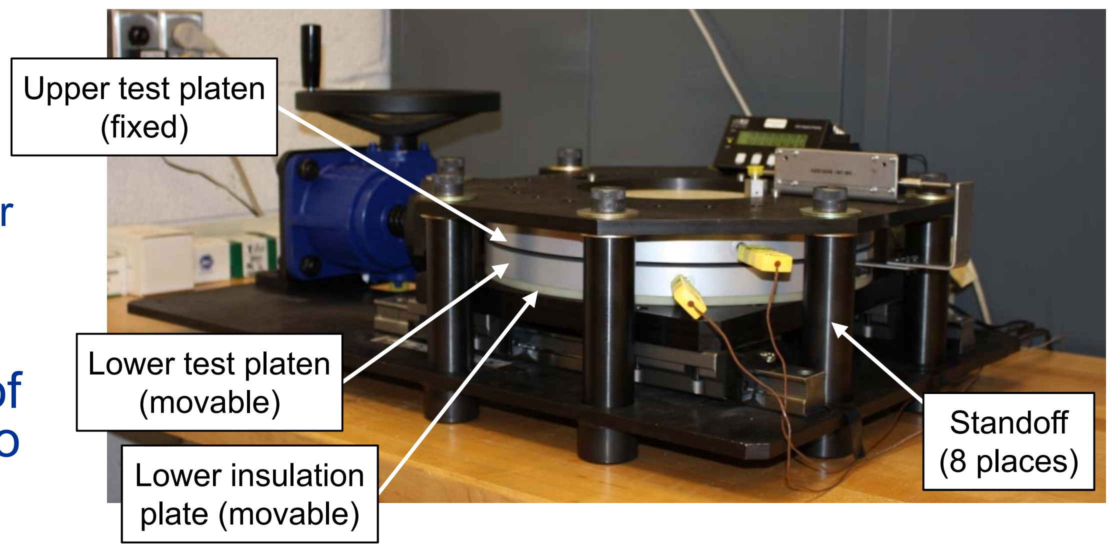
Lower test platen

- Seals were tested in seal-on-flange configuration:
  - Installed in groove in lower platen
  - Compressed against flat, smooth (16 µin. (0.4 µm)) sealing surface on upper platen
- Vent holes included in platens to prevent air entrapment that could otherwise:
  - Be measured as load during compression testing
  - Help separate platens during adhesion testing

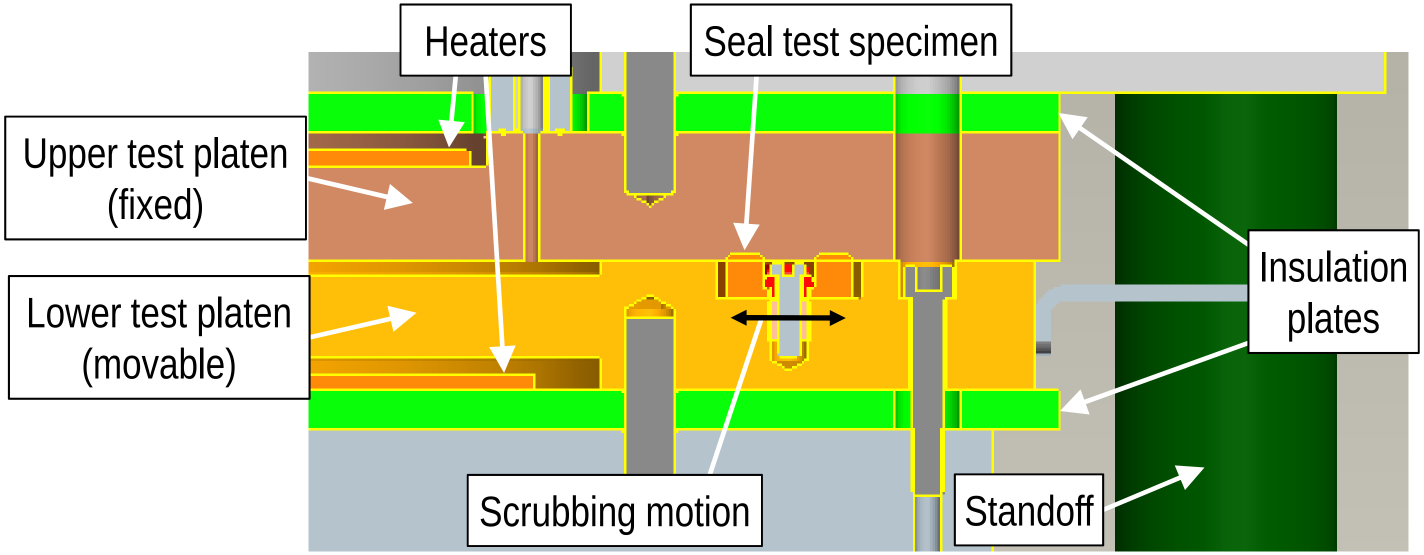
Durability Testing

- Upper test platen with flat surface:
  - Secured to base of test apparatus through standoffs
  - Remained fixed during testing
- Lower test platen with seal:
  - Mounted on pair of linear rails connected to screw jack assembly
  - Moved back and forth during testing
- Amount of compression on seals controlled by precision metal shims installed on top of standoffs
  - Gap between upper and lower platens minimized (~0.005 in. (0.127 mm)) to nearly fully compress seals
- Heaters mounted on backs of platens warmed test fixture to 142°F (61°C) during testing





Durability Testing (cont.)

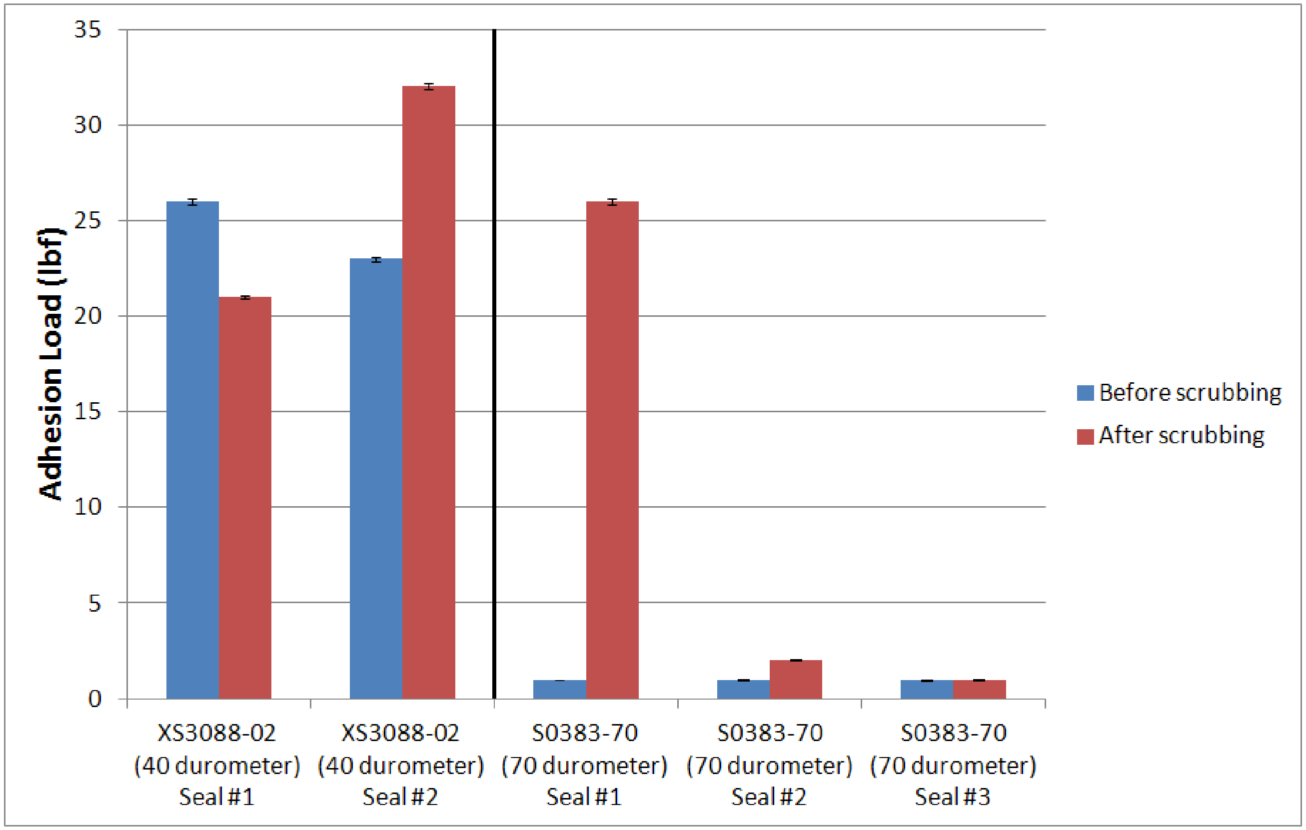


- Each seal subjected to 50 scrub cycles:
  - Each cycle consisted of a movement of 0.056 in. (1.42 mm) away from and back to original home position
  - Simulated amount of movement seal could experience during 50 missions

Adhesion Testing

- Room temperature adhesion tests performed before and after durability tests
- Seals initially compressed in test fixture for 24 hrs at room temperature outside load frame
- Test fixture assembly then installed in load frame for adhesion test:
  - Upper platen raised according to specific displacement profile to simulate undocking sequence
  - Test was completed when seal was no longer in contact with mating surface
  - Maximum force required to separate seal from mating surface was reported as seal adhesion value

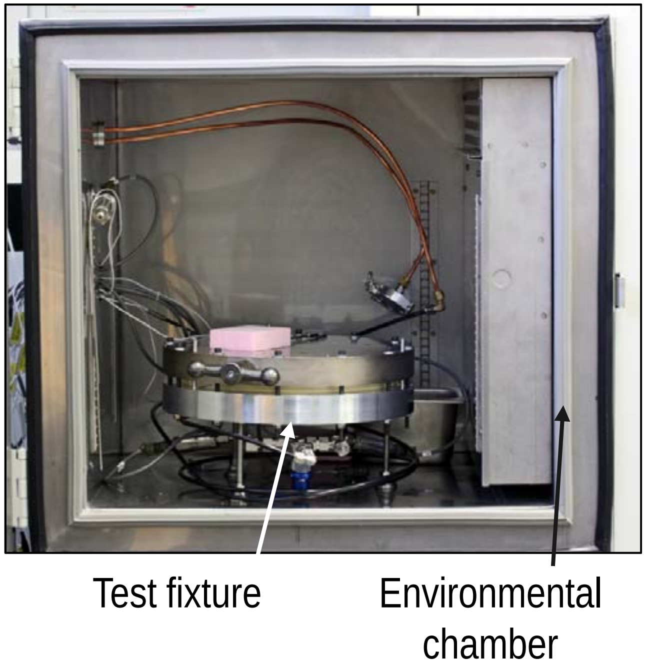
Adhesion Test Results



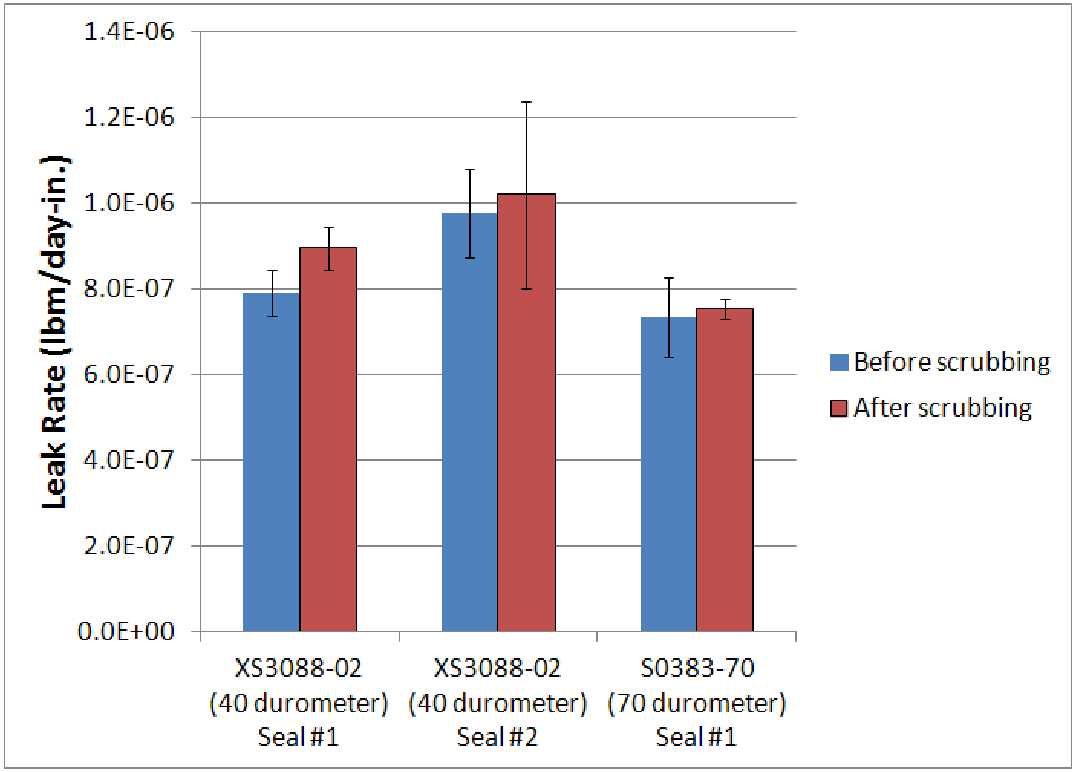
- Before scrubbing, AO pre-treatment was more effective at reducing adhesion loads for seals made of S0383-70 than for seals made of XS3088-02
- Effects of scrubbing on adhesion loads were inconclusive:
  - For XS3088-02 seals, load increased after scrubbing for one seal and decreased for the other
  - For S0383-70 seals, load increased quite a bit for one seal but very little for other two seals; however, even max load was still lower than those for seals without AO pre-treatment

Leak Testing

- Room temperature leak tests performed before and after durability tests
- Control volume inboard of inner seal bulb pressurized with dry air to create Δp across seal of 14.7 psid
- Measured pressure and temperature of volume as air permeated through seal
- After test was completed, utilized mass point leak rate method to quantify leak rate for inner seal bulb
- Calculated uncertainty for leak rate based on 95% confidence interval



Leak Test Results



- Leak rate after scrubbing increased slightly compared to leak rate prior to scrubbing for each seal
- However, leak rates before and after scrubbing were deemed to be statistically equivalent since their confidence intervals overlap

Summary & Conclusions

- Durability tests were performed on subscale seals under anticipated worst-case conditions to evaluate effects of lateral, scrubbing movements on performance of AO pre-treated seals
- Testing revealed:
  - AO pre-treatment was more effective at reducing adhesion loads before scrubbing for seals made of S0383-70 than for seals made of XS3088-02 compound
  - Effects of scrubbing on seal adhesion loads were inconclusive; however, still lower than those for seals without AO pre-treatment
  - Potential increase in seal adhesion after scrubbing must be accounted for in future docking system seal designs
  - Scrubbing of S0383-70 and XS3088-02 seals did not cause statistically significant changes in seal leak rates
- Additional tests and evaluations are warranted to confirm these findings since conclusions are based on limited number of tests

Acknowledgments

- International Low Impact Docking System (iLIDS) team from NASA JSC
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- Parker Hannifin Corporation's Composite Sealing Systems Division (San Diego, CA) for fabricating seal test specimens
- Henry de Groh (NASA GRC) and Bruce Banks (Alphaport) for completing AO pre-treatment of seal test specimens

Appendix

Leak Testing

- Room temperature leak tests performed before and after durability tests
- Control volume inboard of inner seal bulb pressurized with dry air to create Δp across of 14.7 psid
- Measured pressure and temperature of volume as air permeated through seal
- After test was completed, utilized mass point leak rate method to quantify leak rate for inner seal bulb:
  - Calculated mass of air in test section at each time step using Ideal Gas Law:

    $$m(t) = (pV)/(RT)$$

  - Performed linear regression on population of mass sample points using Least Squares Method to yield:

    $$m(t) = a_1 t + a_0$$

  - Variable a_1 was slope of curve and corresponded to leak rate for inner bulb of test seal
  - Calculated uncertainty for leak rate based on 95% confidence interval

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