**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

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

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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
LTF/Fluid and Cryogenic Systems

- 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
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.
SHIIIVER Overview

Test Flow

Baseline Test (SOFI Only) → Install MLI on domes → Pre Acoustic Thermal Test

Post Acoustic Thermal Test → Acoustic Test

SLS

EUS

SHIIIVER

Spray on Foam on barrel and top and bottom domes.

Traditional MLI on top and bottom domes.

Vapor-Cooled Forward Skirt

4-meter Cryogenic Test Tank

Aft Test Skirt

Thermal Test Support Stand

Test Stand Adapter

ISP Test Stand
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.

Resonant RF modes (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 & μg
STAR-CCM/VOF - EMP

Tank Chill-down
Test: Ksite-LH2
FLUENT-Euler-Langragian 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

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>State of the Art</th>
<th>Threshold Value</th>
<th>Project Goal</th>
<th>Estimated Current Value</th>
<th>Projected Flight Design</th>
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</thead>
<tbody>
<tr>
<td>Cooling Capacity (W)</td>
<td>1</td>
<td>17</td>
<td>20</td>
<td>19.1</td>
<td>20</td>
</tr>
<tr>
<td>Specific Power (W/W)</td>
<td>370</td>
<td>80</td>
<td>60</td>
<td>95</td>
<td>71</td>
</tr>
<tr>
<td>Specific Mass (kg/W)</td>
<td>18.7</td>
<td>5.5</td>
<td>4.4</td>
<td>5.3</td>
<td>5.3</td>
</tr>
</tbody>
</table>

*Notes:* 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
LTF/Fluid and Cryogenic Systems Branch

- LTF/Fluid and Cryogenic Systems
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