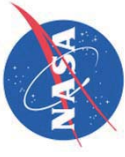


An Overview of Advanced Elastomeric Seal Development and Testing Capabilities at NASA Glenn Research Center

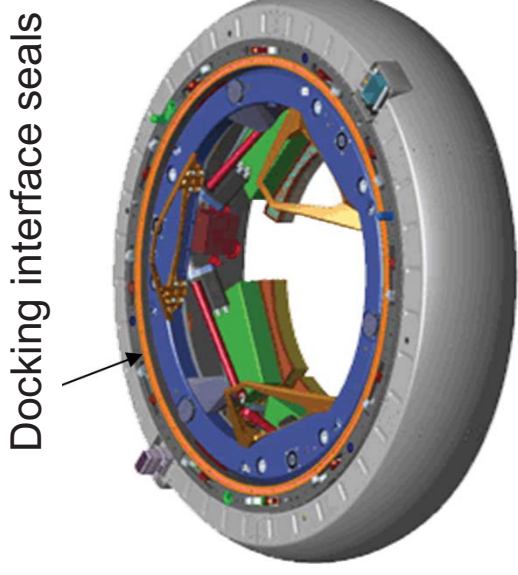
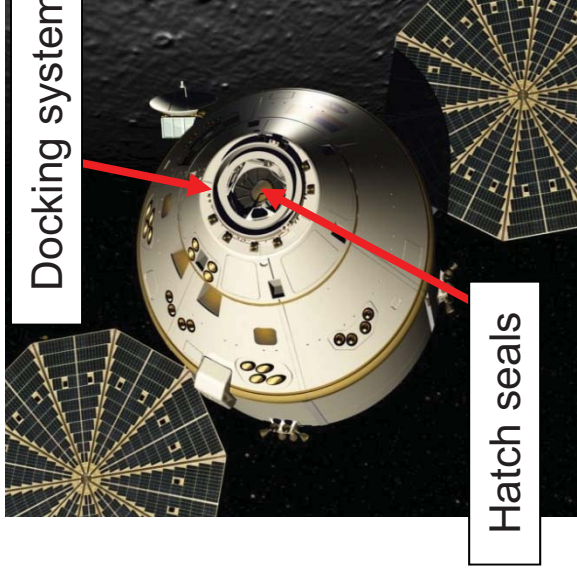
Patrick H. Dunlap, Jr.

NASA Glenn Research Center, Cleveland, OH

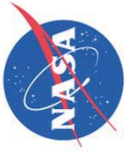
50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference
Cleveland, OH
July 28, 2014



Introduction

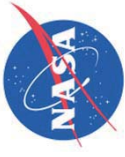


- NASA is developing advanced space-rated vacuum seals for future missions to low Earth orbit (LEO), the Moon, near Earth asteroids, and other destinations
- Includes seals for a new docking system and vehicle hatches
- NASA GRC has developed unique testing capabilities to evaluate seal performance under representative operating conditions (thermal, vacuum, and engagement)

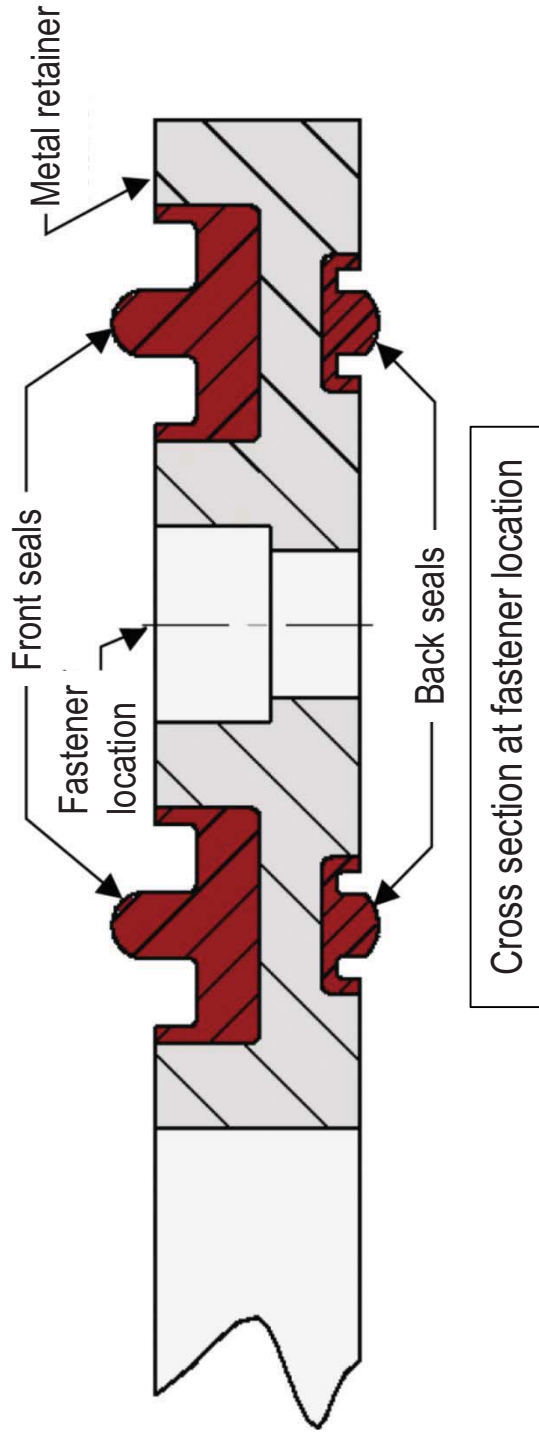


Advanced Seal Development

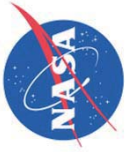
- Seal characteristics:
 - Diameters up to ~50 in.
 - Typically made of elastomeric materials (e.g., silicone)
 - Extremely low leak rates to ensure that astronauts have sufficient breathable air for extended missions
 - Low enough compression loads so mechanisms can compress them
 - Low adhesion loads when sealed interface has to be separated (e.g., undocking, hatch opening)
- Candidate seal designs:
 - Gask-O-seal® (Parker Hannifin Corporation)
 - Multi-piece seal
 - O-rings
- Seal design features are tailored to meet requirements for each application



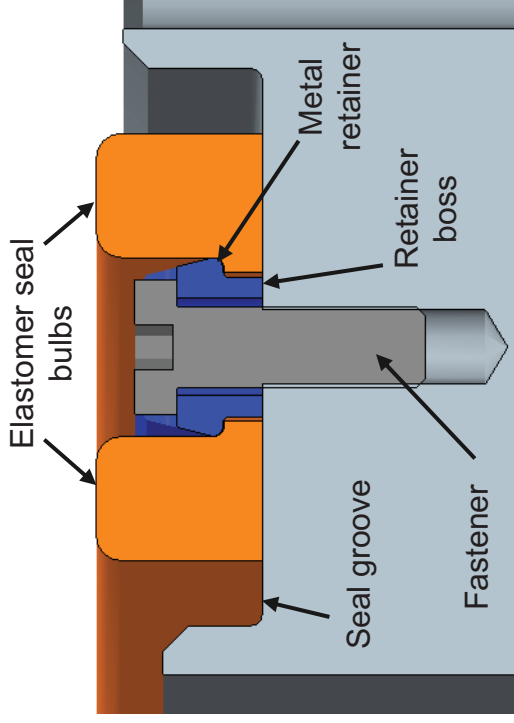
Candidate Seal Design: Gask-O-Seal



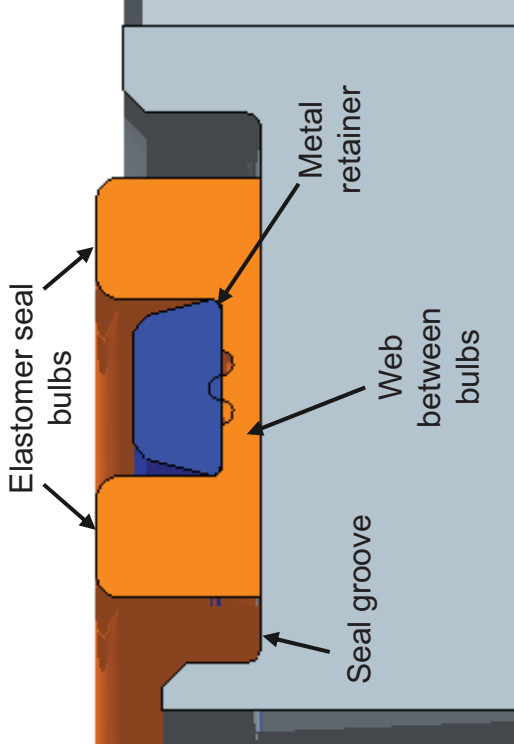
- Silicone elastomer seal bulbs molded directly into grooves of metallic (e.g., aluminum) retainer to form single-piece assembly
- Dual bulbs on front and back for redundancy
- No separate seal groove(s) required on structure
- Space flight experience: Used on Common Berthing Mechanism (CBM) and other locations on ISS



Candidate Seal Design: Multi-Piece Seal

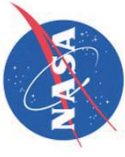


Cross section at fastener location



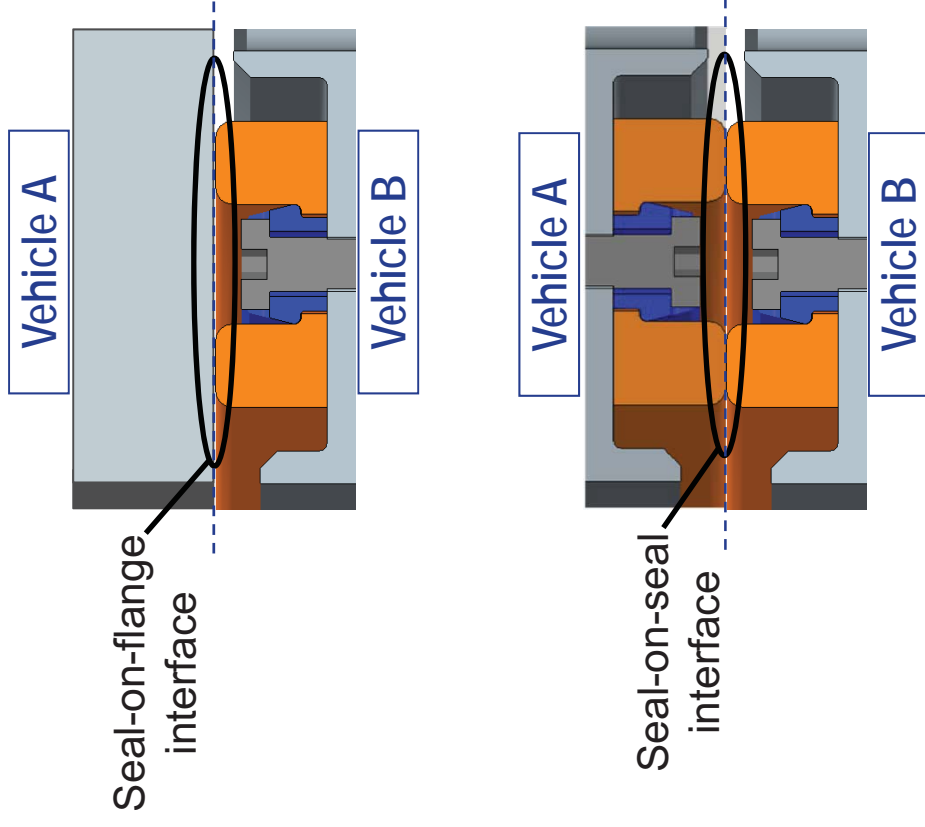
Cross section between fasteners

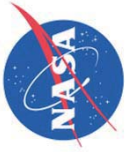
- Seal has separate elastomer and retainer elements
 - Elastomer element: Two seal bulbs (redundancy) connected by web
 - Retainer:
 - Periodic bosses pass through openings in web
 - Anchors elastomer element to structure
 - Single piece or multi-segment
- Installed in groove



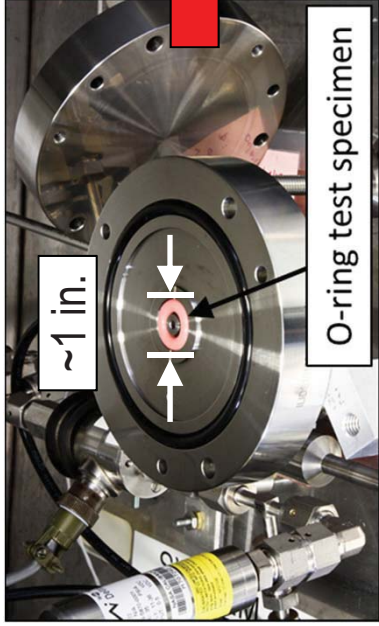
Testing Capabilities

- NASA GRC has developed unique test fixtures to evaluate performance of candidate seal designs under representative operating conditions
- Performance measurements:
 - Leak rate
 - Compression loads
 - Adhesion loads
 - Pull-out/bond strength
 - Durability
- Test conditions:
 - Thermal conditions (warm, cold)
 - Vacuum
 - Mating conditions: Seal-on-seal vs. seal-on-flange
 - Engagement conditions:
 - Fully compressed vs. gapped
 - Aligned vs. misaligned
 - Redundant seals

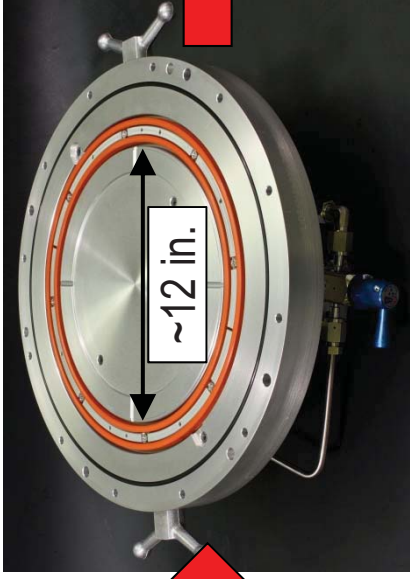




Typical Seal Development & Testing Process

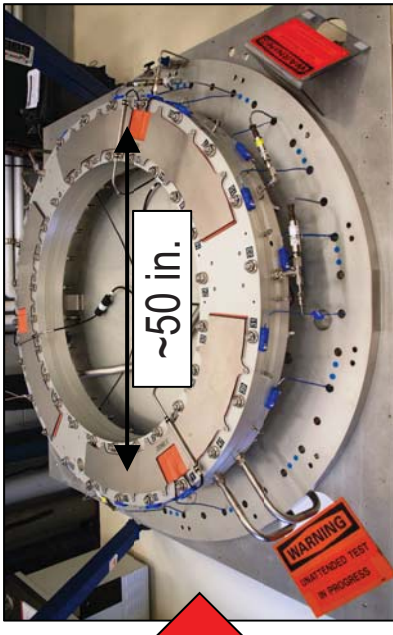


Screening tests using O-rings and small material samples



Development tests using subscale (~12 in. dia.) versions of larger seals

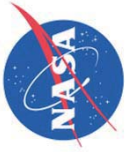
- Less expensive
- Faster
- Some tests too difficult to perform at full-scale



Final demonstration of seal performance at full-scale

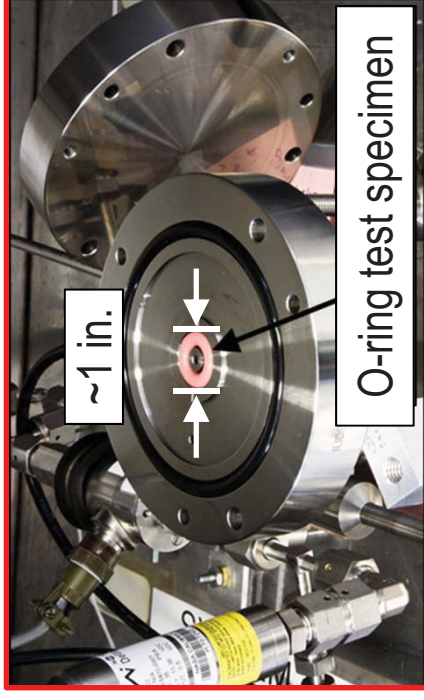


Small-Scale Seal Testing

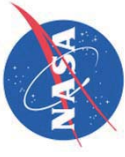


Small-Scale Seal Leak Testing

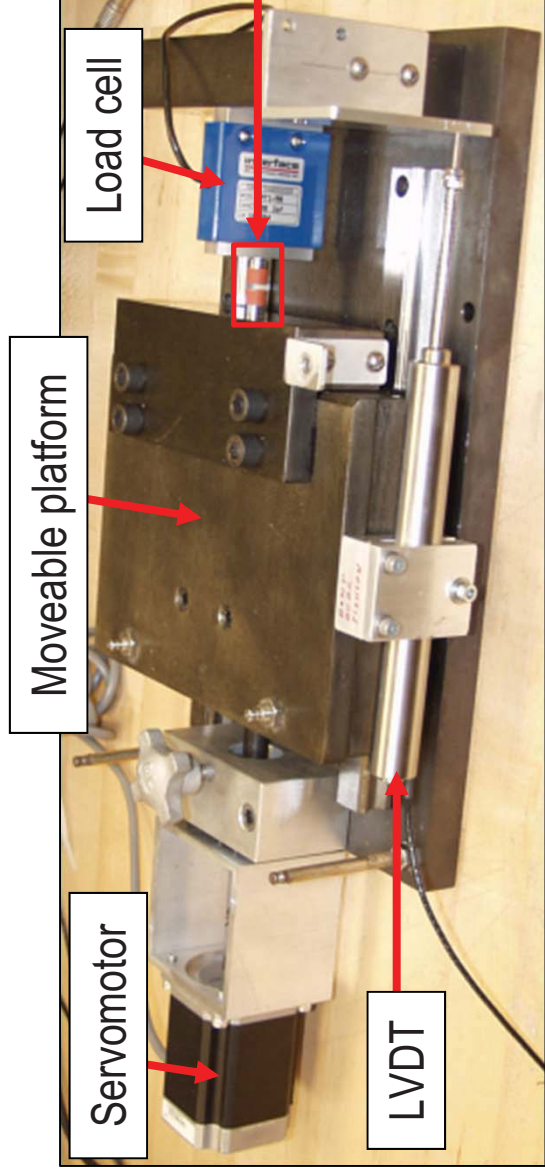
- Objective: Measure leak rates for small-scale seals made of candidate materials
- Testing capabilities:
 - Several versions of test fixtures to test specimens of various sizes and designs (e.g., 2-309 O-rings)
 - Leakage measurements using either helium or air
 - Temperatures of -238 to 1122°F (-150 to 600°C) using Tenney test chambers
 - Adjustable pressure differential across seal (typically 14.7 psid)
 - Fully or partially compressed seals



Test fixture inside environmental control chamber



Small-Scale Seal Compression & Adhesion Testing

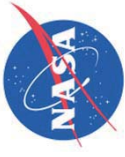


Cylindrical “button”
test specimens

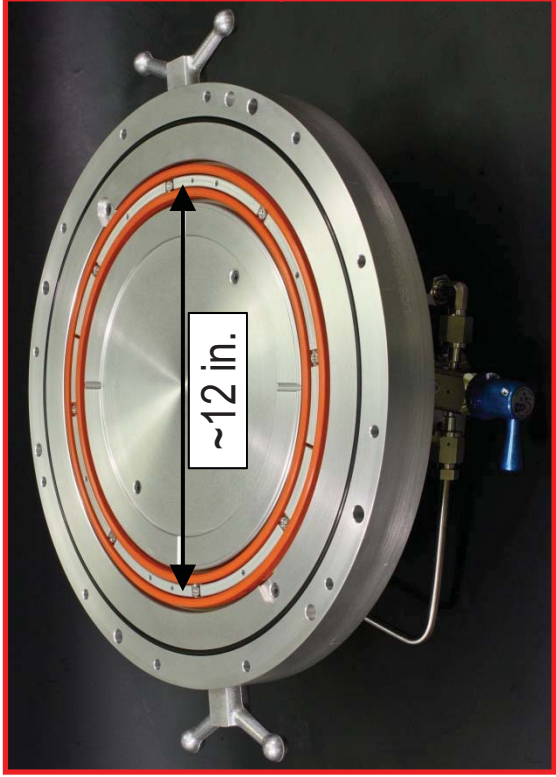
- Objective: Measure compression and adhesion loads for small seals and material test specimens made of candidate materials
- Testing capabilities:
 - Compression and adhesion load measurements
 - Room temperature tests
 - Load cycling with programmable loading and unloading profiles
 - Seal-on-flange or seal-on-seal mating



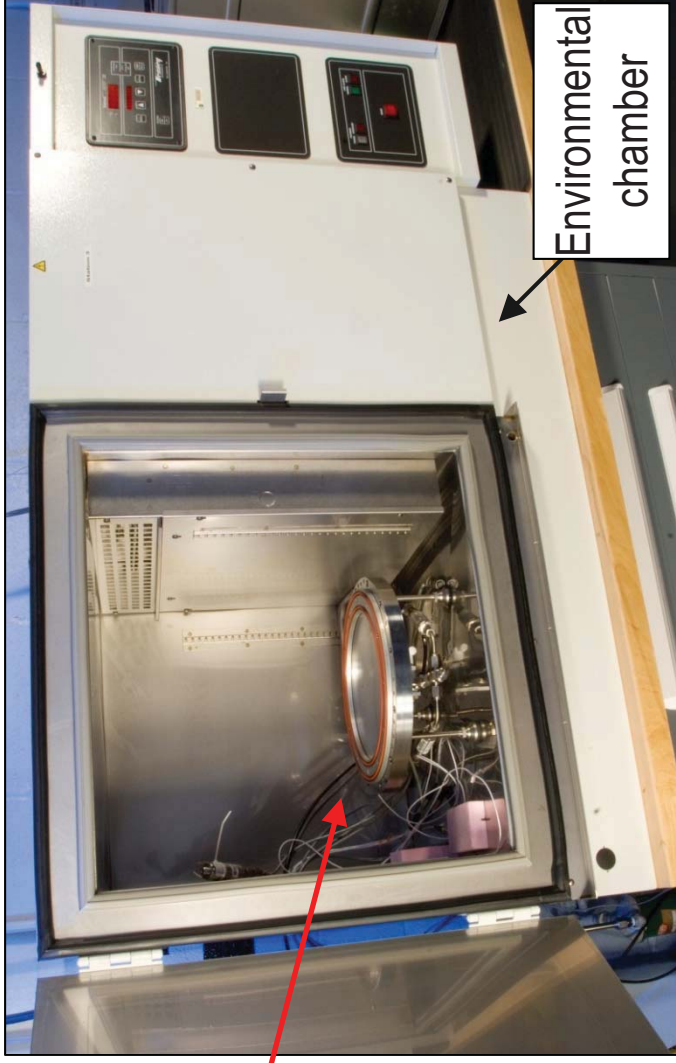
Medium-Scale Seal Testing



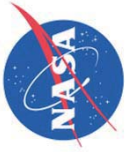
Medium-Scale Seal Leak Testing



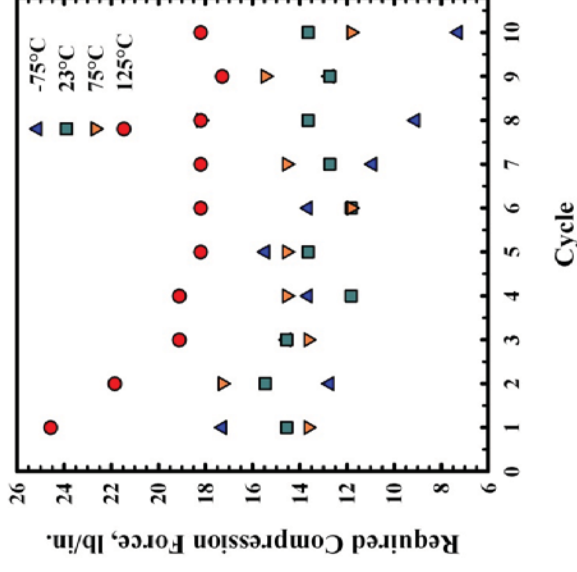
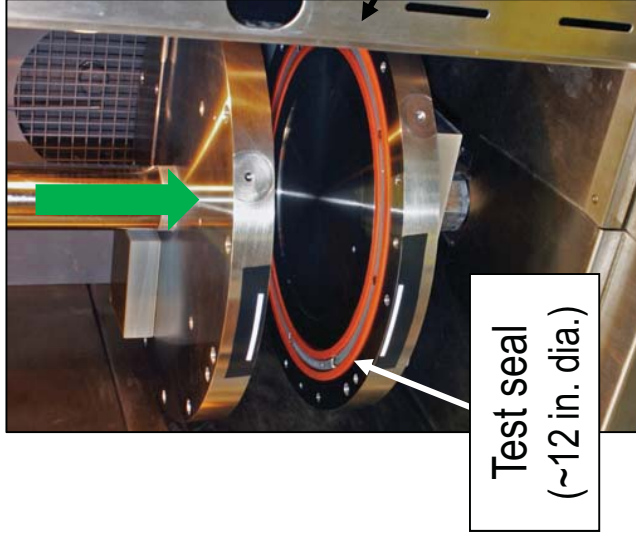
Medium-scale seal leak test fixture
(Note: Top of test fixture not installed)



- Objective: Measure medium-scale seal leak rates under representative operating conditions
- Testing capabilities:
 - Leakage measurements for either inner or outer seal bulb using helium or air
 - Temperatures of -238 to 1122°F (-150 to 600°C) using Tenney test chambers
 - Adjustable pressure differential across seal (typically 14.7 psid)
 - Nominal (fully compressed, aligned) and off-nominal (gapped, radially misaligned) mating
 - Seal-on-flange or seal-on-seal mating
 - Multiple chambers and fixtures facilitate testing in parallel

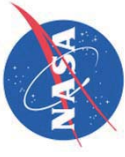


Medium-Scale Seal Compression & Adhesion Testing

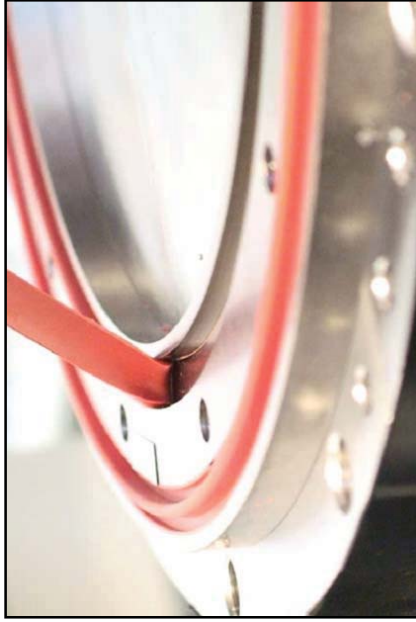


Representative seal compression data
(Ref. Bastrzyk, M.B., AIAA-2010-6908, Fig. 9)

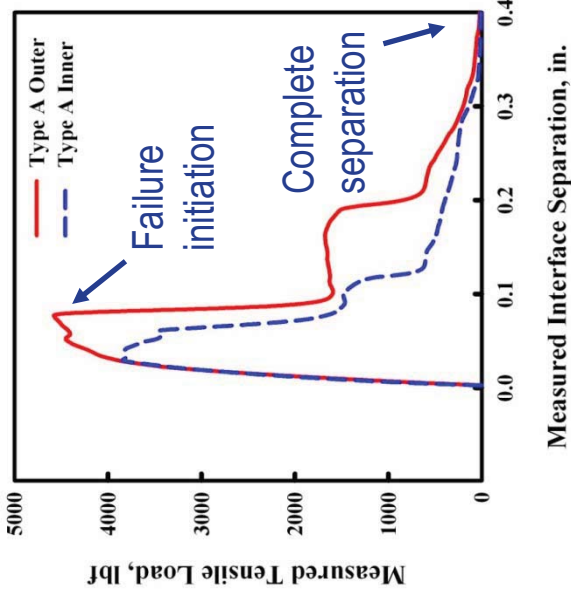
- **Objective:** Measure medium-scale seal compression and adhesion loads under simulated mating conditions
- **Testing capabilities:**
 - Compression and adhesion load measurements
 - Temperatures of -238 to 662°F (-150 to 350°C) using Instron 3119-407A2 environmental chamber
 - Programmable loading/unloading profiles with load cycling via Instron 5584 electromechanical load frame
 - Seal-on-plate or seal-on-seal mating



Medium-Scale Seal Pull-Out/Bond Strength Testing

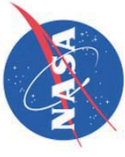


Gask-O-seal bulb being pulled out of retainer during bond strength test

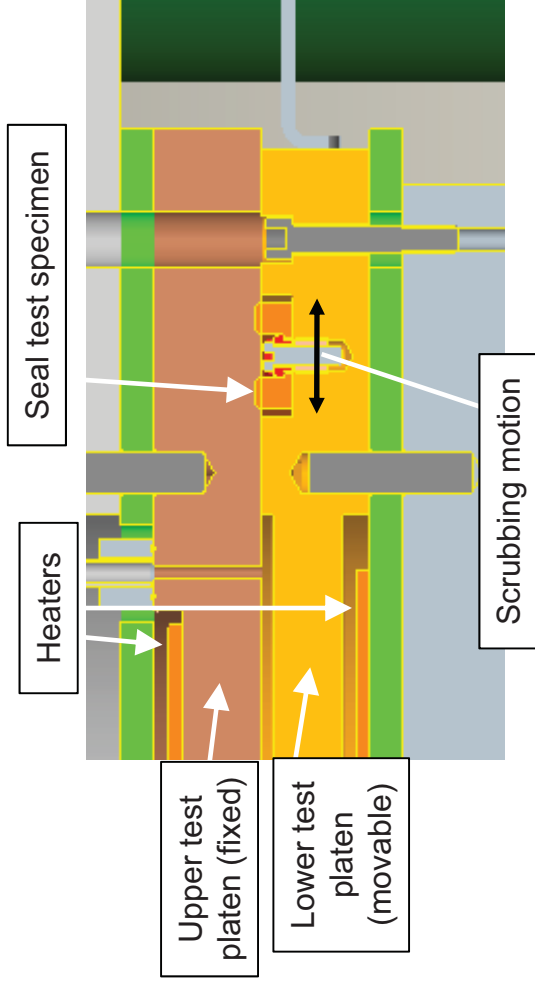
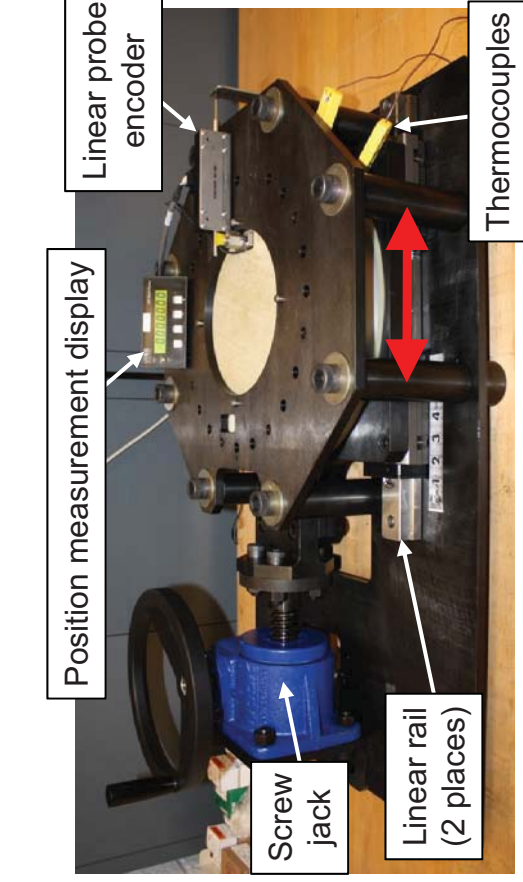


Representative test results (Ref. Conrad, M., AIAA-2009-5318)

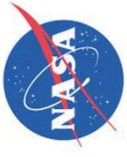
- Objective: Quantify the force required to remove a seal from its retaining feature at representative operating temperatures
- Testing capabilities:
 - Test specimens of various sizes and designs
 - Temperatures of -238 to 662°F (-150 to 350°C) using Instron model 3119-407A2 environmental chamber
 - Tests utilize same load frames used for compression and adhesion tests



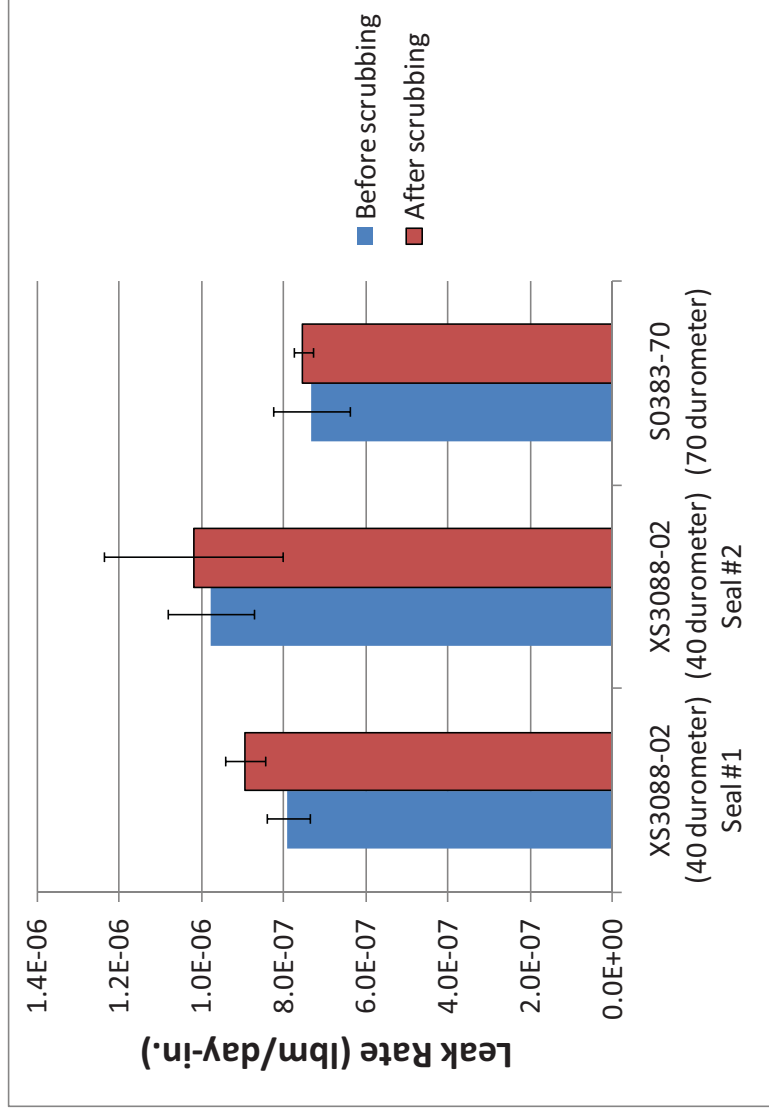
Medium-Scale Seal Durability Testing



- Objectives:
 - Subject medium-scale seals to lateral “scrubbing” they could experience during mating or thermal equilibration
 - Evaluate effects of scrubbing on seal adhesion and leak rates
- Testing capabilities:
 - Multiple scrub cycles
 - Amount of compression on seals can be set independently
 - Temperatures: RT to 142°F (RT to 61°C)
 - Test plates were designed so adhesion tests and leak tests could be performed on a seal before and after it was scrubbed without having to remove it from test plates (minimize handling)



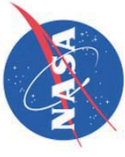
Medium-Scale Seal Durability Testing (cont.)



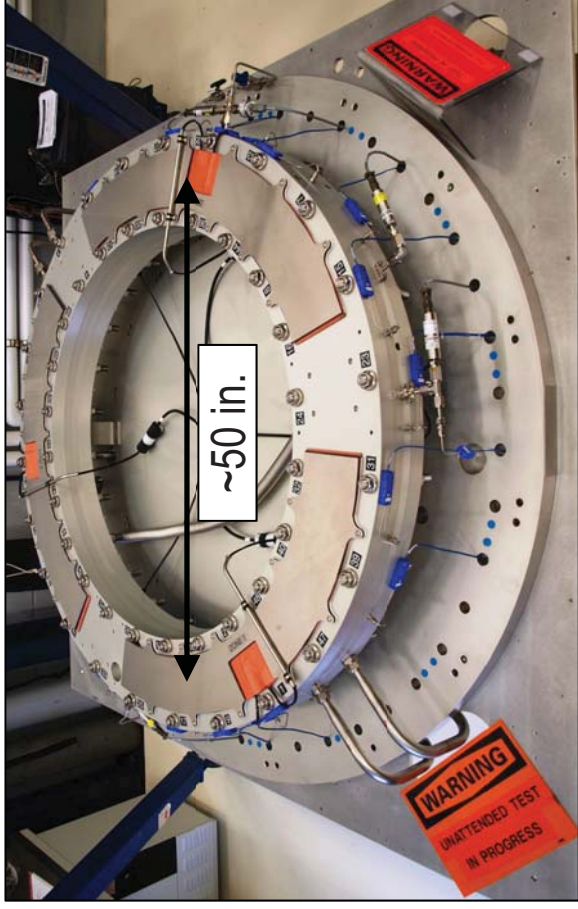
Representative test results
(Ref. Dunlap, P.H., AIAA-2011-5710)



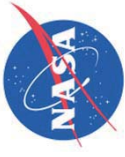
Full-Scale Seal Testing



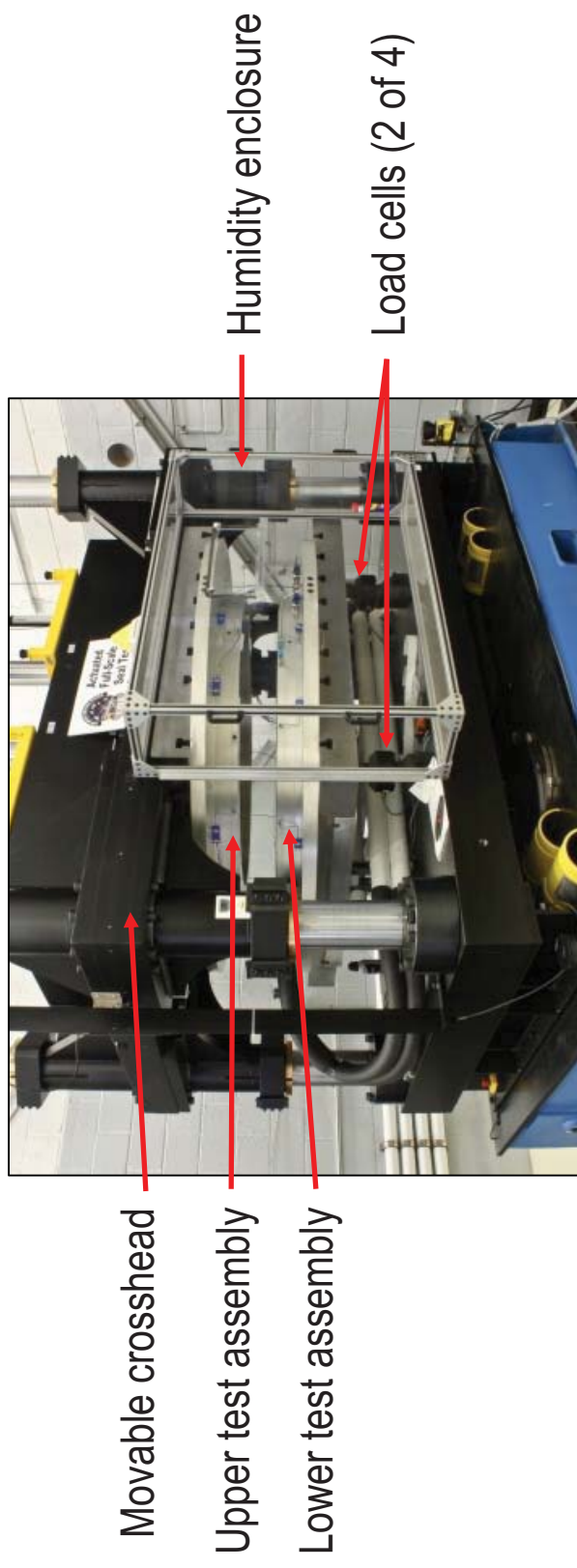
Full-Scale Seal Leak Testing



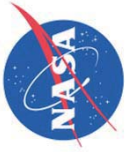
- **Objective:** Measure full-scale seal leak rates under representative operating conditions
- **Testing capabilities:**
 - Leakage measurements for either inner or outer seal bulb using helium or air
 - Temperatures of -67 to 212°F (-55 to 100°C) using Mydax 2VLH30W chiller/heater
 - 14.7 psia to vacuum pressure differential across seal bulbs
 - Nominal (fully compressed, aligned) and off-nominal (gapped, radially misaligned) mating
 - Seal-on-flange or seal-on-seal mating



Full-Scale Seal Compression, Adhesion, & Leak Testing



- Objectives:
 - Measure full-scale seal compression and adhesion loads under simulated docking and undocking conditions
 - Measure seal leak rates after load cycling and at various compression levels
- Testing capabilities:
 - Temperatures of -58 to 203°F (-50 to 95°C) using Mydax 2VLH30W chiller/heater
 - Load cycling via Instron SATEC Series Custom 600KN hydraulic load frame
 - Programmable loading and unloading profiles
 - Seal-on-flange or seal-on-seal mating
 - Simplified leakage measurements using air



Summary

- NASA is developing advanced space-rated elastomeric seals for future space exploration missions
- NASA GRC has developed unique test fixtures to measure leak rates and compression and adhesion loads of candidate seal designs under simulated thermal, vacuum, and engagement conditions
 - Small-scale seal test fixtures used mainly for material screening tests
 - Medium-scale seal test fixtures used to test subscale versions of larger seal designs for development testing and other seal designs ~12 in. in diameter
 - Full-scale seal test fixtures permit testing of seals ~50 in. in diameter under representative operating conditions
 - Test conditions include:
 - Temperatures ranging from -238 to 1122°F (-150 to 600°C)
 - Operational pressure gradients
 - Seal-on-seal or seal-on-flange mating configurations
 - Nominal and off-nominal conditions (e.g., incomplete seal compression)
- Test fixtures are designed with flexibility to accommodate future candidate seal designs required to support NASA's ongoing missions for deep space exploration



Acknowledgments

- International Low Impact Docking System (iLIDS) team from NASA JSC
- Team members from NASA GRC, the University of Akron, the University of Toledo, Ohio Aerospace Institute, Analex Corporation, QinetiQ North America, Vantage Partners, LLC, and Gilcrest Electric & Supply Company who contributed to the design, fabrication, installation, and operation of the test fixtures



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