



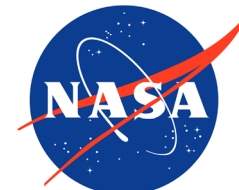
Magnetically Latching Cryogenic Fluid Coupler for Lunar Surface Operations

Nic Heersema, Shideh Naderi, Scott Stebbins, Paul Bean, & Andrew Holguin

NASA Armstrong Flight Research Center

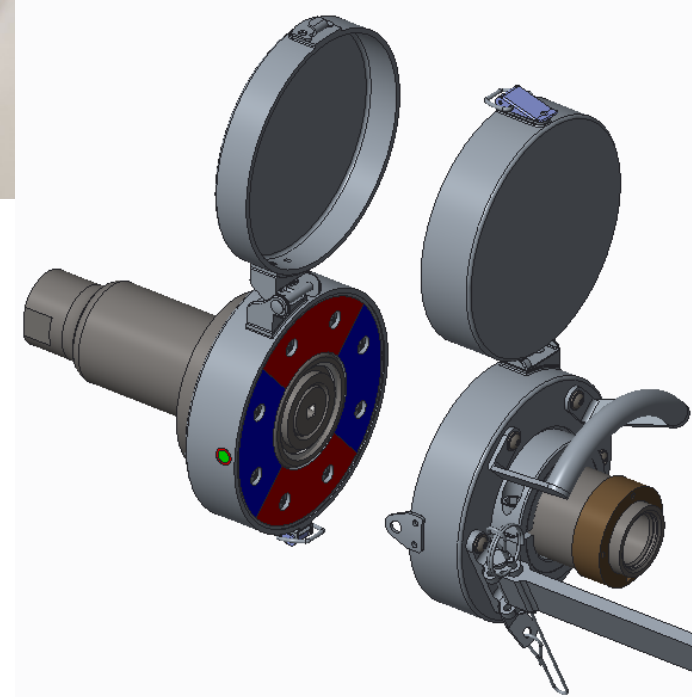
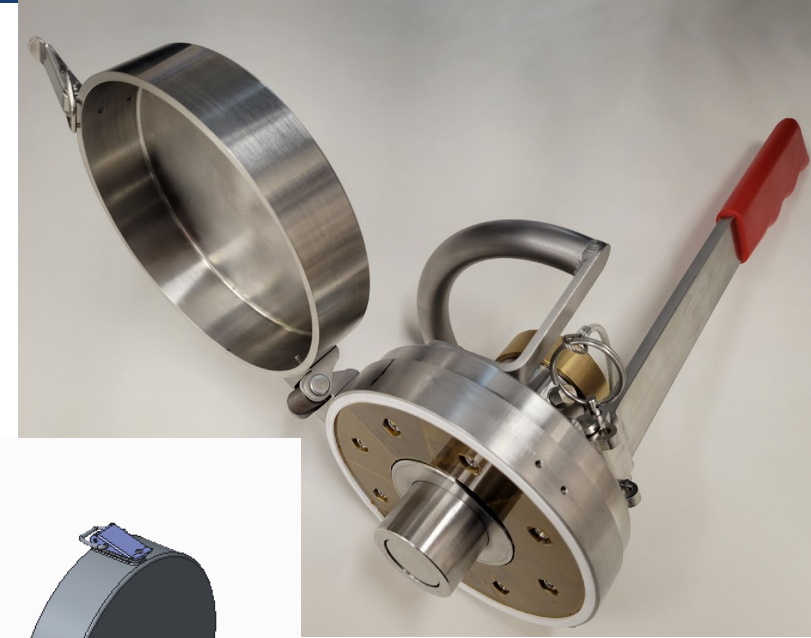
AIAA SciTech, 8-12 Jan 2024

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Outline

- System Overview
 - Background
 - Concept of Operations
 - Design
- Capabilities Evaluation
 - Structural analysis
 - Thermal analysis
 - Functional Evaluation
 - Dust Environments testing
 - Cryogenic Flow testing
- Conclusion



Background

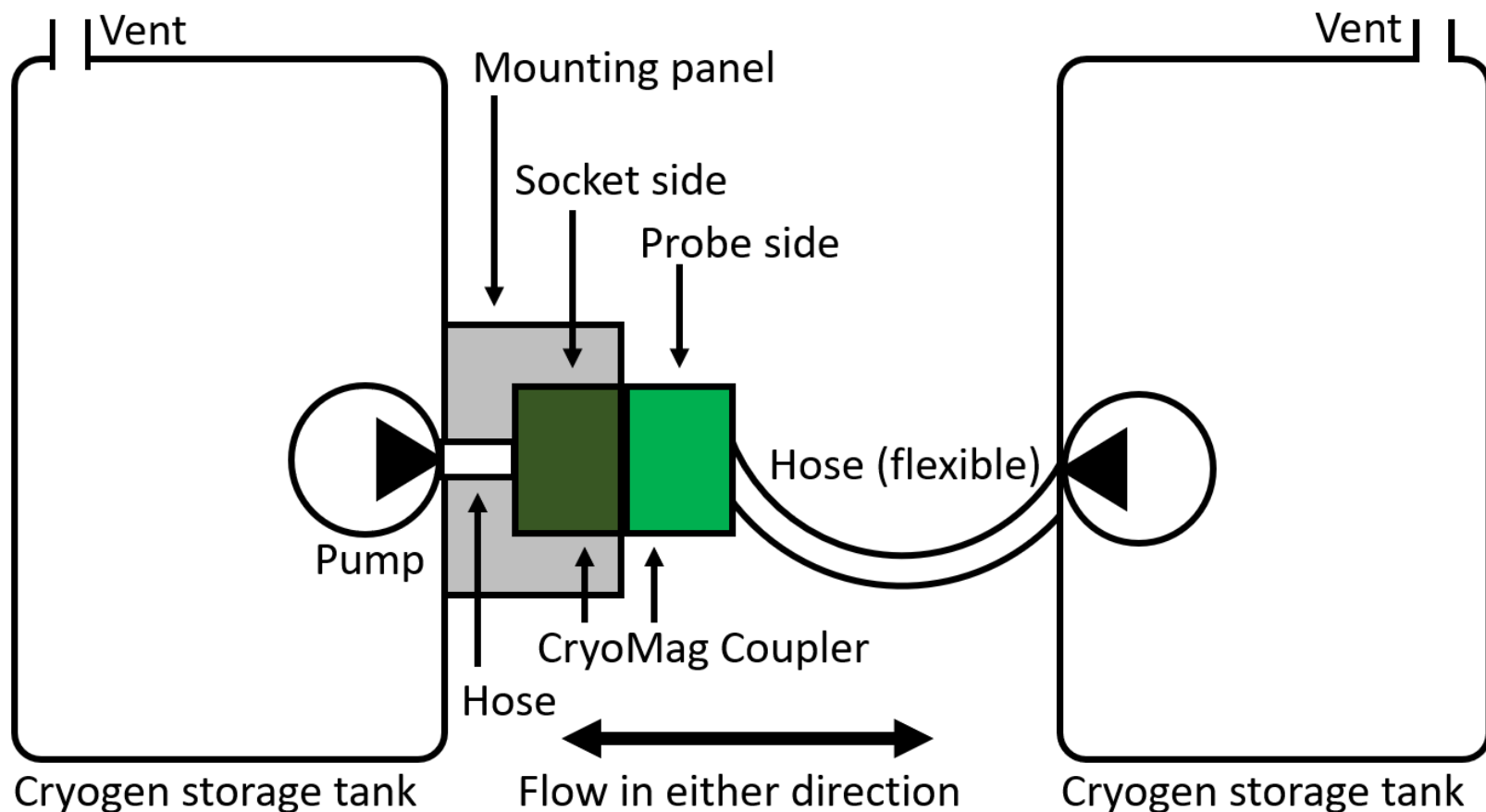
- NASA aims to return to the lunar surface for sustained operations



- Lunar surface ops will require dust-resistant cryogenic fluid transfer

Operational Scenario

- Temporary connection between cryogen tanks
- In-Situ Resource Utilization
- Pressurized rovers
- LN_2 only for initial development



Concept of Operations (ConOps)

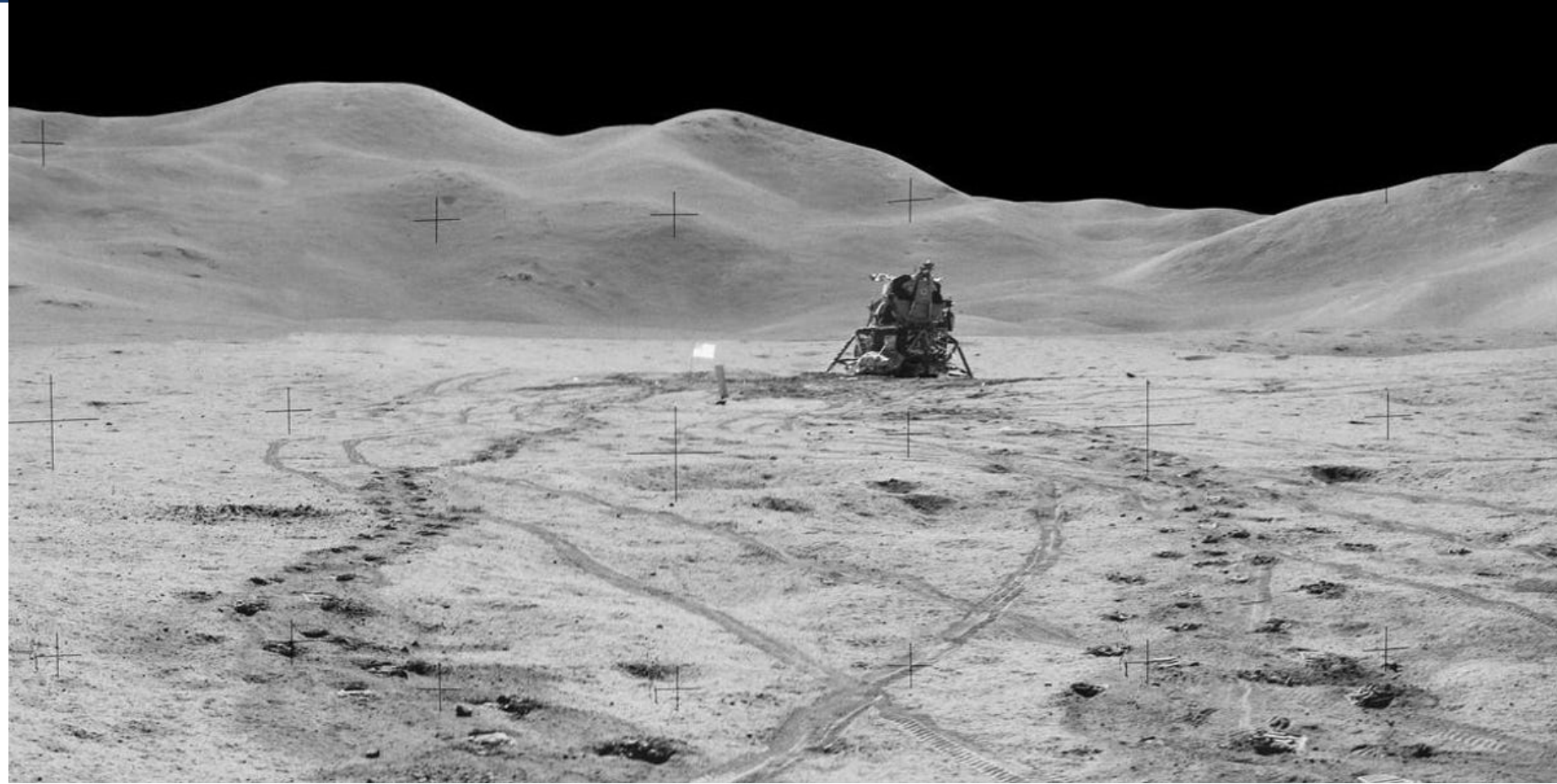
Mate
coupler



Flow LN2



Demate
coupler

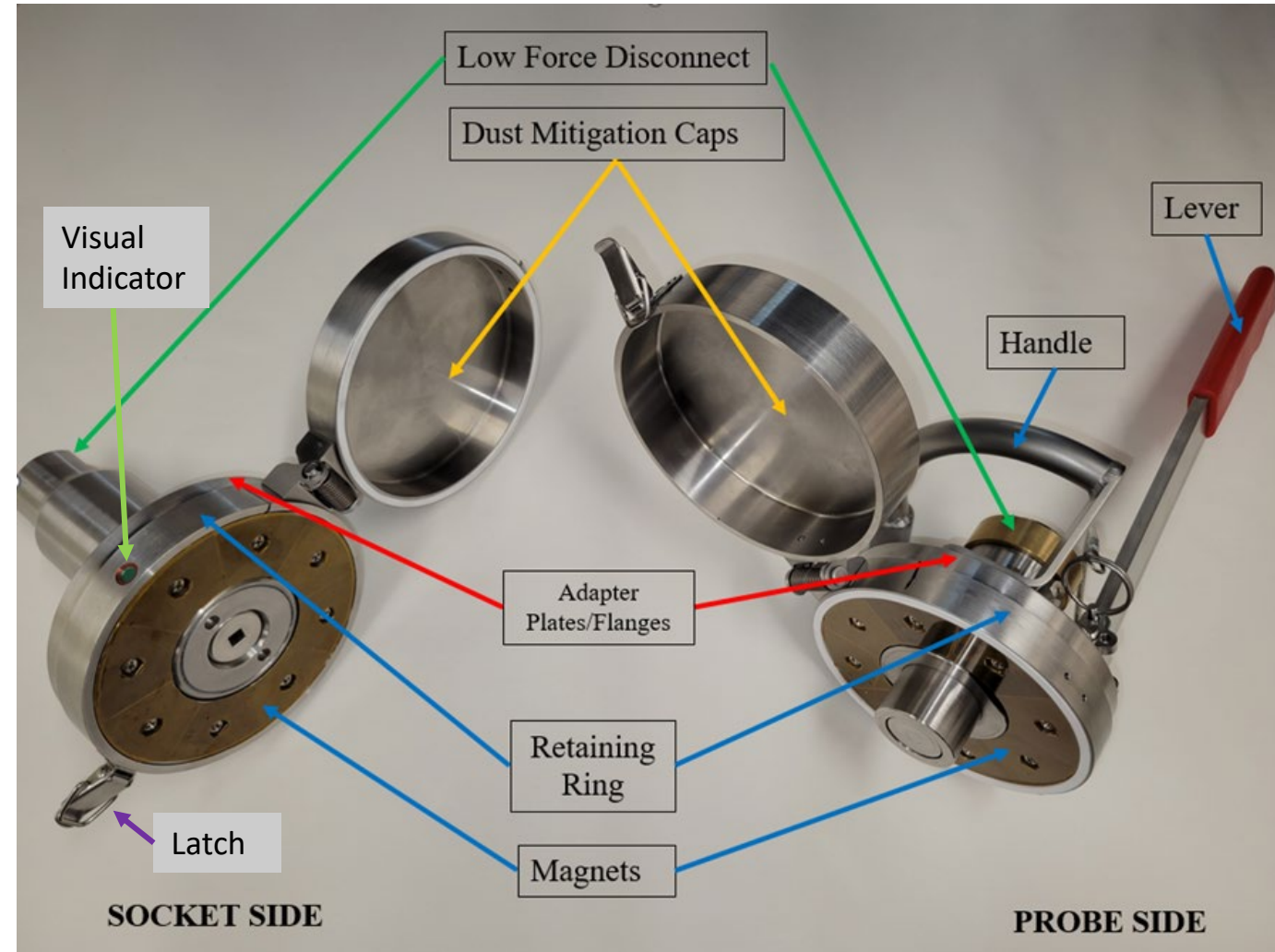


- Lunar surface forecast = dusty with wide temperature range

Requirements: an Abbreviated List

- To successfully achieve ConOps, coupler must be able to:
 - Mate and demate in lunar environment multiple times over lifecycle
 - Operations performed by astronauts in EVA suits (assumed limit 22 lbf) or rovers
 - Dusty lunar surface: dust accumulation must not interfere with mating/demating process
 - Lunar thermal environment: equatorial and/or polar regions
 - Allow flow of cryogenic fluid with minimal leakage

Cryogenic Magnetic (CryoMag) Coupler Design



- Key innovation: use of magnets for mating/demating
 - Magnets provide all latching force
 - External user input required during mating/demating
 - Also contributes to dust resistance
- Magnets and dust mitigation caps adapted to existing cryogenic fluid coupler
 - Low Force Disconnect (LFD) chosen for initial study – other options possible
- Feasibility demonstration hardware; not optimized yet
 - Weight: ~20 lbs

CryoMag Coupler Capabilities Evaluation

Capabilities

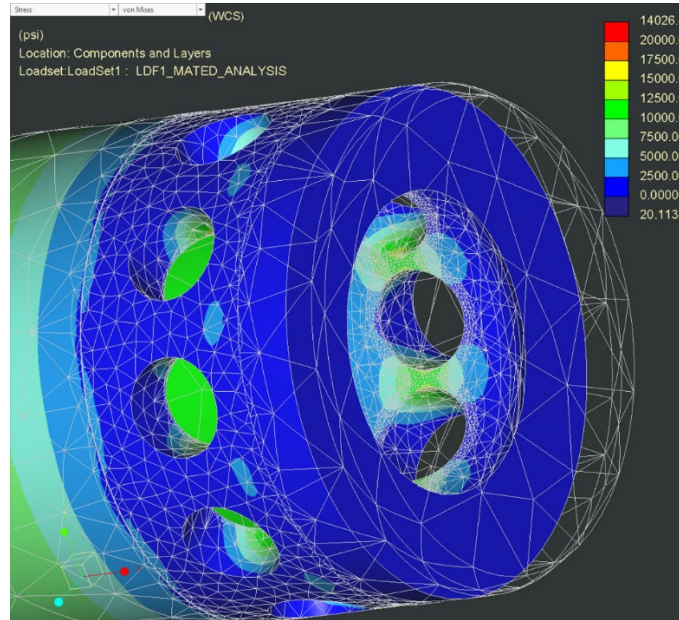
- Mating Force
 - < 22 lbf external input required
- Operational Environment
 - Lunar equatorial thermal environment
 - Lunar surface regolith
- Dust Resistance
 - No dust intrusion in fluid path
- Cryogenic Fluid Flow
 - > 14 L/min LN₂ with no leakage

Evaluation

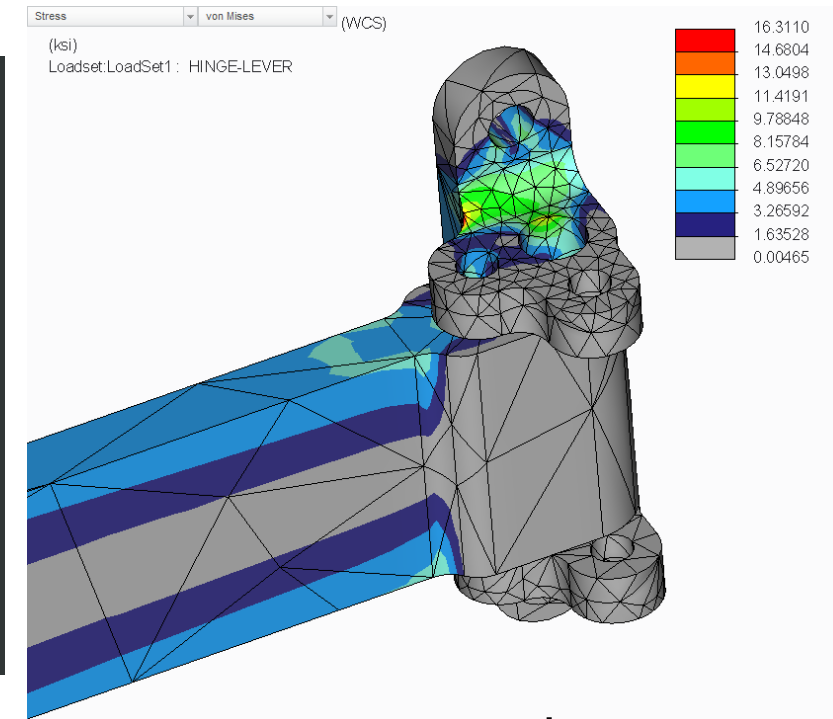
- Mating Force
 - Functional Evaluation – mate & demate
- Operational Environment
 - Structural and thermal analysis
 - Dust Exposure test – mate & demate in dusty environment
 - Evaluate dust intrusion into fluid path
- Cryogenic fluid flow
 - Cryoflow test

Structural Analysis

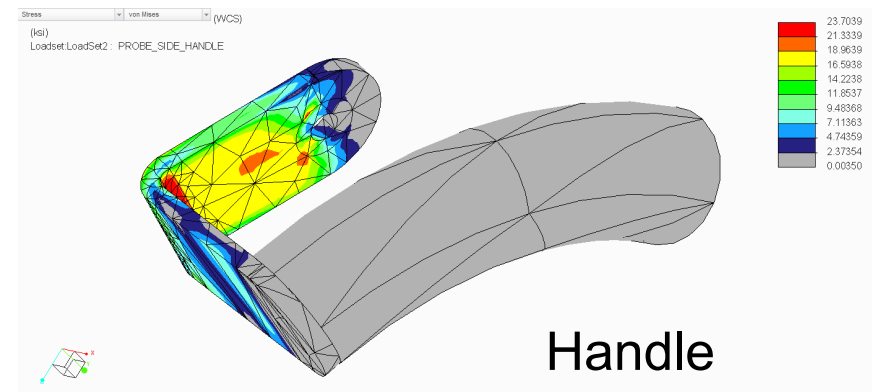
- Objectives:
 - Analyze static and inertial loads – **Factor of Safety:**
 - Demonstrate margin of safety for nominal operations
 - Examine margin of safety for failure modes (e.g. worst-case tolerance stackup)
- All cases have adequate margin except dust cap worst case misalignment



Probe



Lever



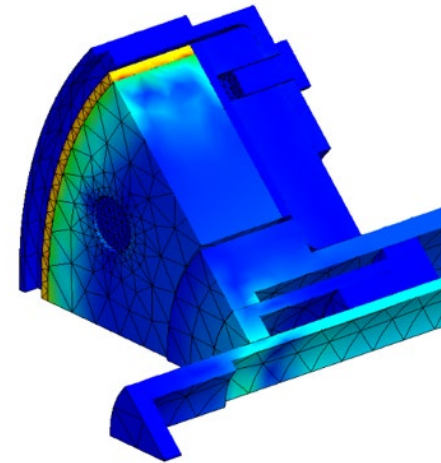
Handle

Thermal Analysis

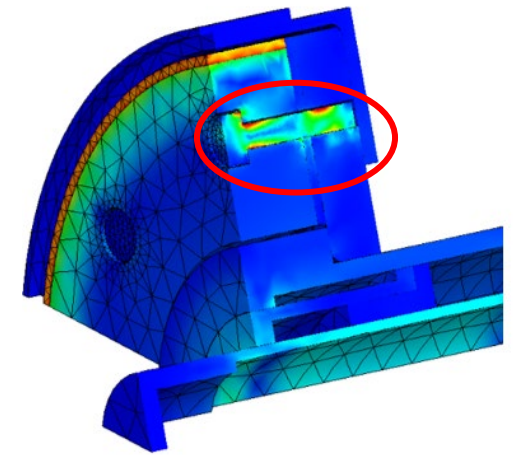
- Objectives:
 - Analyze for survivability across lunar surface temperature range
 - Analyze temperature gradient during test: internal cryogen to external cryoflow test facility

Location	Temperature, K
Lunar equatorial maximum	400
Lunar equatorial minimum	95
Lunar polar minimum	26
Cryoflow test facility	311

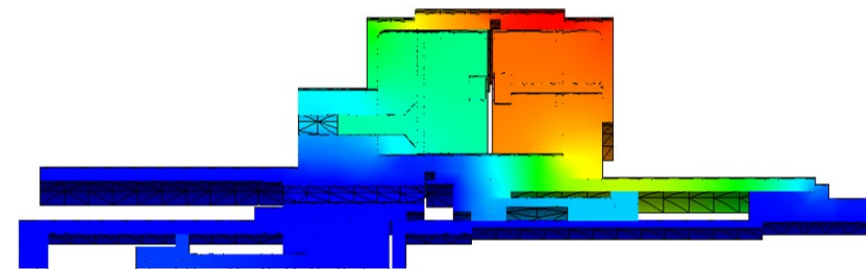
- Can thermally withstand lunar equatorial conditions
- Requires minor redesign for lunar polar minimum



Lunar equatorial minimum,
Steady state



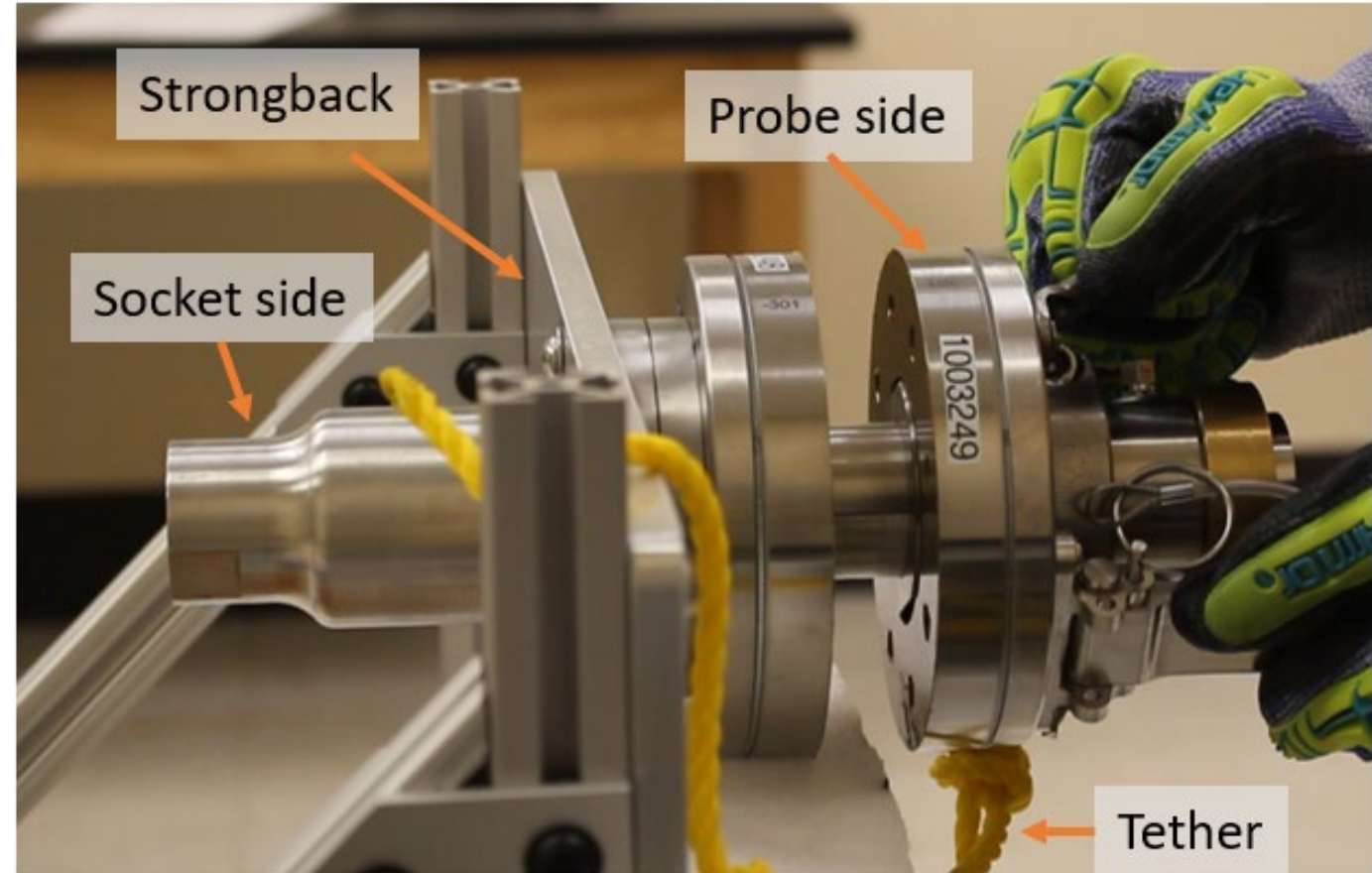
Lunar polar minimum,
Steady state



Cryoflow test, transient

Functional Evaluation

- Objectives:
 - Assess mating/demating capability of 3 magnet patterns
 - Firm-assist
 - Soft-assist
 - Fully-automatic
 - Evaluate human interface and ease-of-use
- Users preferred soft-assist pattern
- Fully-automatic pattern works as intended



Fully-Automatic



Soft Assist – User Preferred

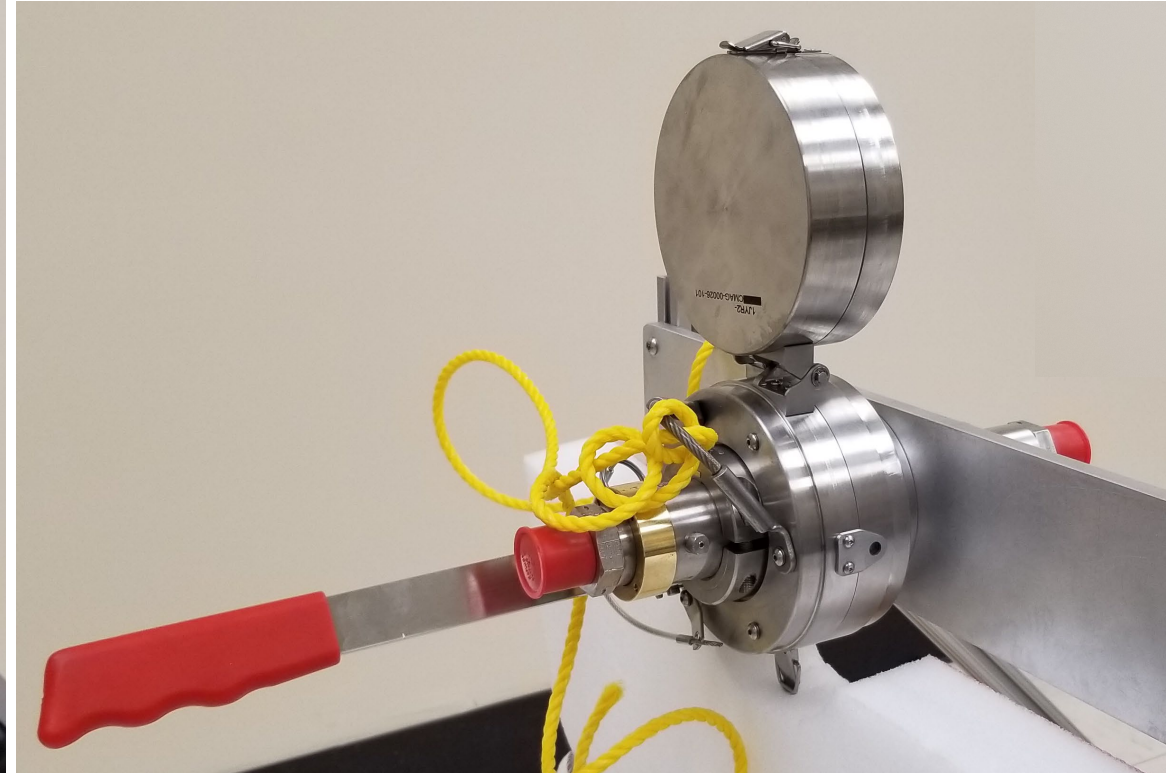
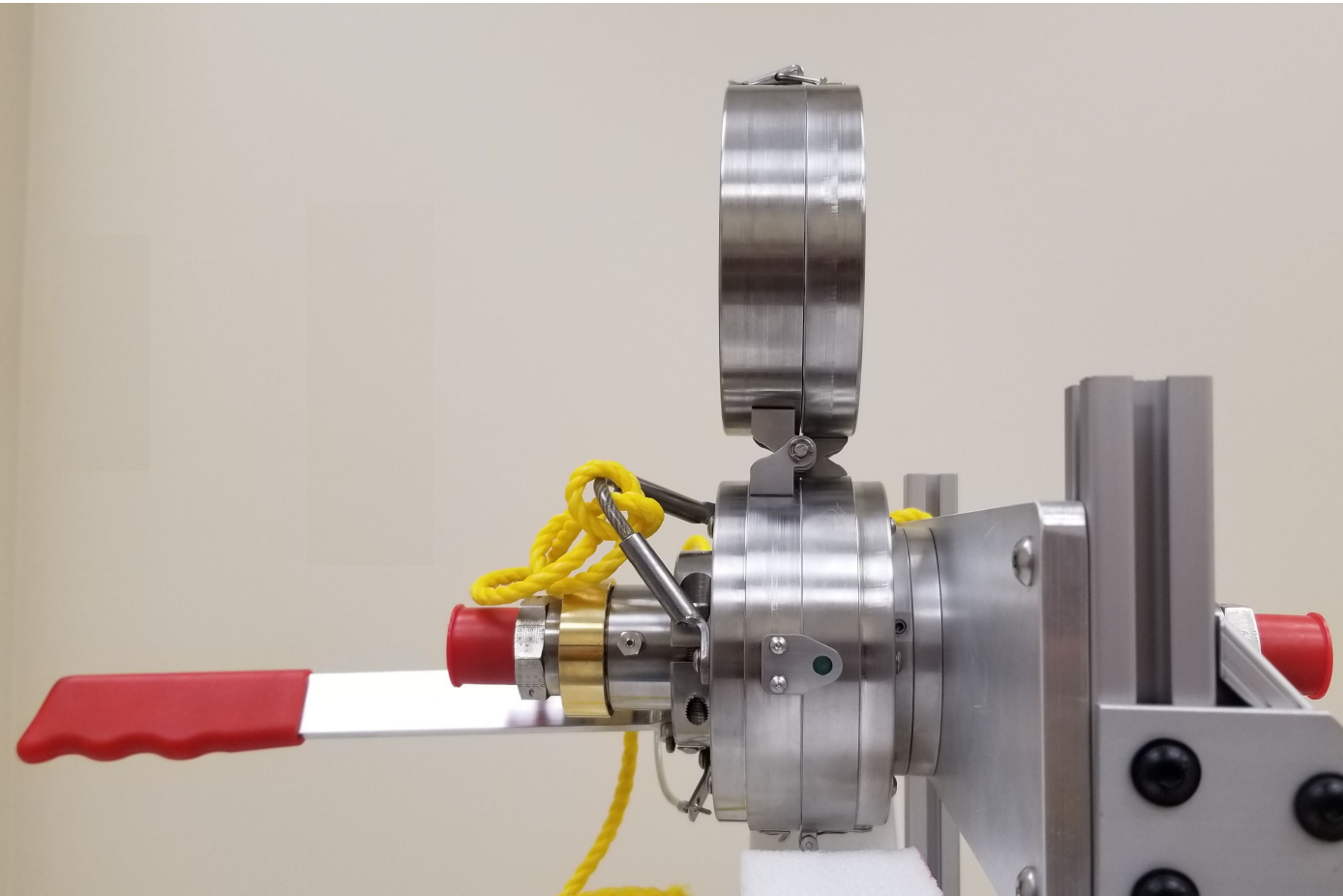




Demate



Functional Evaluation



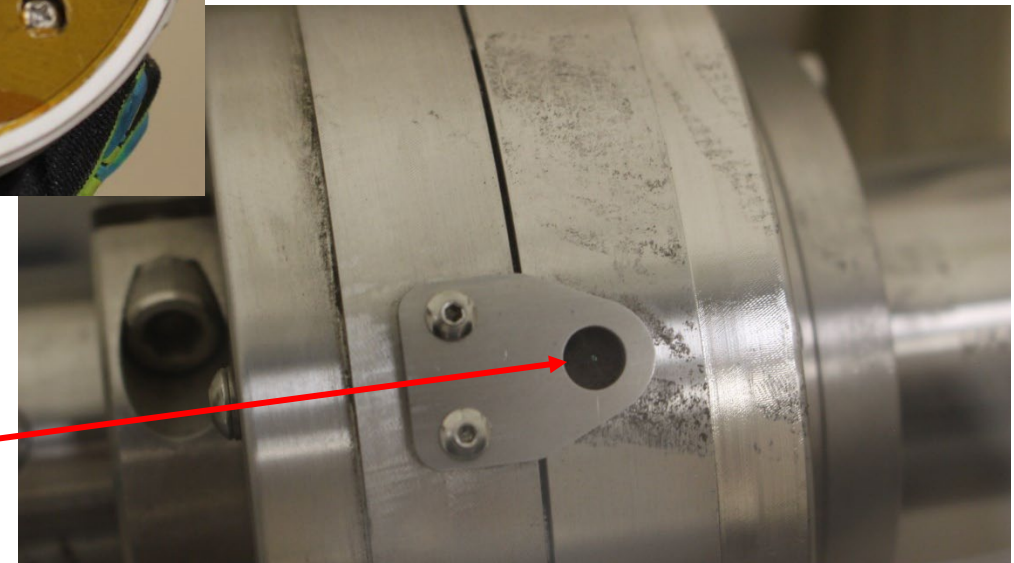
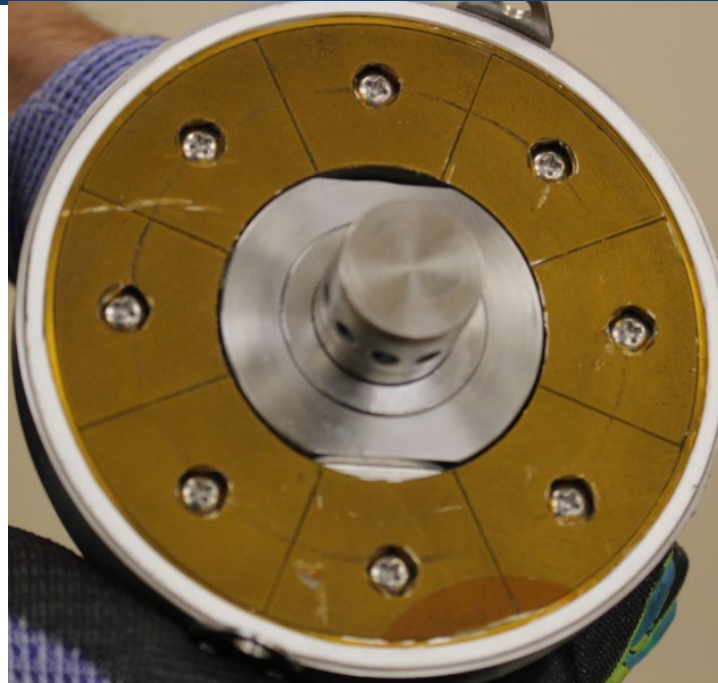
Dust Intrusion Test

- Objective:
 - Examine areas of potential dust intrusion into coupler while fully mated
 - Evaluate seals
- Tested in Dust Environment Low-fidelity Test Apparatus (DELTA) glovebox with JSC-1A lunar regolith simulant
 - Tested without dust caps due to space limitations
- Test location: Armstrong Flight Research Center



Dust Intrusion Test

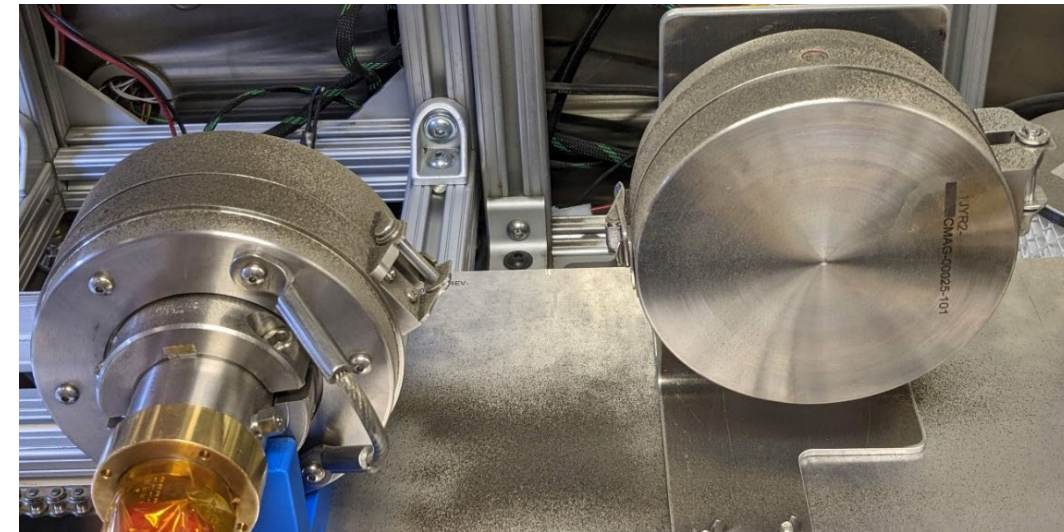
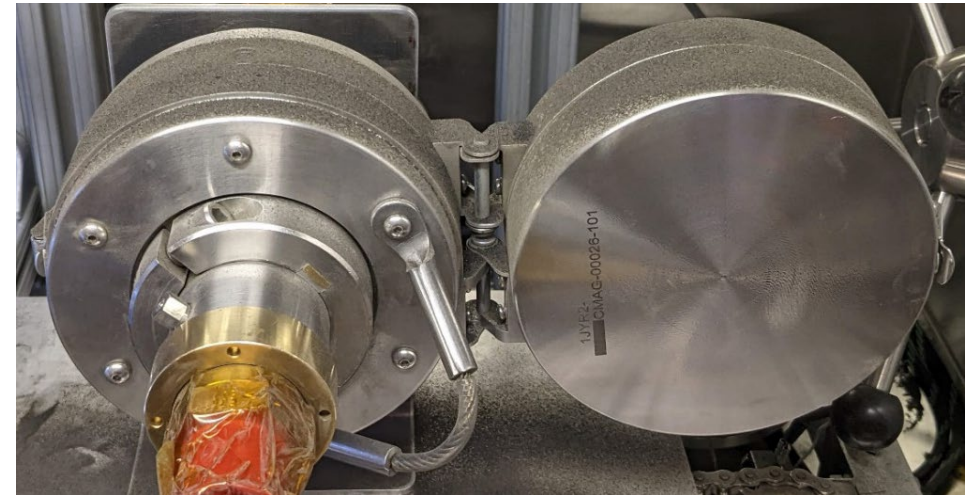
- No dust intrusion into fluid flow path
- Minimal dust intrusion onto seals and magnet faces
- Dust trapped in visual indicator may have intruded during demate



Visual indicator
clogged with dust

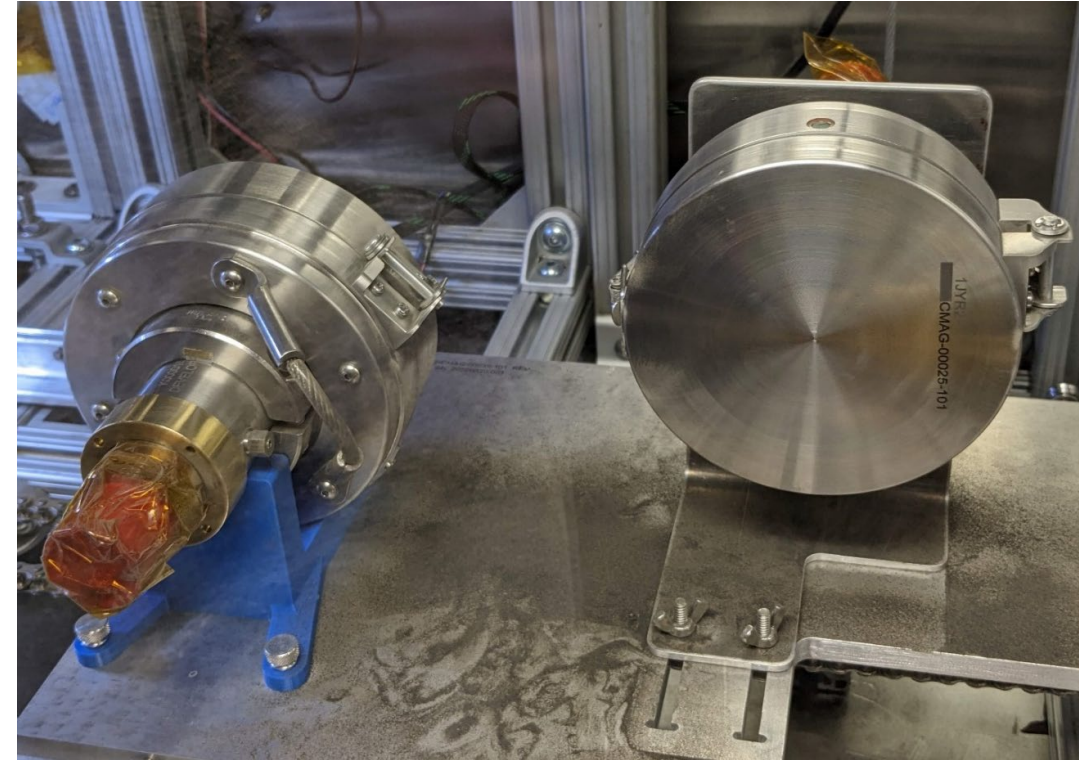
Dust Exposure Test

- Objective:
 - Evaluate potential dust intrusion into coupler during multiple mating/demating cycles
- Tested in Universal Dust Deposition System (UDDS) with JSC-1A lunar regolith simulant
 - Dust deposited during various stages of the mating and demating processes
- Test location: Glenn Research Center



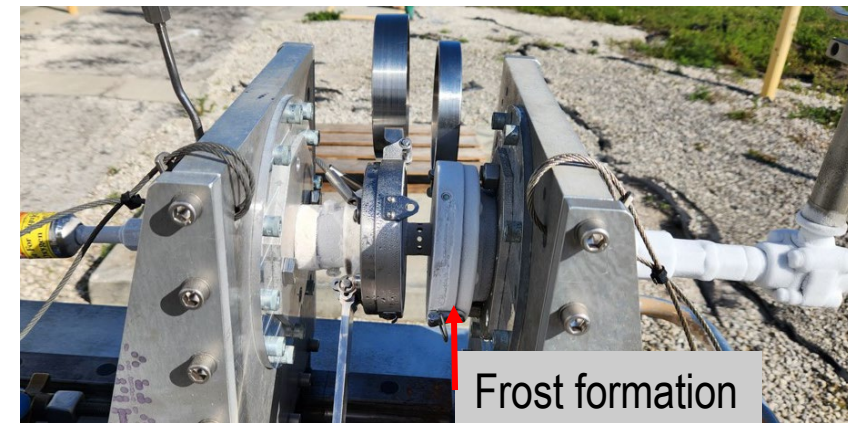
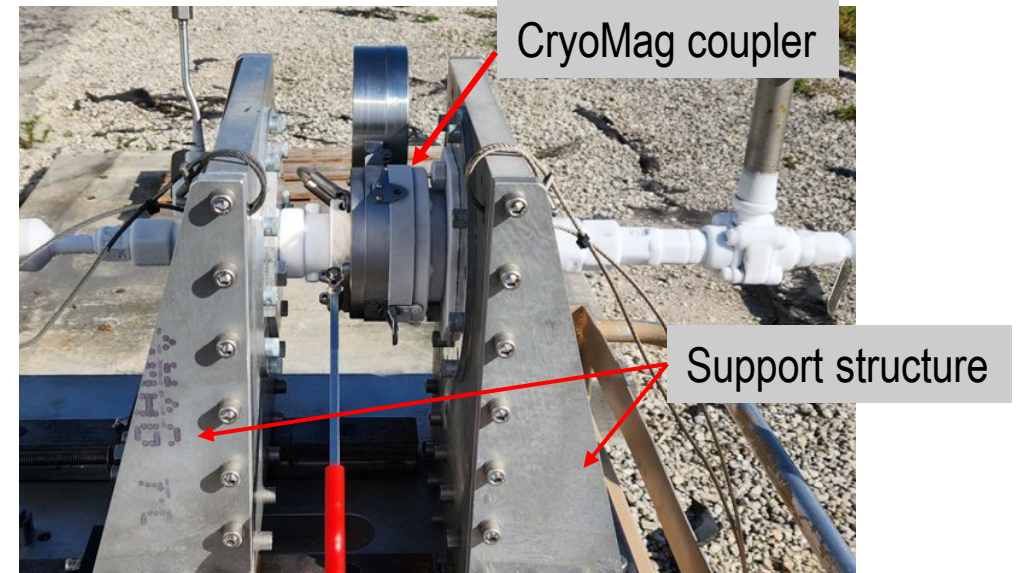
Dust Exposure Test

- No dust intrusion into fluid flow path
- More dust intrusion onto seals and magnet faces than observed in previous test
 - No impact to mating ability
- No significant dust adherence to outer surface



Cryogenic Flow Test

- Objective:
 - Demonstrate flow of LN₂ through coupler without leakage
- Mated using magnetic subsystem with support structure for safety
- LN₂ flow at >14 L/min, 72 psi with no visible leakage
- Test location: Kennedy Space Center



Conclusions

- CryoMag coupler has completed system-level testing and analysis to prove capabilities (to TRL 4) and is ready for further environmental testing and/or integration into cryogenic fluid system
 - Survival across lunar equatorial temperature range and normal operations
 - Minor design modifications should enable survival at lunar polar minimum temperature
 - No dust intrusion into fluid flow path
 - LN₂ flow at >14 L/min, 72 psi with no visible leakage
 - Proved feasibility of concept, not yet optimized for weight, human factors, etc.
- Different magnet patterns assessed for human usability
 - Soft assist pattern determined best of the three for human use
 - Fully automatic pattern may be useful for automated rover systems



Points of Contact

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- Paul Bean: paul.bean@nasa.gov

➤ Related papers:

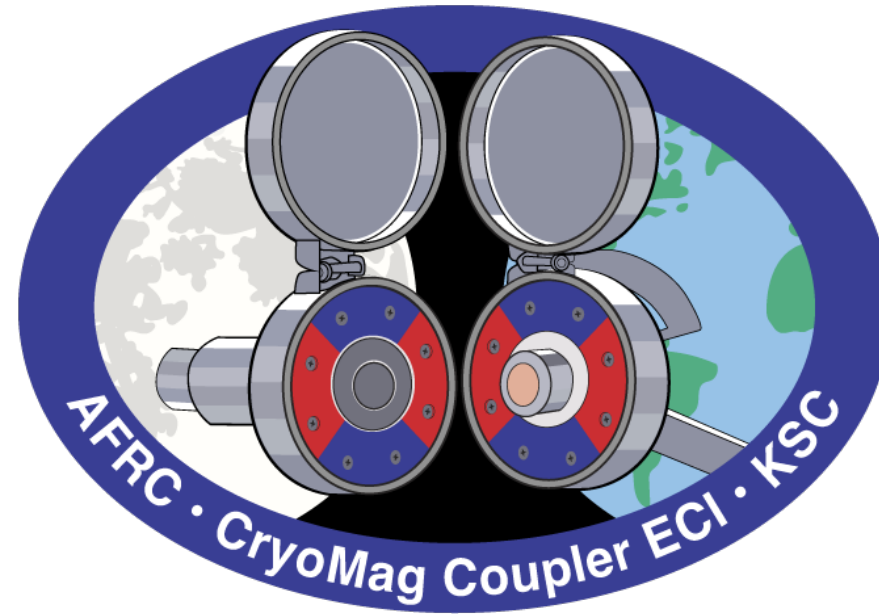
- Bean, P., and Heersema, N., Holguin, A., Lopez, J., and Stebbins, S., “Magnetic Subsystem Design and Testing for the NASA Magnetic Latching Cryogenic Coupler,” AIAA Scitech 2023
- Manley, W., and Heersema, N., “Low Force Disconnect Cryogenic Coupler Design Development,” AIAA Scitech 2023
- Stebbins, S., and Heersema, N., “Low-cost Testing in Representative Lunar Regolith Environment,” AIAA Scitech 2023

➤ Interested in the technology?

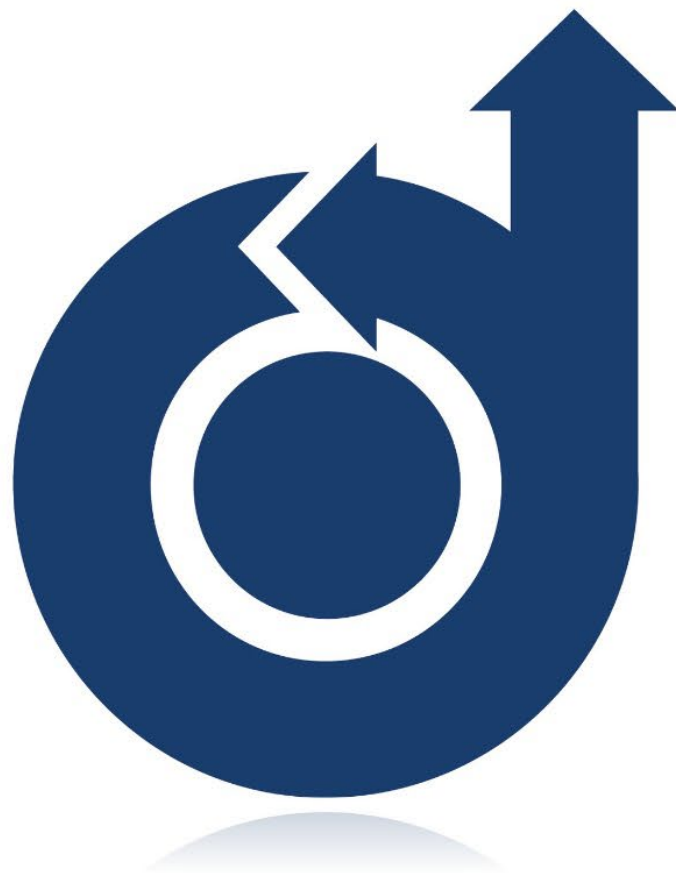
- Technology Transfer Office, NASA AFRC Edwards, CA 93523
AFRC-TTO@mail.nasa.gov
 - Patent number: 63431416

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 - Gabor Tamasy and the staff of the Kennedy Space Center Cryogenic Test Laboratory



Questions?



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