

LTF/Fluid and Cryogenic Systems Branch



Fluid and Cryogenic Systems Branch

Branch Chief: Robert Buehrle

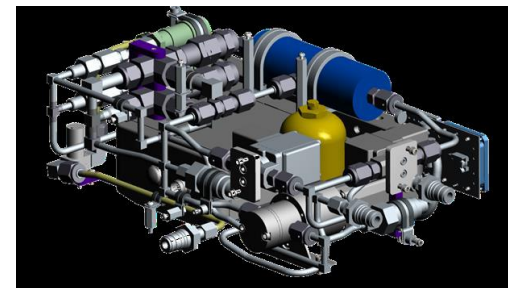
NASA GRC

Functions of the Branch:

- Cross-Cutting Fluids Engineering
- Research and Technology Development of Cryogenic Fluid Management (CFM) Systems
- Component and System level; Design, Development Test and Evaluation (DDT&E) for Fluid, CFM, Propellant and Gaseous Systems
- Fluid Component Specification and Selection
- Code Compliance of Pressurized Systems
- Fluid/Cryogenic System Performance Analysis and Trade Studies
- Hazards Analysis and Risk Assessment of Fluidic Systems
- Fluids Modeling and Simulation Capabilities



eCryo SHIIVER – liquid hydrogen vapor cooling test in the ISPF facility. (4 meter LH2 PV)



ISS - Flow Boiling and Condensation Experiment



NASA developed the following product based on the requests received from Appendix E

Cryogenic Fluid Management - State of the Art Technologies **BAA Appendix E Partners - August 2019**

Compiled by:

**Cryogenic Fluid Management Technical Experts across the NASA
(including 8 from LTF and 10 from GRC)**

104 pages

Format:

- **Describes the state of the art of each technology.**
- **Provides a list of the reference publications.**

Available to companies upon request

Appendix of the CFM Technologies:

1. Advanced External Insulation
2. Autogenous Pressurization
3. Automated Cryo-couplers / Quick Disconnects
4. Cryogenic Thermal Coating
5. Helium Pressurization
6. High Capacity, High Efficiency 20 K Cryocoolers
7. High Capacity, High Efficiency 90 K Cryocoolers
8. Insulation Systems
9. Liquefaction Operations
10. Liquid Acquisition Devices
11. Low Conductivity Structures
12. Line and Propellant Tank Chilldown
13. Para to Ortho (Hydrogen) Cooling
14. Propellant Densification
15. Pump Based Mixing
16. Soft Vacuum Insulation
17. Structural Heat Load Reduction
18. Thermodynamic Vent System
19. Transfer Operations
20. Broad Area Cooling (Tube-On-Tank, Tube-On-Shield)
21. Unsettled Liquid Mass Gauging
22. Valves, Actuators, and Components
23. Vapor Cooling
24. Flow Meters
25. Sun Shields
26. Composite Tanks and Feedlines

Other relevant topics include:

- Modeling and Simulation
- Integrated System Operations
- Ground & Loading Con Ops

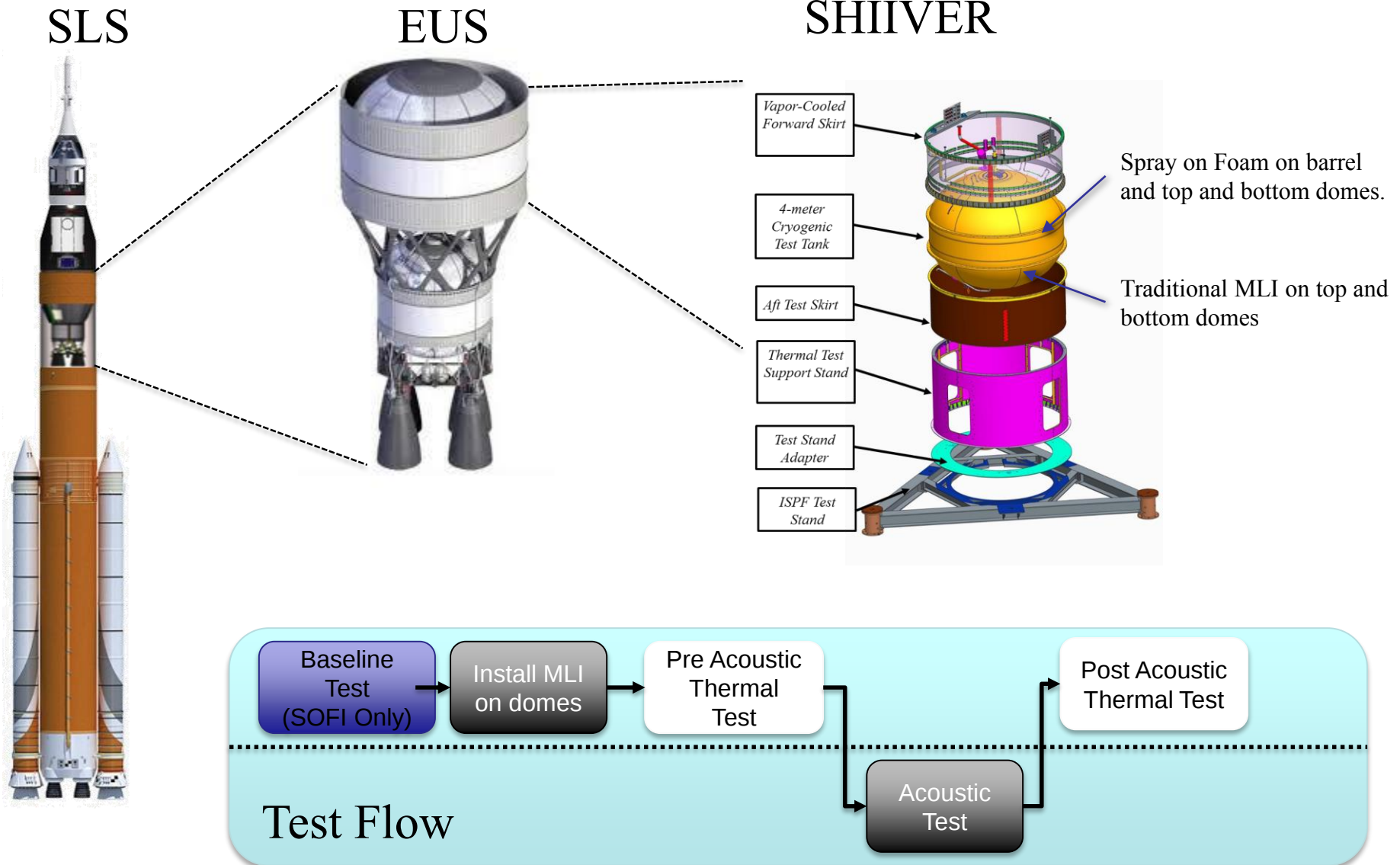
- Highlight of LTF/CFM projects
- eCryo – Evolvable Cryogenics (STMD – TDM)
 - SHIIVER (Structural Heat Intercept, Insulation, and Vibration Evaluation Rig)
 - RFMG (Radio Frequency Mass Gauge)
 - DVAT (Development and Validation of Analysis Tools)
- Cryogenic Fluid Technologies (STMD – GCD)
 - Cryocoolers
 - Reduced Gravity Cryogenic Transfer

Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)



SHIIVER will demonstrate heat-intercept via vapor cooling on the forward skirt, as well as SOFI and MLI insulation tests. Installed in ISPF facility at Plumbrook.

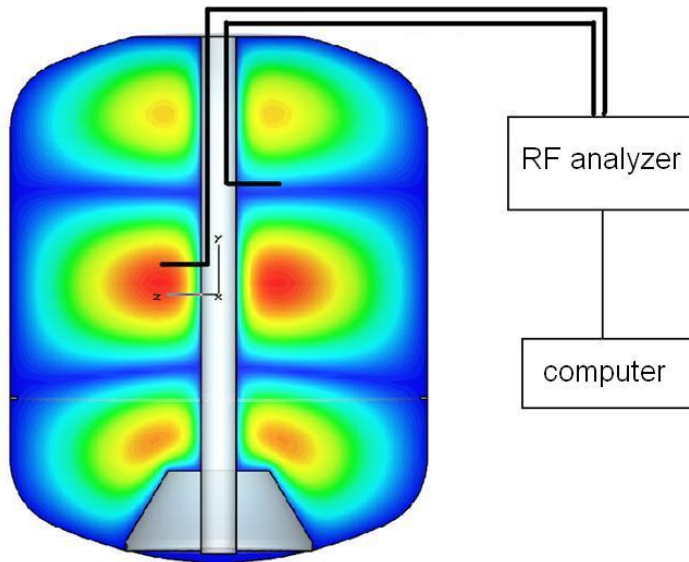
SHIIVER Overview



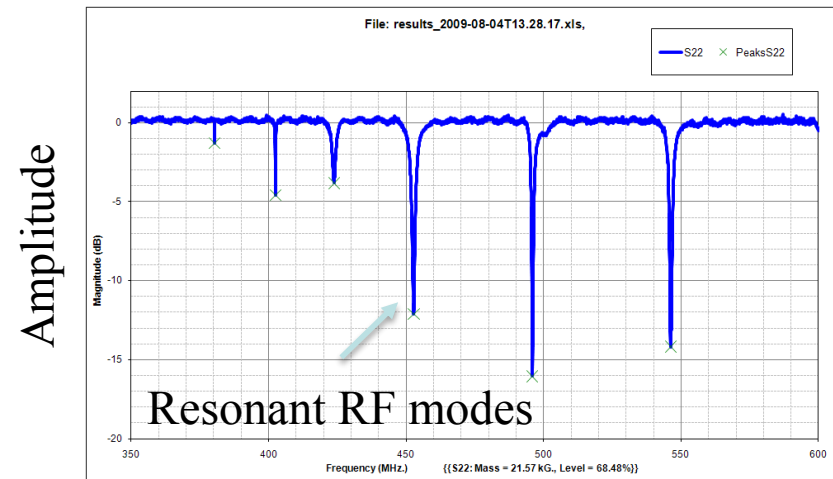
Radio Frequency Mass Gauge (RFMG)

- The Radio Frequency Mass Gauge (RFMG) was developed to gauge propellant quantity in low-g and settled environments
- Technology development at NASA GRC through STMD; currently TRL-6
- Applicable to cryo-propellants
- Not applicable to some storables (electrically conductive fluids absorb the RF energy)

RF antennas located inside tank broadcast and receive the reflected RF signal



- Tank RF spectrum measured by RF analyzer
- Spectrum changes with fluid fill level



Frequency
(typically 0.1 – 1 GHz)

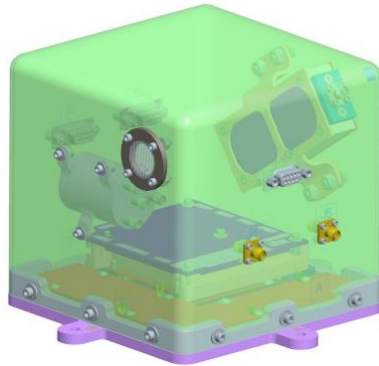
Radio Frequency Mass Gauge (RFMG)



The RFMG is an STMD/eCryo technology development success story
Integrated into the GSFC/Robotic Refueling Mission 3 (RRM3)

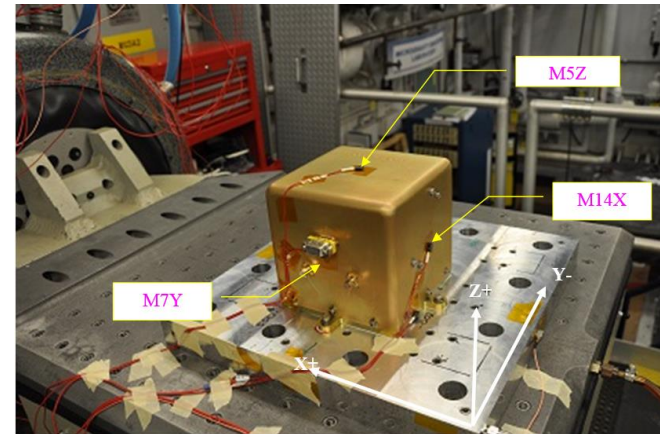
DESIGN

2016



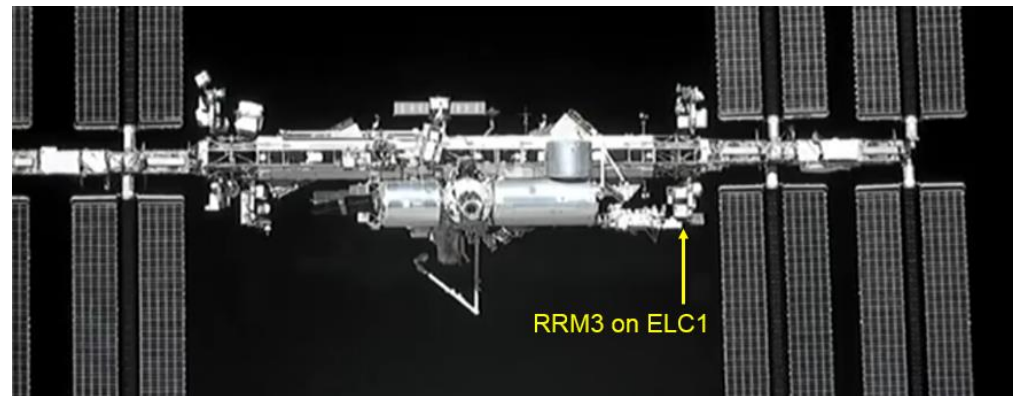
TEST

2017



INTEGRATE

2018



FLY

2019



Predictive Modeling Capabilities

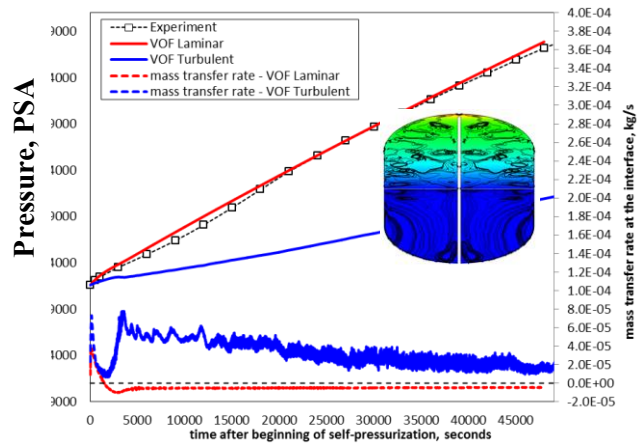
Goal: The DVAT activity involves developing and/or enhancing tools capable of predicting thermodynamic and fluid behavior of settled and unsettled cryogenic fluid management systems.

- ◆ Develop and validate modeling capabilities to predict performance of a range of complex fluid systems.
 - ◆ Cryogenic Fluids (LH2, LO2, LCH4, & LN2)
 - ◆ Two Phase Refrigeration (ISS Flow Boiling and Condensation Experiment).
 - ◆ Supercritical fluids including Xenon for Electrical Propulsion.
 - ◆ Fluid systems requiring complex fluid/mechanical interaction including modeling of valves with moving parts within valve. (Orion Service Module Pressure Control Assembly)
- ◆ Branch has multiple members with intimate knowledge and proficiency of the following commercial software tools (CFD and Multi-node) used for predictive analysis:
 - ◆ Multi-node Lumped Fluid/Thermodynamic Modeling
 - ◆ C&R Thermal Desktop (SINDA/FLUINT)
 - ◆ MSC EASY-5
 - ◆ GT-suite
 - ◆ GFSSP
 - ◆ AFT Arrow/Fathom
 - ◆ Full Navier-Stokes Computational Fluid Dynamics (CFD) Modeling
 - ◆ ANSYS FLUENT
 - ◆ ANSYS CFX
 - ◆ FLOW-3D
 - ◆ STAR-CCM

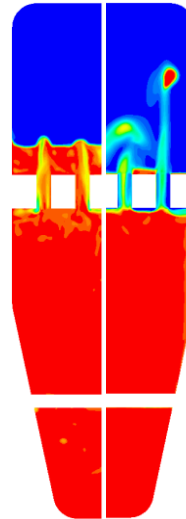
Recently Validated Cryogenic Predictive Models



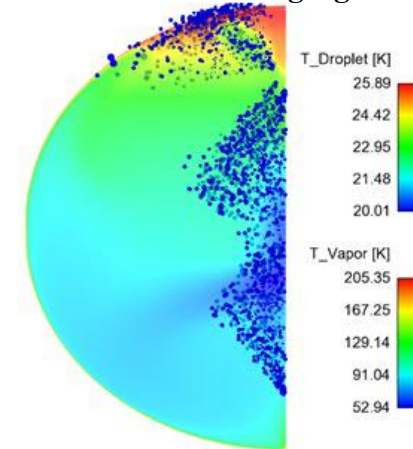
Tank Self-Pressurization
LH2-MHTB
FLUENT VOF CFD



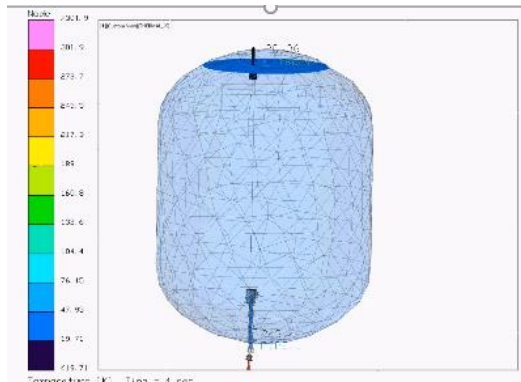
Turbo-pump Chill-down
Test: JAXA-LN2-1g & μ g
STAR-CCM/VOF - EMP



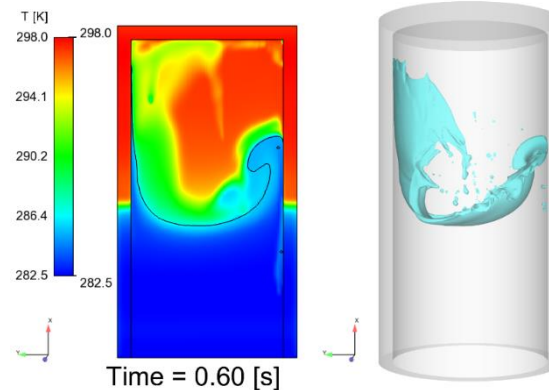
Tank Chill-down
Test: Ksite-LH2
FLUENT-Euler-Lagrangian CFD



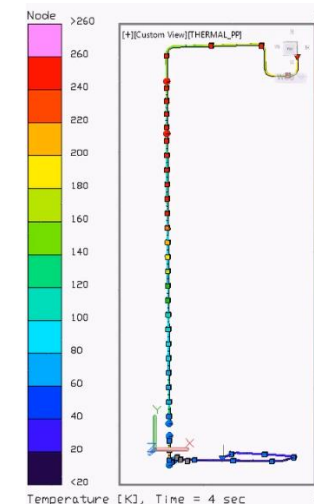
Tank GHE Submerged Pressurization
LH2-EDU
Thermal Desktop-Multi-node



Sloshing with Phase Change
Test: JAXA Silicon Slosh
FLUENT-RANS CFD



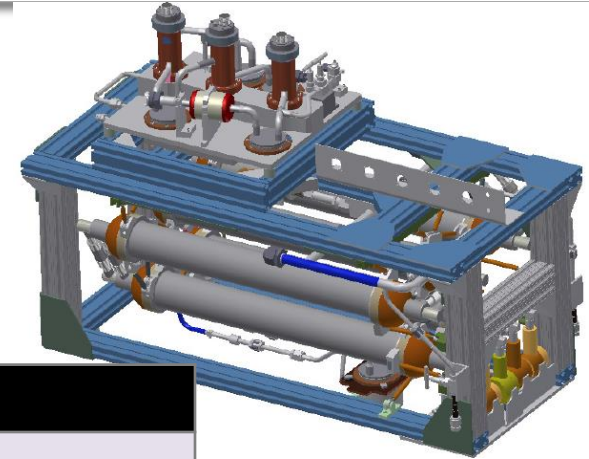
Transfer Line Chill-down
Test: LH2
Thermal Desktop: Multi-node



Cryocoolers:

NASA is making investments in Cryocooler Technology

- 20K/20Watt RTB (Reverse Turbo-Brayton)
- 90K/150 Watt RTB and non-RTB cycles



Key Performance Parameters					
20K Cryocooler					
Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value	Projected Flight Design
Cooling Capacity (W)	1	17	20	19.1	20
Specific Power (W/W)	370	80	60	95	71
Specific Mass (kg/W)	18.7	5.5	4.4	5.3	5.3
<u>Notes:</u> Performance Parameters for Cooling Capacity @ 20K					

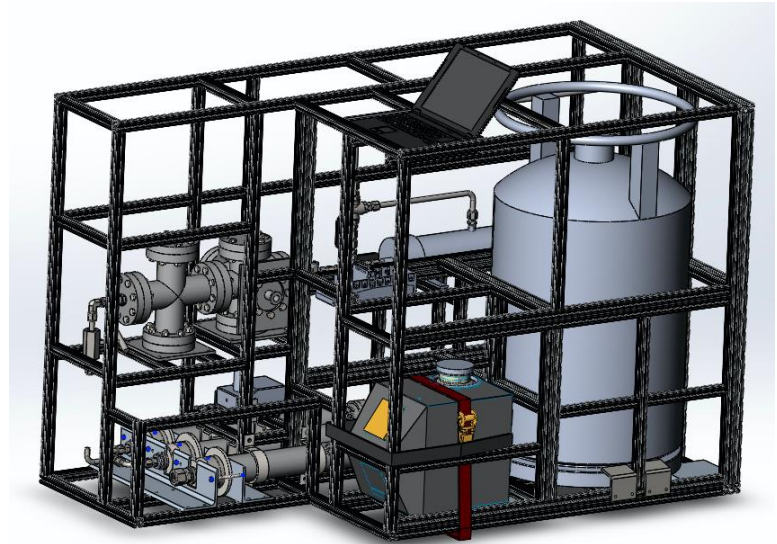
Reduced Gravity Cryogenic Transfer (RGCT)



- The transfer of cryogenic propellants is not well understood in a reduced or micro-gravity environment

Project goals:

- Develop and demonstrate mass and energy efficient methods for reduced gravity cryogenic line and tank-to-tank chilldown
- Prove feasibility of low-g cryogenic tank-to-tank chilldown and fill
- Determine what type of gravitational sensitivity exists in line and tank chilldown
- Develop a set of analytical design, sizing, and scaling models for cryogenic tank chilldown and tank fill



**Low G – Aircraft Parabolic Flight
Transfer Line Chilldown Test Rig**



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