Innovative Technology and Product Development

Microgravity Demonstration of a Hybrid Screen Channel Liquid Acquisition Device for Transfer of Cryogenic Fluids

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Dr. Lucas E. O’Neill, Creare LLC
Dr. Thomas M. Conboy, Creare LLC
Dr. Mark V. Zagarola, Creare LLC
Dr. Jason W. Hartwig, NASA Glenn Research Center

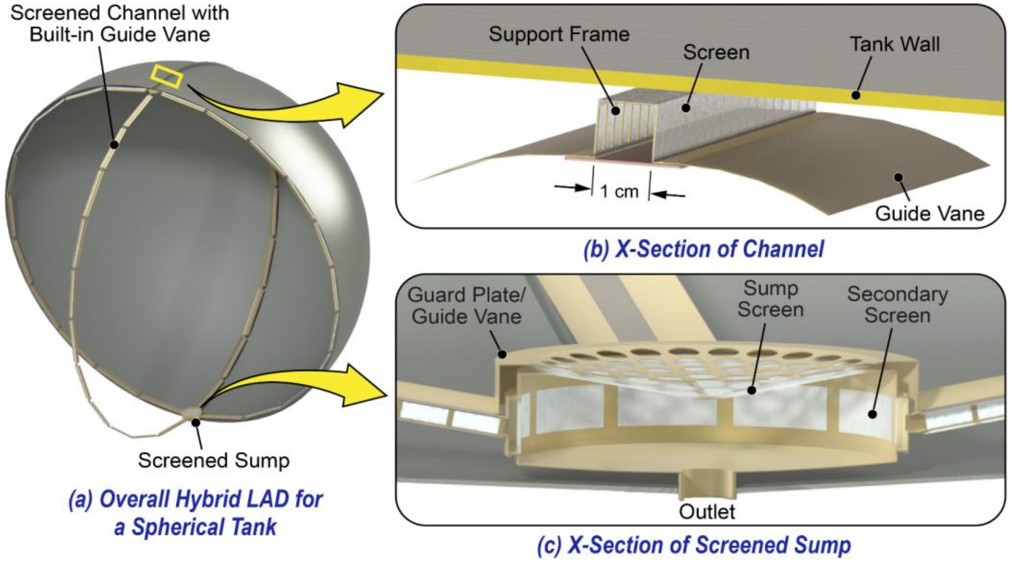
Background

- **Refueling spacecraft in orbit offers tremendous benefits for increased spacecraft payload capacity and reduced launch cost**
- **Acquiring vapor-free liquid cryogenic propellants from supply tanks and transferring to receiving tanks is challenging:**
  - **Liquid, pressurant gas are not easily segregated in microgravity environment**
    - » **Phase separators must be reliable, have low pressure drop, high turn-down ratio**
  - **Low surface tension of propellants, cryogenic operating temperatures, large tank internal volumes**
- **Among PMD types, screen channel LADs offer higher resistance to gas ingestion under high demand flow, adverse accelerations**
  - **Currently no flight cryogenic screen channel devices**

Propellant production, storage, and transfer in-orbit is key to enabling the next generation of advanced space missions.

Creare's Hybrid LAD Technology

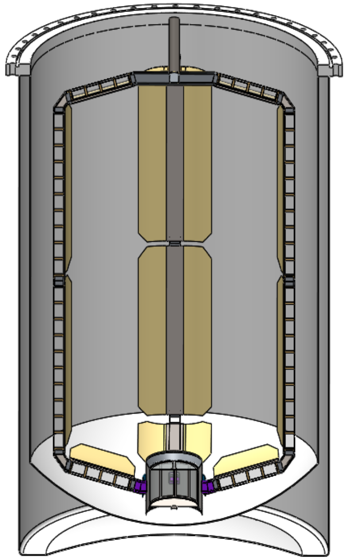
- **Based on laser welding of metal mesh screen and light-weight solid frame to form square screened ducts**
- **Four or more screened channels follow propellant tank contour**
- **Each screened channel has a baseplate that serves as a guide vane**
  - **Position liquid next to screened channel to redistribute liquid locally along channel length**
- **Screened sump located above the tank outlet**
  - **Screen channel outlets are connected to sump**
- **Synergistically combines screened channels, a screened sump, and guide vanes together to create a hybrid capillary structure**

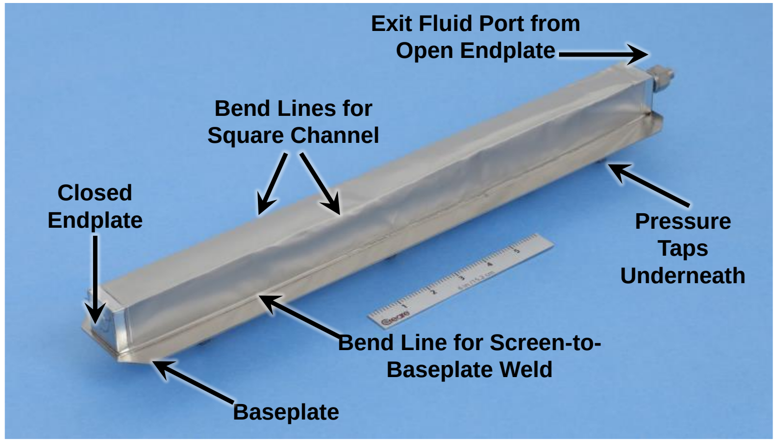


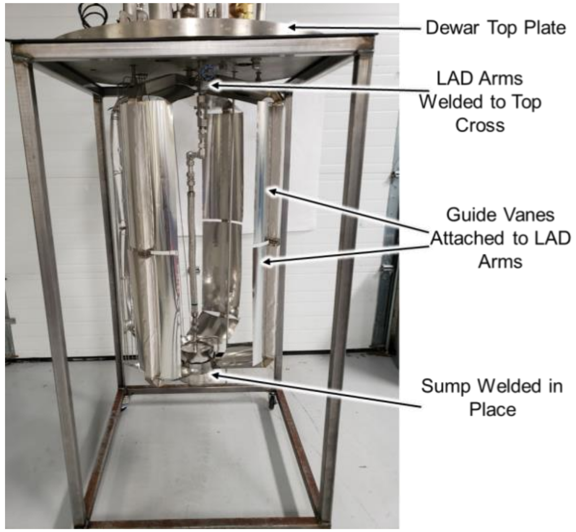
(a) Overall Hybrid LAD for a Spherical Tank

(b) X-Section of Channel

(c) X-Section of Screened Sump





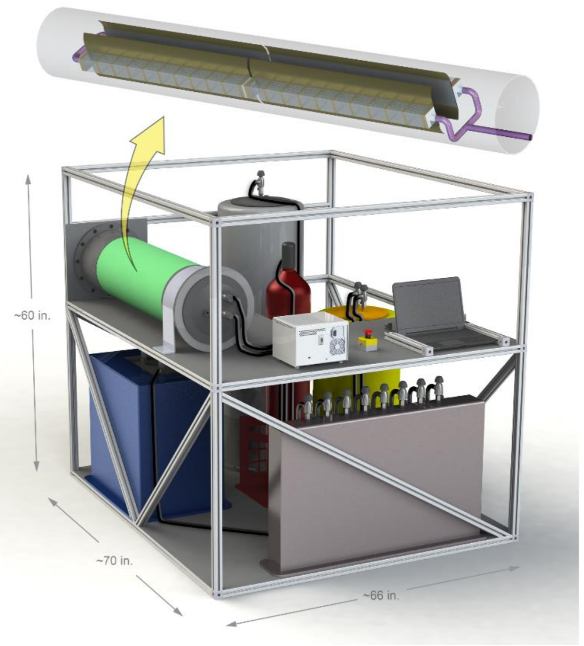


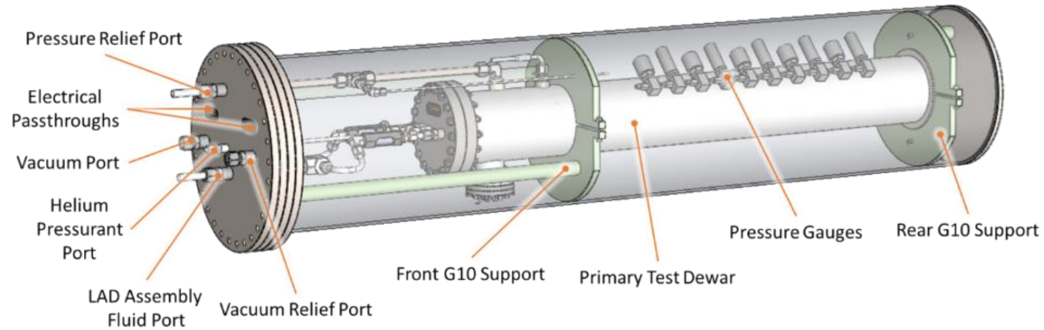
Creare's modular approach to LAD construction scales to different tank sizes and geometries.

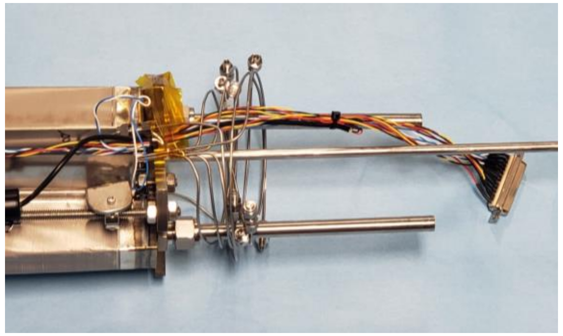
Microgravity Liquid Acquisition Integral DEmonstratioN (MAIDEN)

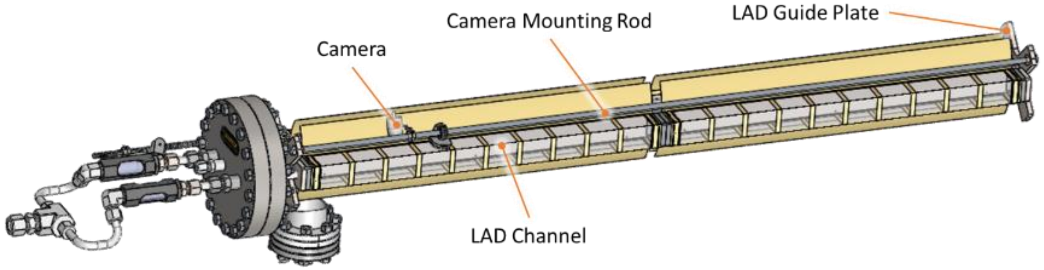
Objective: Demonstrate functionality of the Creare LAD for cryogenic fluid transfer in microgravity, including high expulsion efficiency,

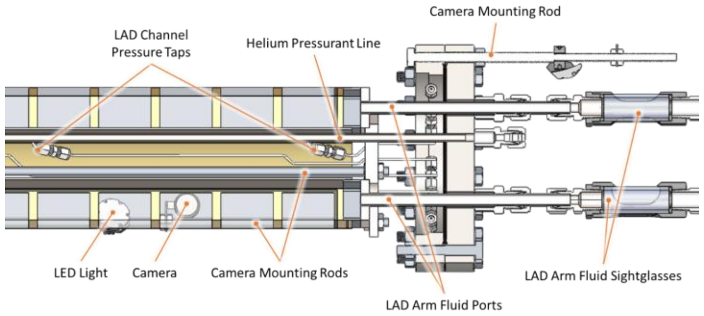
- **Demonstration in relevant environment raises TRL from 4 to 6**





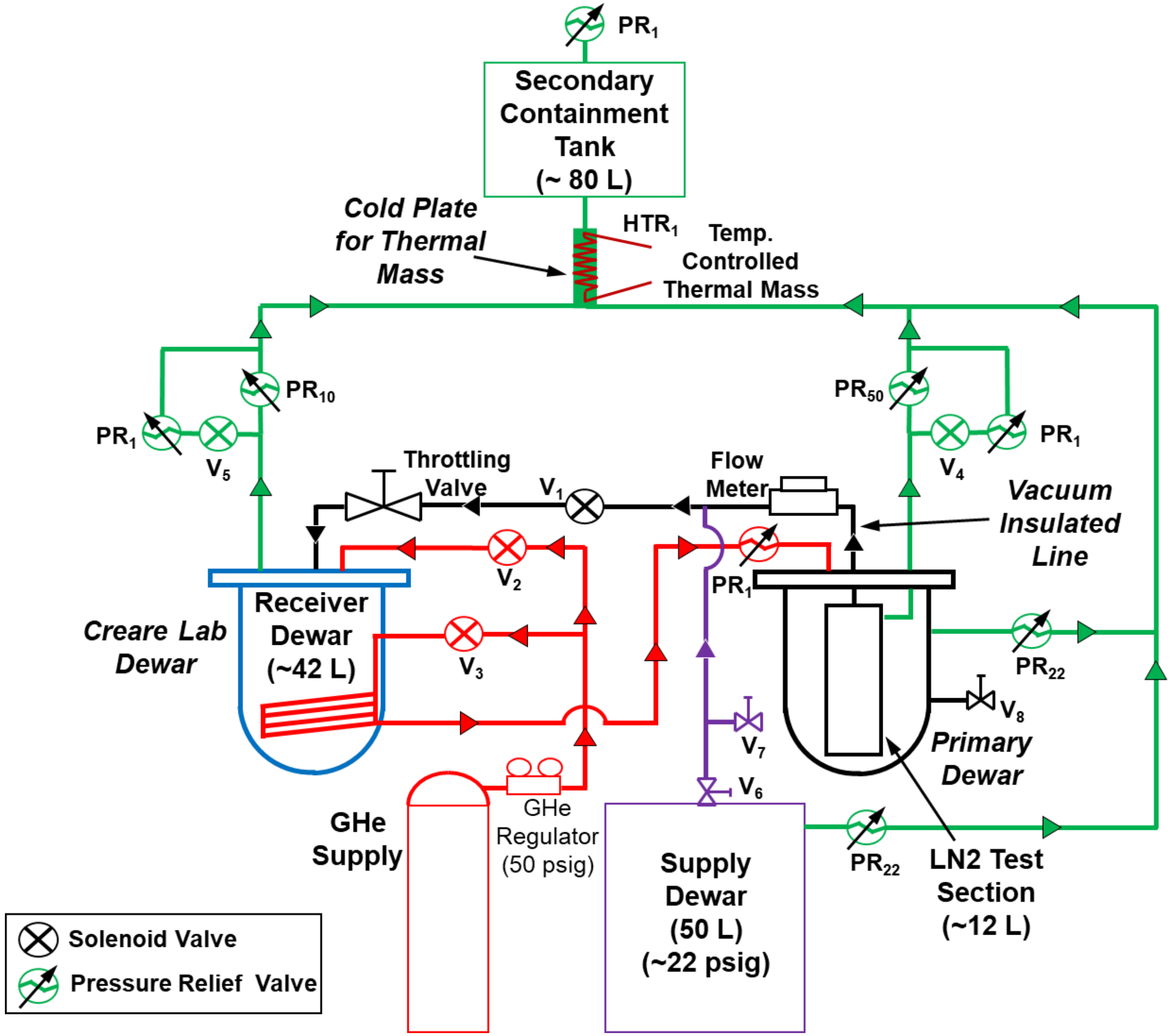






Our parabolic flight payload features two sets of 2" x 18" LAD sections plumbed in parallel inside a cylindrical vessel.

Concept of Operations

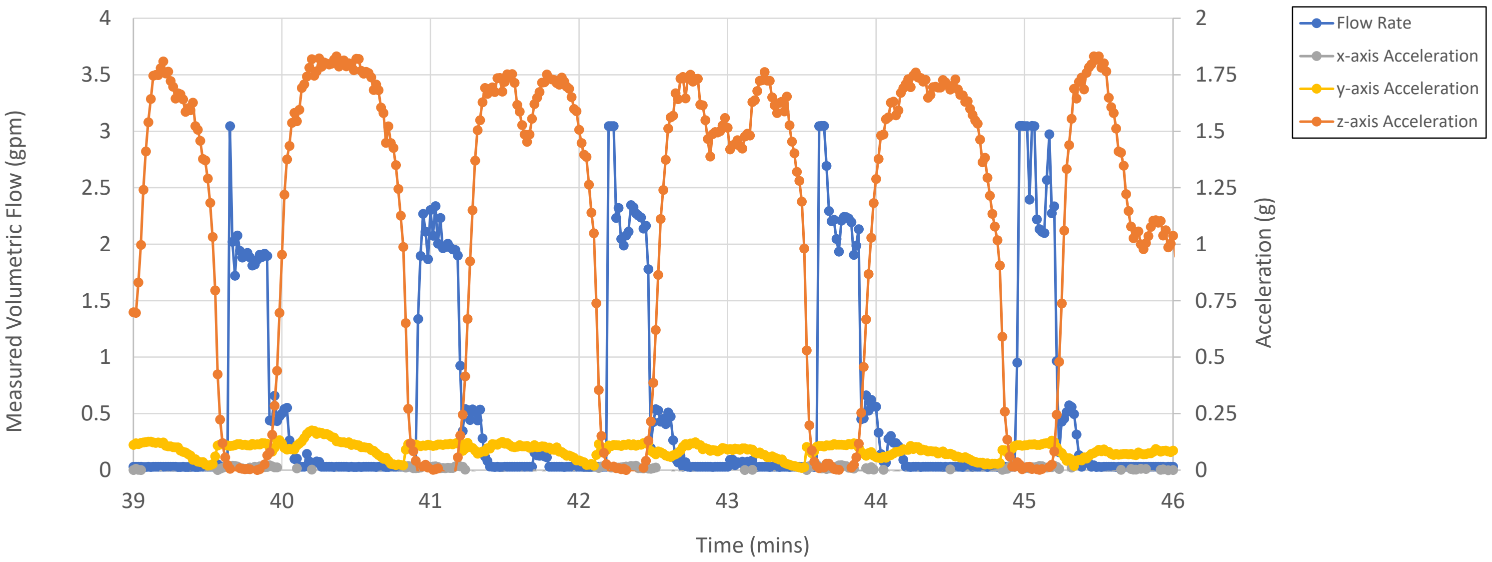


Our test facility measures LN2 flowrate, pressure differential across screened channels, liquid level within the primary dewar, and records video of flow through sight-glasses to verify LAD operation.

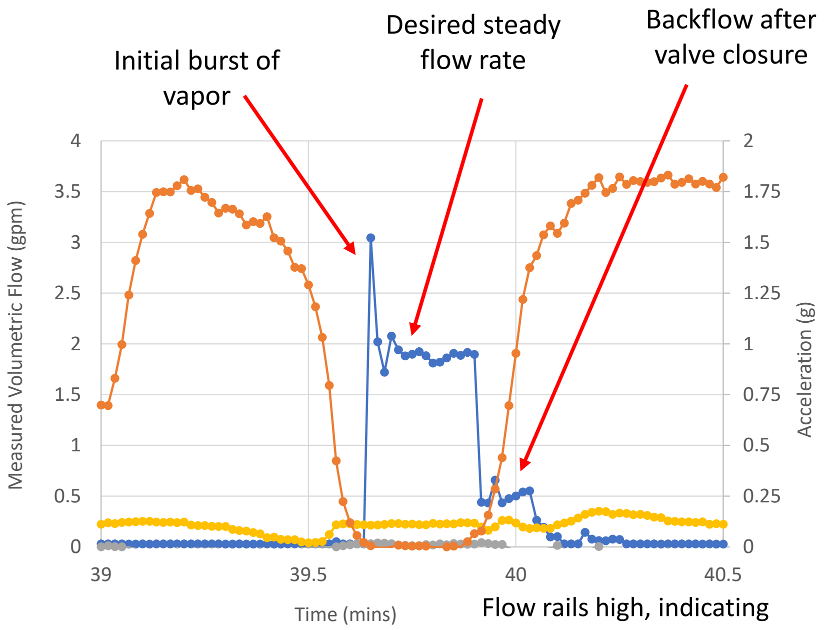
- **LN_2 flow from primary tube containing LAD to receiver tank driven by helium pressurant**
- **During transfer testing, helium (and vaporized LN_2) vented overboard**
  - **Heaters, secondary container used to ensure no cryogen is expelled**
  - **Can be enclosed during zero-g, vented during interim periods after LN2 settling**
- **Testing proceeds in 15–30 s bursts of zero-g, pauses when gravity restored**
- **LN_2 then driven back into primary tank from receiver tank using pressurant**
- **Testing repeated as time allows**
- **Supplementary LN_2 dewar to re-supply if needed**
- **Goal to fully drain primary dewar using Creare LAD over several successive zero-g cycles**
  - **Design of LAD prevents breakdown when gravity is intermittently restored**

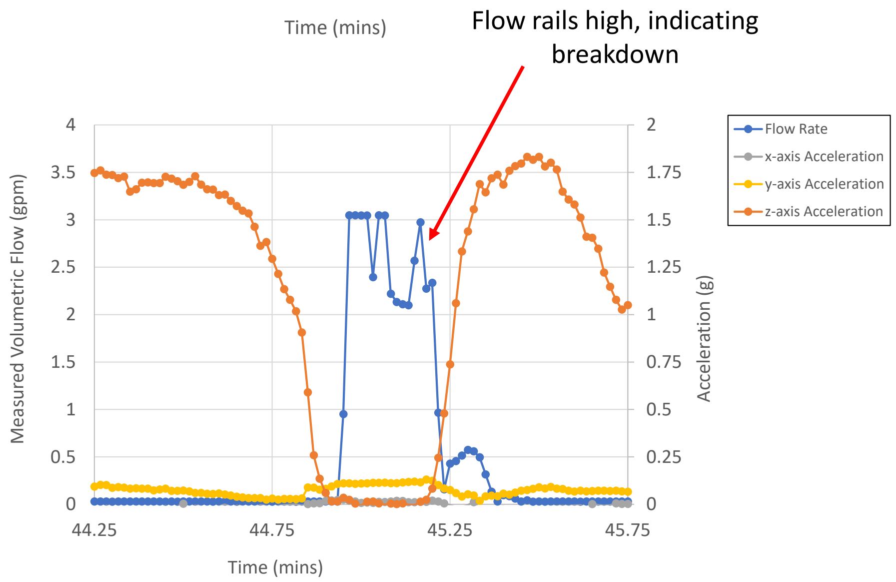
Experiment Execution

- **Transfer LN2 during successive micro-gravity periods**
  - **Solenoid valves used to start/stop flow**
  - **Accelerometer data informs when to test**
- **Monitor flowrate, pressure, and video data to determine when breakdown occurs**
- **Measure steady (1-g) liquid level after breakdown**
- **Reset for next transfer test**



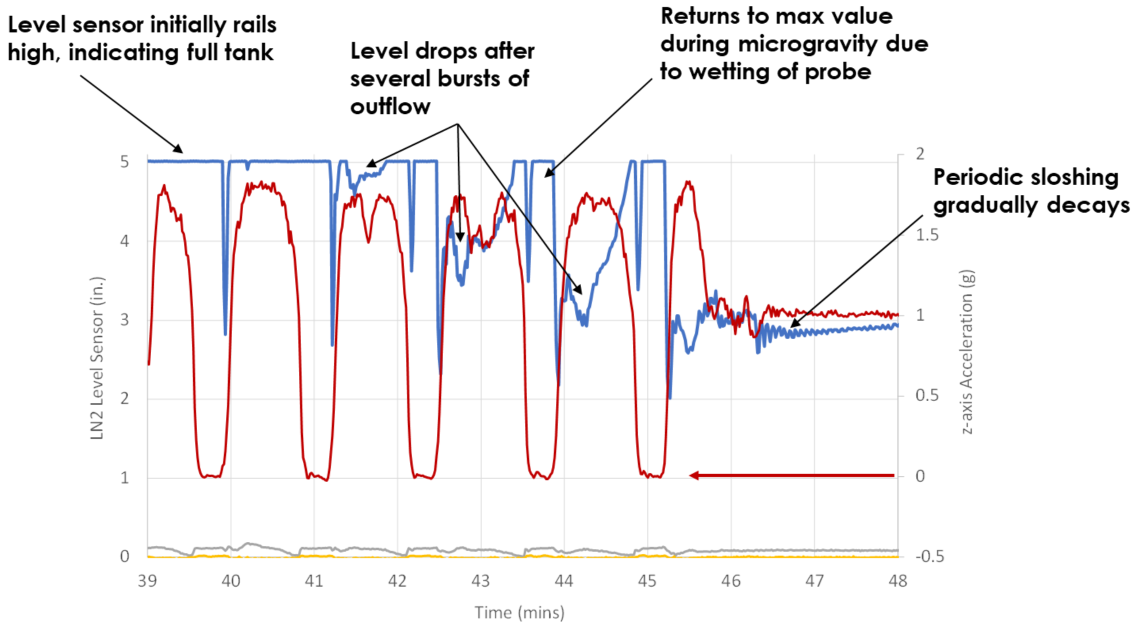
Five consecutive microgravity outflow events ending in breakdown.

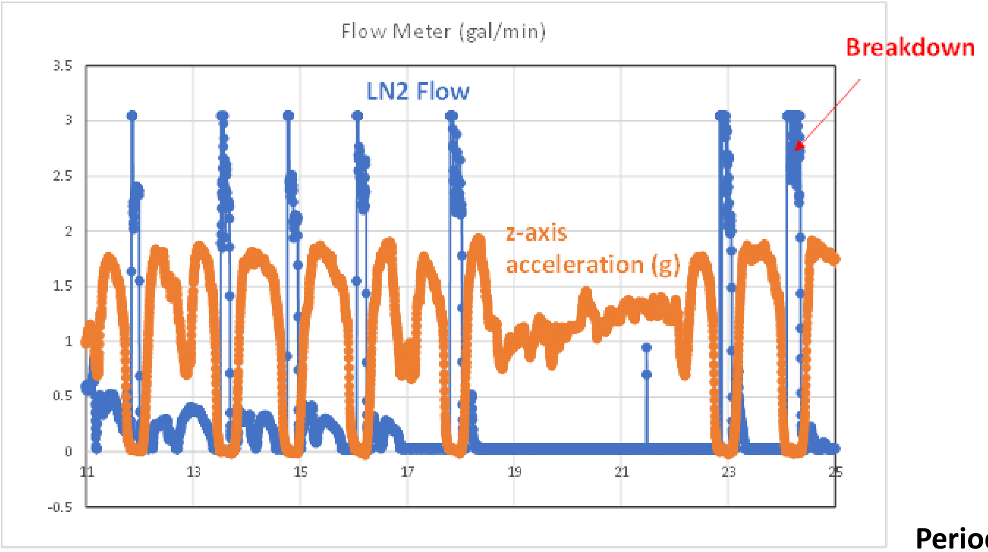


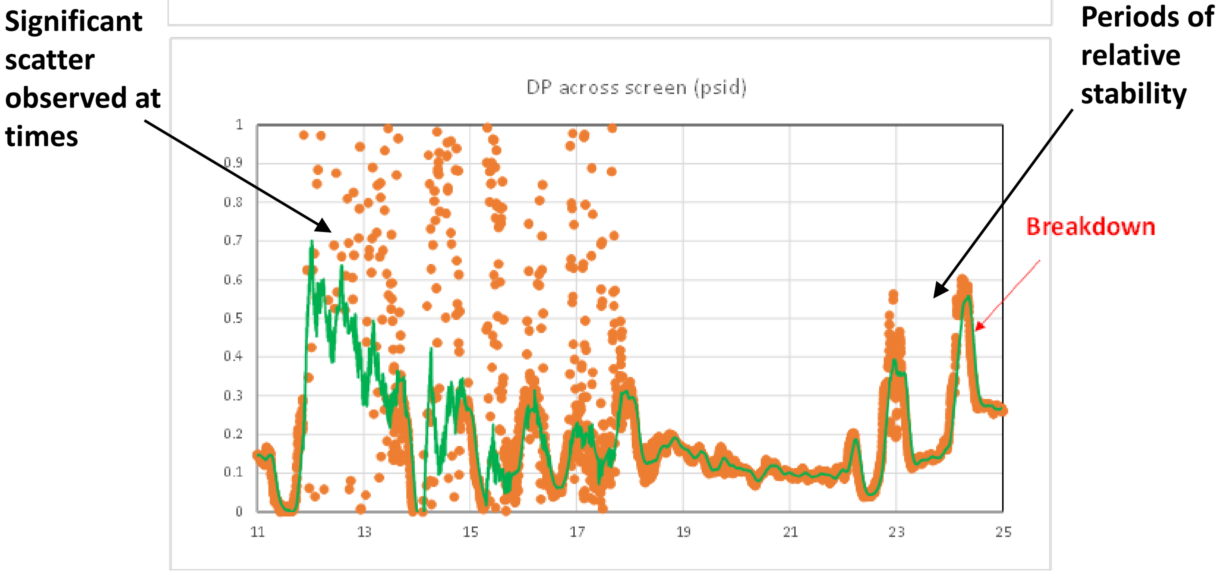


Pressure, Flow, and Liquid Level Measurements

- **Liquid level measurements have limited utility during microgravity**
  - **Important after breakdown for confirming liquid volume remaining**
- **Volumetric flowrate measurement is important for identifying breakdown**
- **Pressure was unreliable**



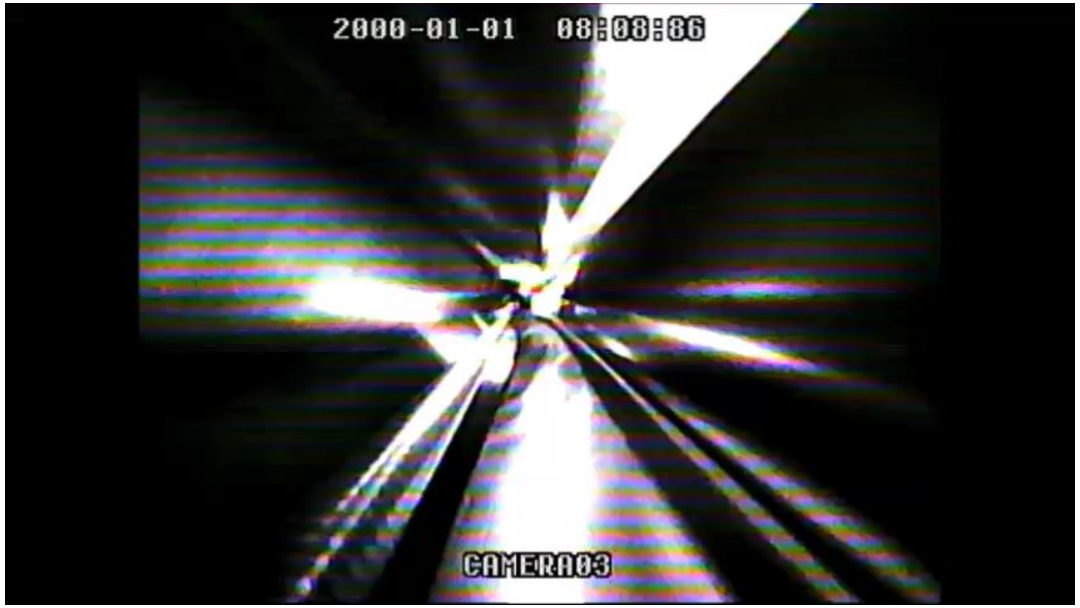




Flowrate (top), pressure (bottom), and liquid level (left) measurements during microgravity testing.

Video Verification of Observed Test Phenomena

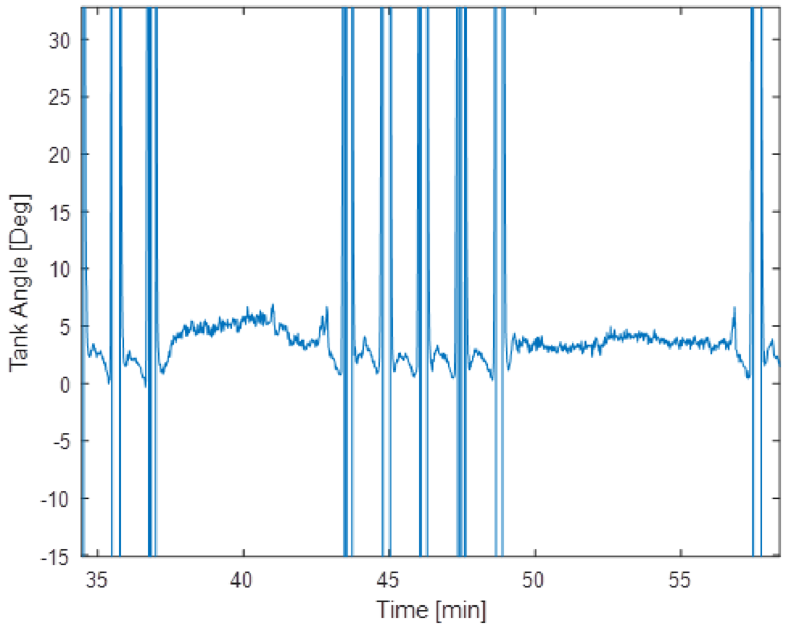
- Cameras installed in our test article provide important qualitative verification of observed test behavior
- Confirm guide vane function, channel wetting, channel breakdown, tank liquid level, etc.

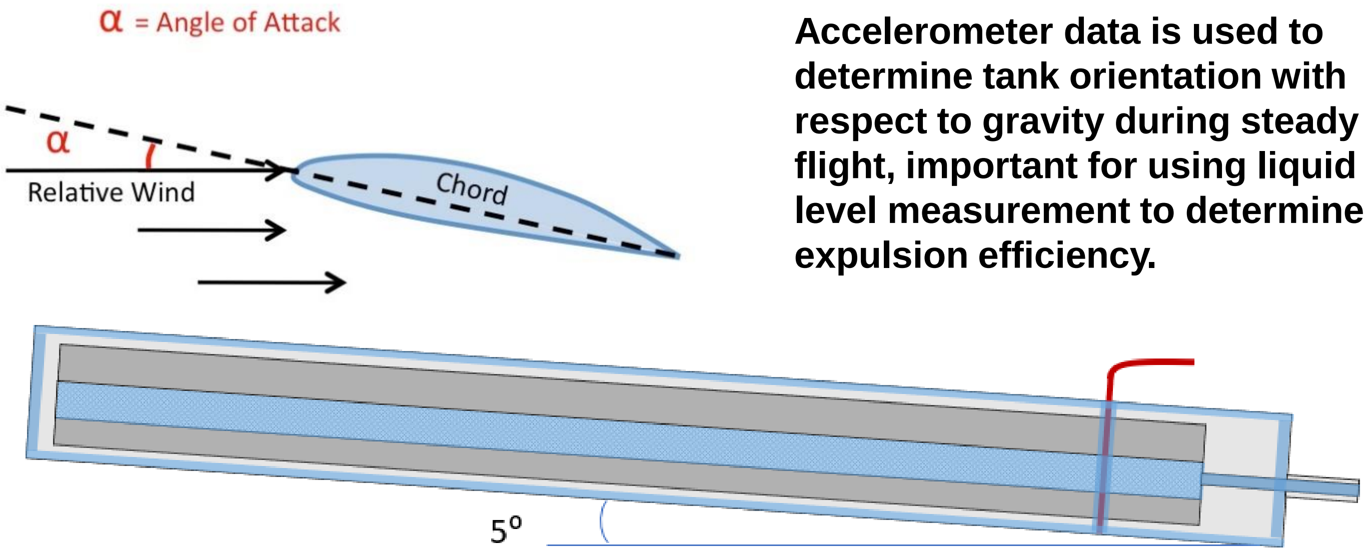


Video footage showing liquid slosh after the transition into microgravity (left) and video confirmation of breakdown during flow testing in microgravity (right).

Determination of Expulsion Efficiency

- **Expulsion efficiency is the key metric for gauging LAD performance**
  - **Expulsion Efficiency = (Initial Fill Volume – Liquid Volume @ Breakdown) / (Initial Fill Volume)**
- **Verified in our testing by measuring liquid level during steady flight after breakdown has occurred**
- **Important to correct for aircraft angle of attack, dead volume inside tank, liquid released during breakdown**

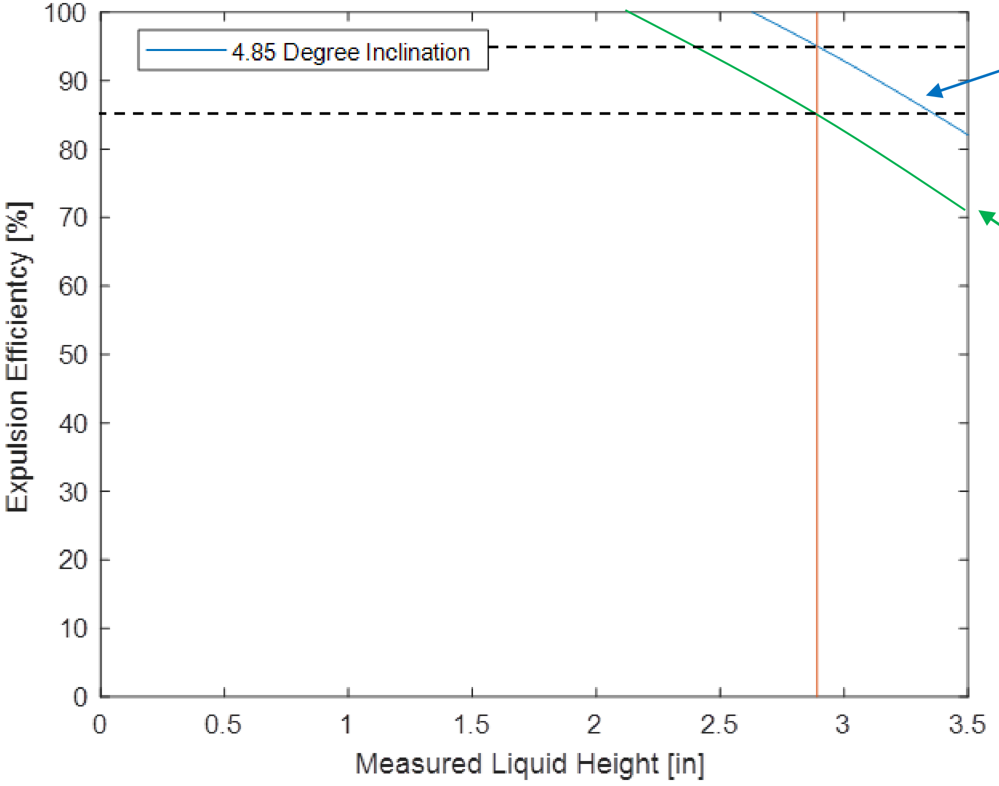




Accelerometer data is used to determine tank orientation with respect to gravity during steady flight, important for using liquid level measurement to determine expulsion efficiency.

Measured Expulsion Efficiency

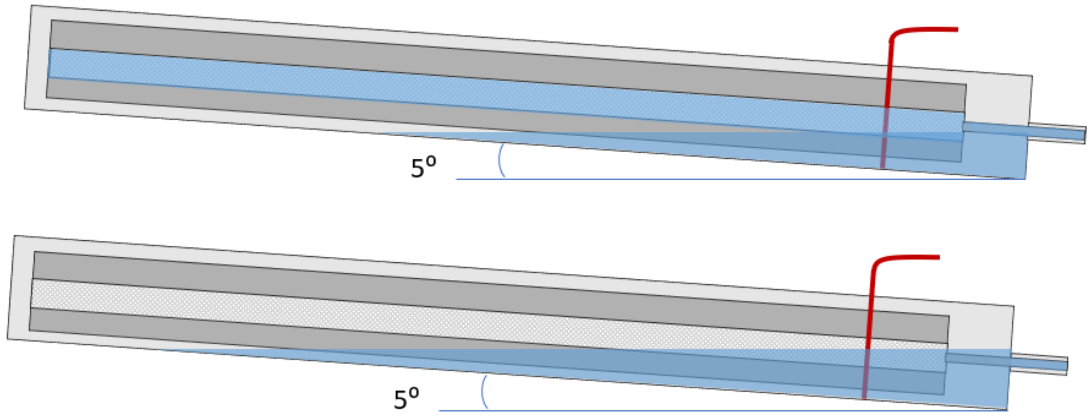
- **Expulsion efficiency calculated to be 86–95% (depending on assumptions)**
- **Indicates our LAD is highly effective at separating liquid from helium gas pressurant**



95% - Assumes LAD spills out into vessel following breakdown (realistic)

86% - Uses liquid height measurement as is (conservative)

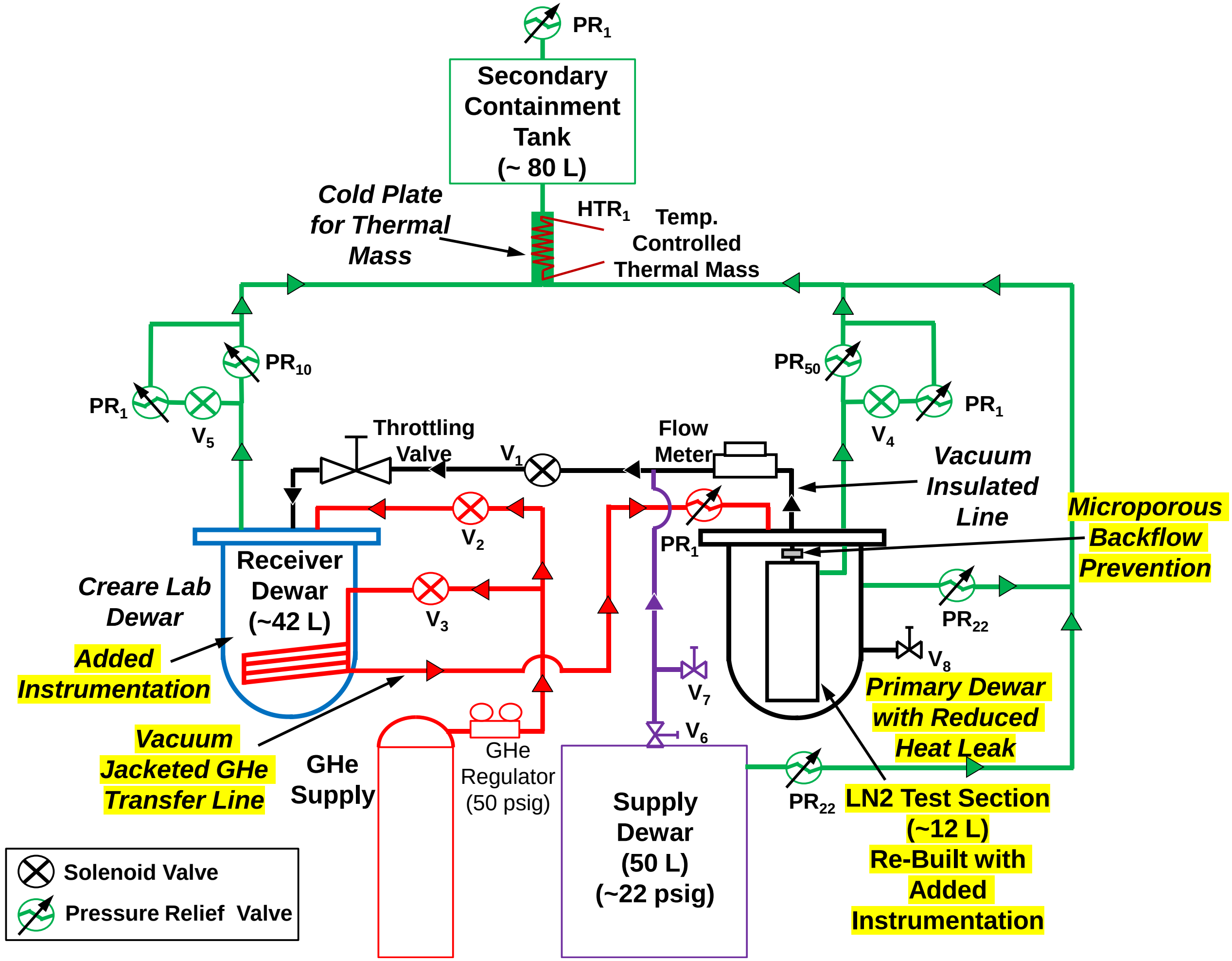
Bookkeeping of trapped liquid volumes after breakdown is important to accurately determine liquid level from test data.



Next Steps

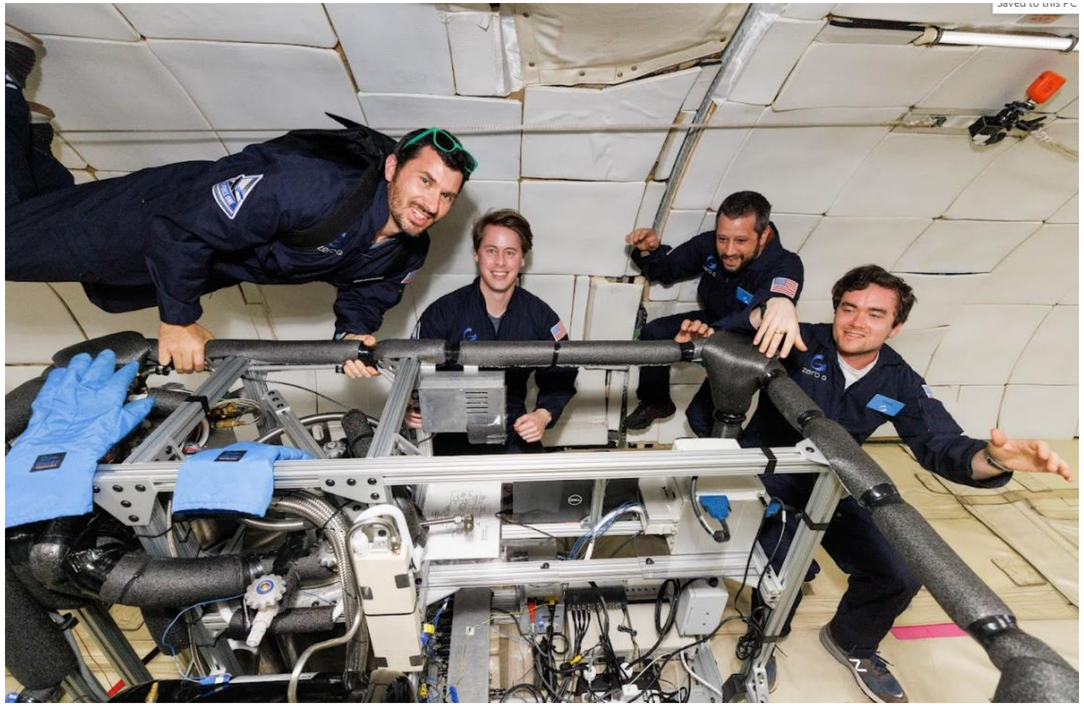
- **Initial experiment was successful in demonstrating LAD performance**
  - **Lessons-learned will improve measurement fidelity in upcoming (2024) flight campaign**

Summary of Key Improvements to Existing Parabolic Flight Payload	
Improvement	**Description**
Mitigate Tank Slosh between Microgravity Periods	Orient tank axis perpendicular to aircraft thrust axis, reducing slush length from 60" (tank length) to 5" (tank diameter).
Ensure Camera Stability	Reduce passthrough resistance, increase passthrough mechanical stability, and increase operating voltage of CMOS cameras.
Eliminate Temperature Difference between Helium Pressurant and LN_2 in LAD	Replace tubing connecting our helium pre-cooling coil with a vacuum jacketed flex tube to greatly reduce heat gain prior to entering our test article.
Enhance Instrumentation	(1) Switch to precision LN2 rated pressure transducers, (2) add a second liquid level sensor, (3) add a pressure sensor to the receiver dewar, (4) add temperature measurements near screen surfaces.
Reduce LAD Heat Leak and Improve Vacuum Level	Re-design G10 support struts, add MLI, and precision clean our vacuum chamber to reduce outgassing to help achieve a lower vacuum level.
Eliminate Vapor Backflow	Add a microporous element to our primary outflow line to prevent vapor backflow into the LAD between microgravity periods.



Questions?

- **Funded through NASA SBIR**
  - **Phase IIE Contract 80NSSC19C0198**
  - **Phase III Contract 80NSSC21C0446**



Photographs courtesy of Zero-G and Steve Boxall.