Space Technology Mission Directorate

Game Changing Development Program

Jenna Fothergill | Samuel (Adam) Howard | Dust Tolerant Mechanisms (DMDev) | Annual Review Presentation | 09.18.2023

Project Overview

Technology Development Needs Addressed by Project		
STMD	Fulfills critical performance testing and dust mitigation strategies for rotary bearings which are used in a wide-range of applications.	TX4.2,TX7.2, TX6.1, TX6.2, TX12.3
MDECE (STMD)	Test rig and capabilities may be used to test bearing performance for the magnetically-geared motor	

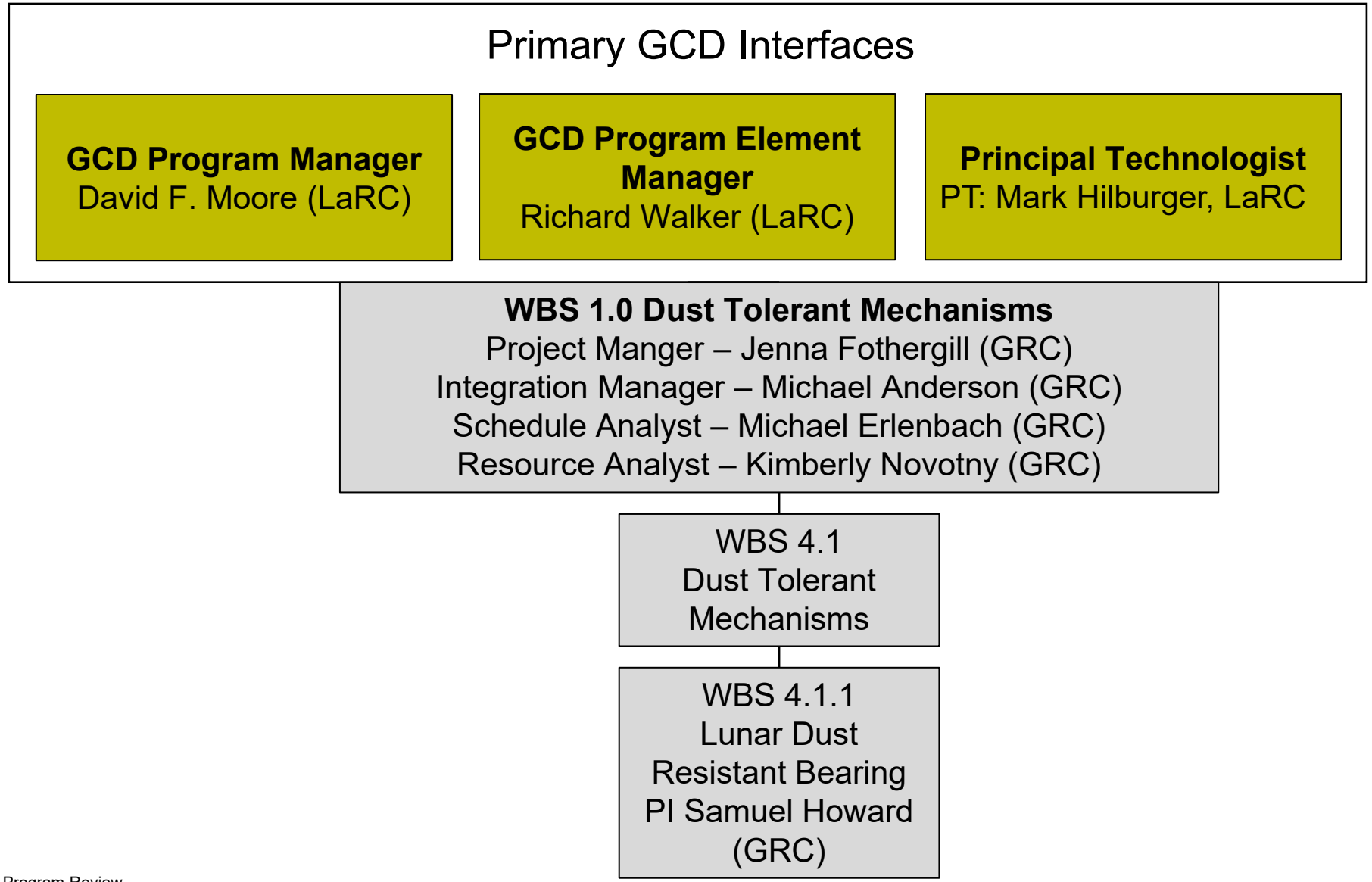
Project Goals	
Goal #1	Develop and demonstrate in a simulated lunar environment dust tolerant space mechanism bearings.

Project Objectives	
Objective #1	Conduct performance testing of (grease-packed) space mechanism bearings using COTS and best practice sealing technologies in lunar simulant and quantify the degree of dust infiltration during testing.
Objective #2	Identify advanced technologies and strategies to reduce dust infiltration and/or increase life expectancy of space mechanism bearings in the presence of lunar dust.
Objective #3	Conduct performance testing of advanced technologies/strategies for lunar dust resistant space mechanism bearings in lunar simulant and quantify the degree of dust infiltration during testing.
Objective #4*	~~Conduct performance testing of advanced technologies/strategies for lunar dust resistant space mechanism bearings in relevant lunar surface environment and quantify the degree of dust infiltration during testing.~~

Goals and Objectives from draft project plan

*Objective 4 terminated due to lack of funding in FY24

Team Members / Project Org Slide

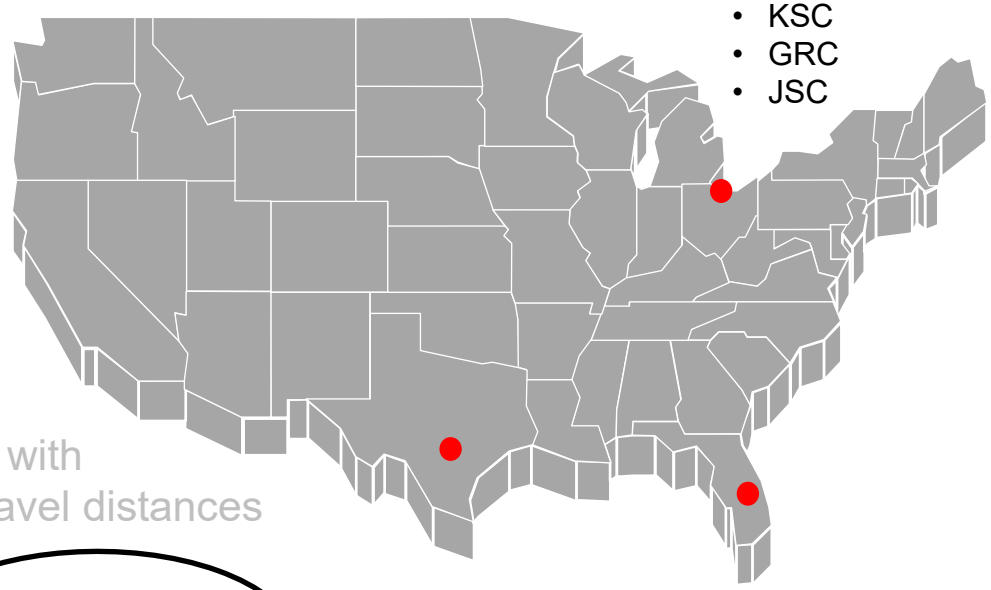


Collaborations & Partnerships

- Infusion/transition plan
  - Target applications
    - Lunar dust resistant bearings:
      - EVA Suit, Pumps, Motors, Gearboxes, Mobility Systems, Robots, and Prospecting and Extracting equipment for ISRU
    - Rotary seals:
      - Novel designs create custom test equipment
      - Increase lifetimes of sensitive mechanical joints and bearings with novel rotary seals as demanded for vehicles like LTV (must travel distances (11,000km) ~550x farther than previous efforts)

NASA Centers

- KSC
- GRC
- JSC

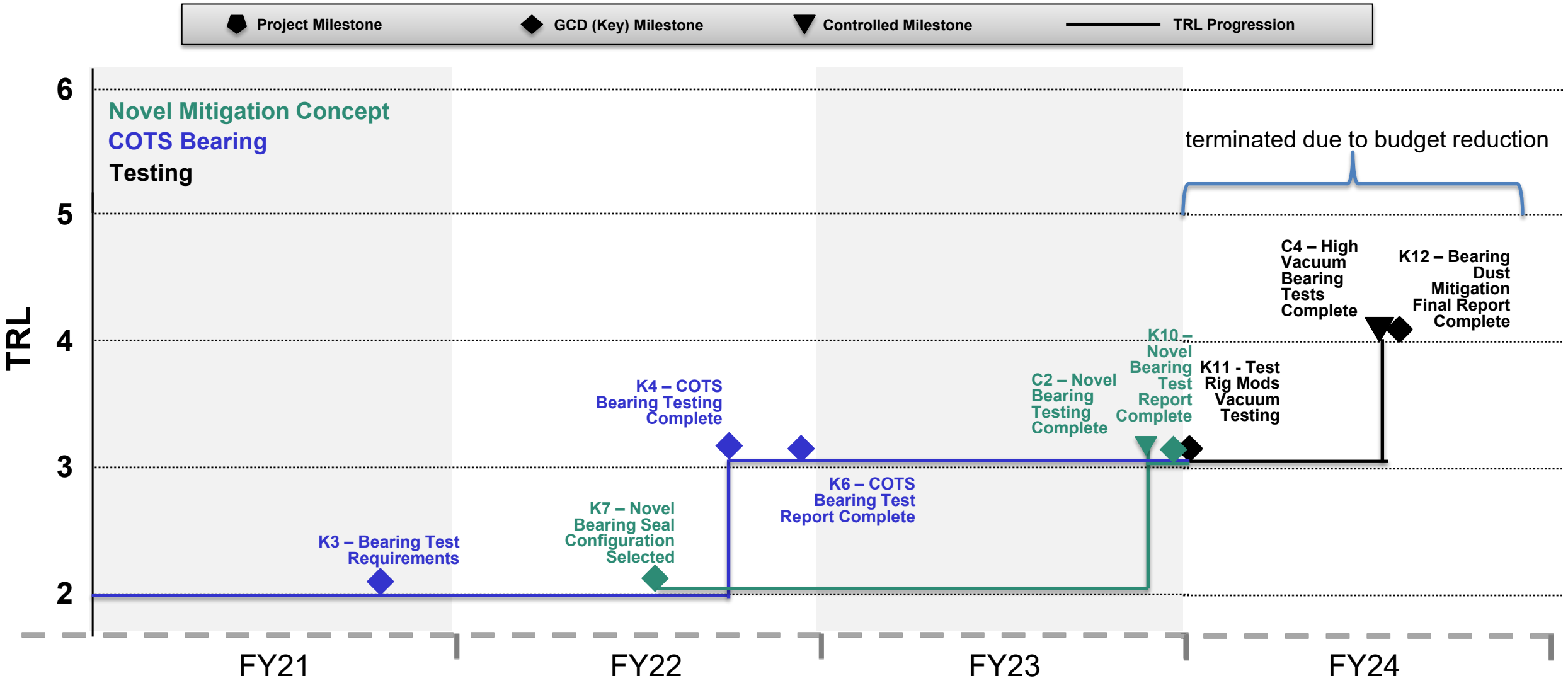


Rotary seal work paused due to budget reductions

  - NASA missions impacted
    - The Moon, Mars, Others Inside the Solar System, Foundational Knowledge, Artemis, Volatiles Investigating Polar Exploration Rover (VIPER), Lunar Terrain Vehicle (LTV), Exploration Extravehicular Mobility Unit (xEMU), Lunar Surface Manipulation System (LSMS), Robotic Excavation, Extravehicular Activity (EVA), Gateway, Ascent/Descent Elements, Habitats, Lunar Crew Module, Robotic Systems

DM Dev: Dust Tolerant Mechanisms

TRL Lifecycle

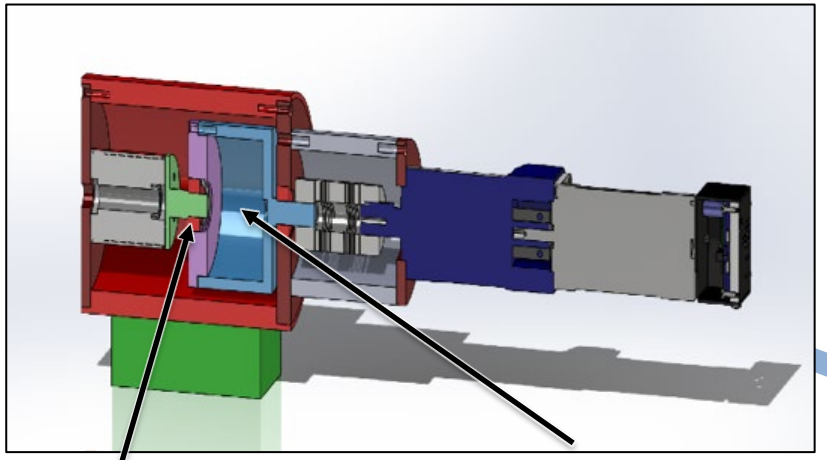


*Combined vacuum testing terminated due to budget reduction

Accomplishments

- Summary of Major Accomplishments over the past 12 Months:
  - Bearing test rig designed and built at GRC for exposing bearings to lunar simulant was permanently installed and utilized for testing of bearings and seals exposed to simulant.
  - Major objective of this task (C2 Milestone - Novel Bearing Testing) completed in August 2023.
    - Investigate/assess advanced strategies to mitigate dust infiltration and damage in bearings.
  - Preparations for future testing in representative extreme environments (cryogenic temperatures and hard vacuum) have begun for potential infusion into follow-on programs.

Bearing Test Rig Section View

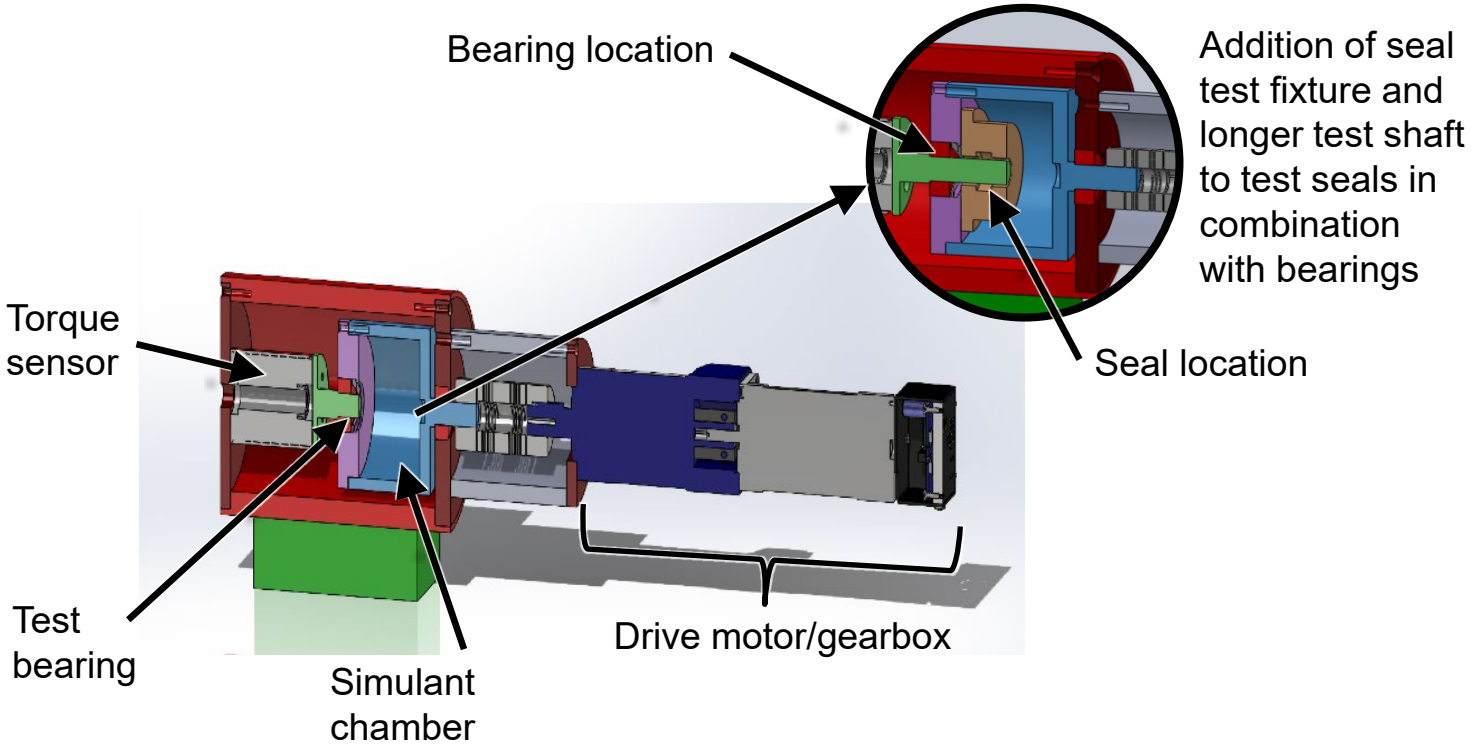


Bearing Test Rig In Lab at GRC

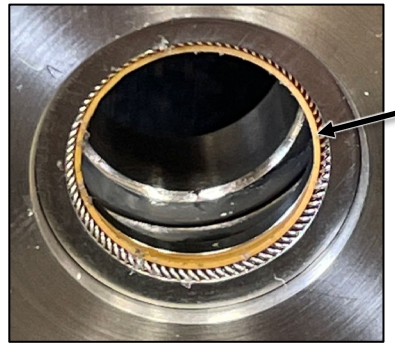
- Bearings/Seals can be tested to millions of cycles while exposed to simulants in a realistic manner.
- Horizontal and Vertical configurations are possible to vary the severity of exposure.

Accomplishments

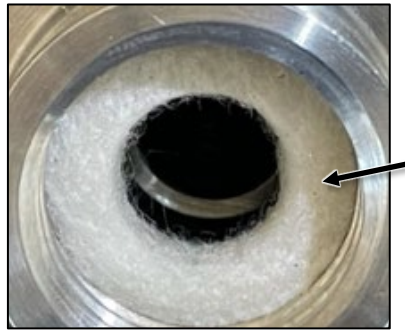
- Summary of Major Accomplishments over the past 12 Months:
  - Test rig was modified to enable testing of various bearing + seal configurations with dust exposure.
  - Matrix of test configurations completed includes:
    - COTS Bearings (Prior Year)
    - COTS bearings with various additional external seals, NiTi bearings (NASA developed material) (Current Year)



Example Seals:



PTFE (Teflon) Seal



Felt (Nomex) Seal

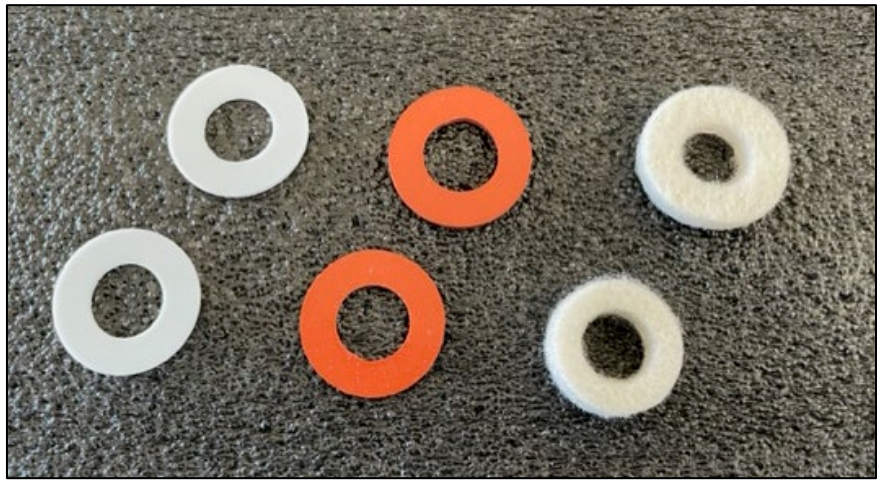
Accomplishments

- Additional Accomplishments
  - Commissioned a new CNC Knife-based cutting machine to fabricate candidate mitigation test articles (seals and shields).
  - Enables in-house manufacturing of test pieces difficult to procure due to custom nature / one-off quantities necessary for testing of candidate designs.

Computer Numerical Control (CNC)
Oscillating Tangential Knife

Enables Precision cutting of difficult materials

Example Test Articles



Thin PTFE Sheet Goods

Rubber Sheet Goods

Nomex Felt Sheet Goods

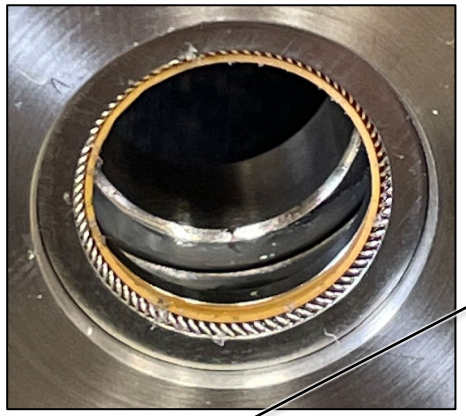
Typical Test Hardware

Typical Mitigation Testing Hardware Appearance

"Dusty" Side of Seal Before Testing

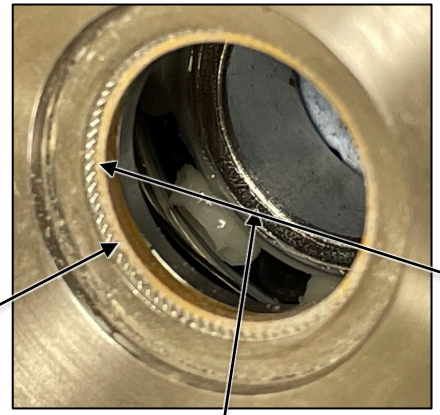
"Dusty" Side of Seal After Testing

Pre-Test Seal:



PTFE (Teflon) Seal tan color

Post-Test Seal:



Test Bearing Behind Seal

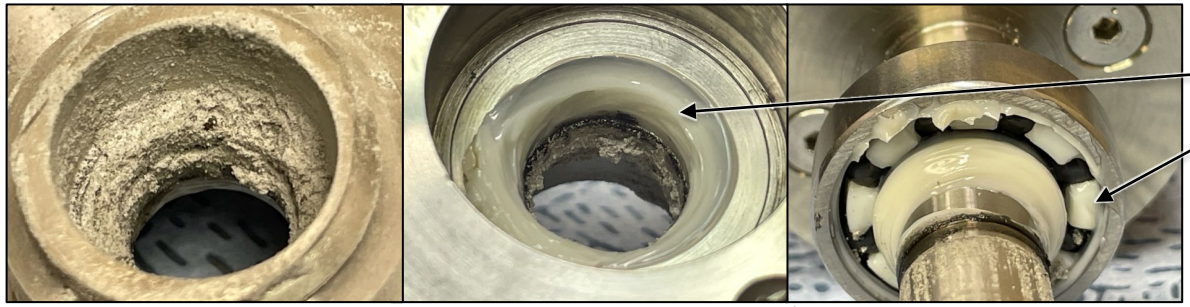
Test Metrics Include:

- Torque
- Wear
- Grease cleanliness
- Bearing surface topography

Simulant packs into cavities

Illustration of "effectiveness" of one seal configuration

Teflon external seal configuration (open bearing, vertical orientation, ambient environment)



"Dirty" Side ⇨ "Clean" Side ⇨ Bearing: post test

Bearing and Grease remain clean after very aggressive exposure test to 1,000,000 revolutions

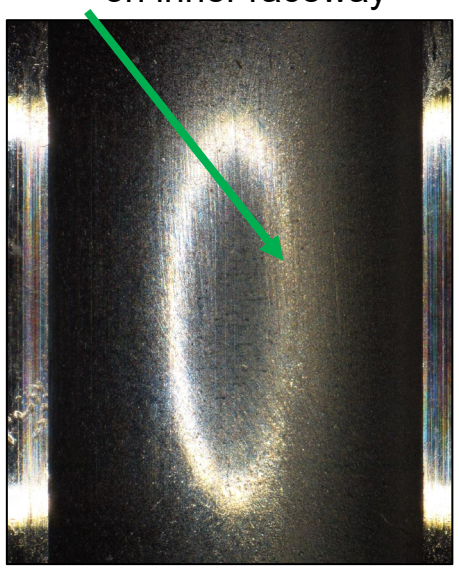
Remaining Work

- Metrology work to quantify bearing damage from dust and reporting are in progress.
  - Imaging and surface profiling currently underway.
  - Relative effectiveness of different dust mitigation strategies as determined by torque measurements and surface damage to be documented in final report (end of FY23).

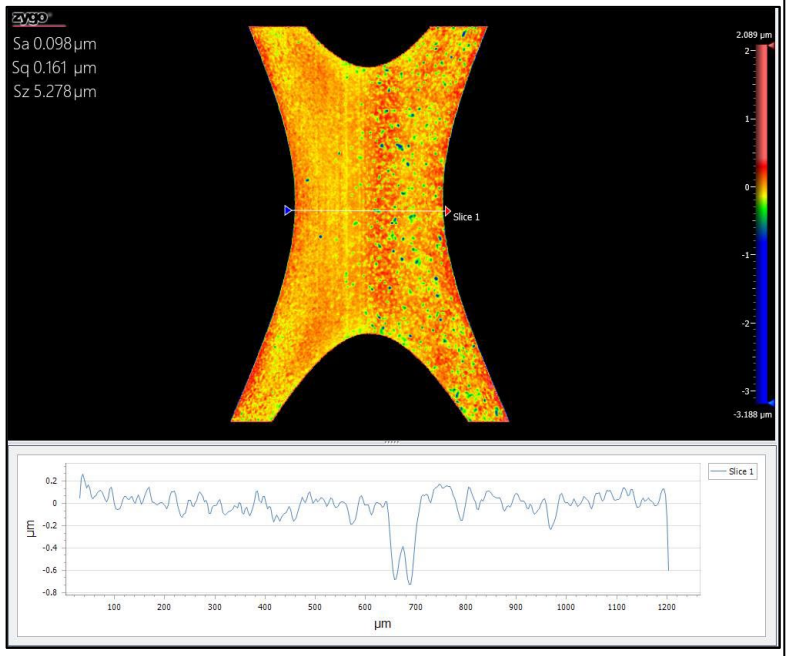
Sample Microscope Images of Bearing After Dust Exposure

Photograph of contaminated grease inside bearing

Photograph of damage (denting) on inner raceway



Corresponding 3-D Profilometer Image



- Image stacking for high res. depth measurements with large focal length
- Individual dents can be identified
- Surface statistics (roughness) can be measured
- 2-D trace also possible

Summary of Preliminary Findings

- Rolling Element Bearings are fairly robust against lunar simulant.
  - Almost all tested bearings and bearing/seal configurations survived a minimum of 1,000,000 revolutions (eg. on the order of 3-4 KM range for an LRV-size rover wheel bearing).
- In general, seals can reduce damage and torque fluctuations, but “cost” more in power loss/efficiency.
  - Seal effectiveness is not always directly proportional to efficiency
- Lubricants themselves can be effective barriers to dust intrusion.
- Additional testing should be conducted in lunar thermal and vacuum conditions for a fully representative lunar environment.
- The new test rig performs well, and exposes bearings in a realistic manner with a range of exposure severity.

Project Assessment Summary

Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – Utilizing newly procured machinery and test apparatuses - Cutting machine for sheet goods is being utilized for material preparation. Novel seal testing started in humidity-controlled dusty chamber Cost – No issues Schedule – Schedule for Dust Resistant Bearings has been shifted due to budget cuts in FY22 by 3-6 months Programmatic – No issues
Annual					Technical – Project made steady progress testing a wide range of COTS and novel bearing concepts – strong insights and useful results will be published in a TM Cost – No cost issues Schedule – No schedule issues Programmatic – Project terminated early – did not meet TRL goal due to lack of environmental testing which was planned for FY24

Plans Forward and Transition / Infusion Plan

- MDECE (GCD project) will be using some of the bearing expertise and testing capability developed by this project.
- NASA missions requiring with bearing exposure to lunar dust include: Exploration Rover (VIPER), Lunar Terrain Vehicle (LTV), Exploration Extravehicular Mobility Unit (xEMU), Lunar Surface Manipulation System (LSMS), Robotic Excavation, Extravehicular Activity (EVA), Gateway, Ascent/Descent Elements, Habitats, Lunar Crew Module, Robotic Systems

Education/Public Outreach

EPO Involvement

- 2023 STLE Annual Meeting and Exhibition in Long Beach, CA May 21-25. As an Associate Editor for STLE's journal, Tribology Transactions, attend editors annual face-to-face meeting and attend technical sessions in the tribology community.

- Plan to present/publish final results to 2024 STLE Annual Meeting – Abstract due Nov. 2023

EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead	
2024 STLE Annual Meeting	2024

Summary

- Soft Sheet goods cutting with Computer Numerical Control (CNC) Oscillating Tangential Knife
- Bearing damage analysis and assessment methodology
- The new test rig performs well, and exposes bearings in a realistic manner with a range of exposure severity