Energy Efficient Cryogenics
TC67_JWG Meeting

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Energy Efficient Cryogenics

Overview of Technology Focus Areas and Capabilities

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The Cryogenics Test Laboratory, NASA Kennedy Space Center, works to provide *practical solutions to low-temperature problems* while focusing on long-term technology targets for the *energy-efficient* use of cryogenics on Earth and in space.

*Space launch and exploration is an energy intensive endeavor; cryogenics is an energy intensive discipline.*
Energy Efficient Cryogenics

- **Cost-Efficient Storage & Transfer on Earth**
- **Mass-Efficient Storage & Transfer in Space**
- **Low-Temperature Materials & Novel Applications**

Cryogenics Enables:
- Propulsion
- Power
- Life Support
- Science
- Manufacturing
- Testing
The **Cryogenics Test Laboratory, NASA Kennedy Space Center**, is a unique community for research, development, and application of cross-cutting technologies to meet the needs of industry, government, and research institutions.

Technology focus areas include:

- ✔ **Thermal insulation systems**
- ✔ **Integrated refrigeration systems**
- ✔ **Advanced propellant transfer systems**
- ✔ **Novel components and materials**
- ✔ **Low-temperature applications**

*Cryogenics is about two things:*

1) using low-temperatures to do something useful,
2) storing something in a small space (energy density).
Success in cryogenics has always been defined as a healthy triangle of interaction among research, industry, and training.
Preservation of the Cold

\[ \Delta T = 500 \, ^\circ\text{F} \]

\[ H_2O \]

\[ LH_2 \]

\[ \Delta T = 500 \, ^\circ\text{F} \]
Technical Consensus Standards for Thermal Insulation Systems

• To help meet the today’s needs and further the possibilities for future gains in *global energy efficiency*, cryogenic insulation standards are being developed.

• Under ASTM International’s Committee C16 on Thermal Insulation, two new standards were published in 2014:
Thermal Insulation Systems Development and Materials Research

- Foams: Polystyrenes (Styrofoams), Polyimides, Polyurethanes
- Aerogels: (Space Technology Hall of Fame and R&D 100 winner)
  - Flexible blanket [Aspen Aerogels, Inc.]
  - Particles and expansion packs [Cabot Corp.]
  - Polymer cross-linked aerogels (X-aerogels) and experimental
- Bulk-Fill Powders: Glass bubbles, Perlites, Aerogels
- Multilayer insulation (MLI):
  - Aluminum foil and micro-fiberglass paper
  - Double-aluminized Mylar and polyester non-woven fabric
  - Double-aluminized Mylar and polyester netting
Thermal Insulation Systems Development and Materials Research (cont.)

• Layered composite insulation (LCI) systems: (patents and patents pending)
  – High vacuum or soft vacuum applications (LCI), or,
  – Non-vacuum, external environment applications (LCX)
• Vacuum insulated panels (VIP) with glass bubbles
• AeroPlastics and AeroFiber composite panels (patents and patents pending)
• AeroFoam composites for insulation, cryofuel storage, or cold batteries (patents)
• Novel smart, multifunctional composites: (patents pending)
  – Insulating – Conducting Composites (ICCs)
  – Passive-Acting Switchable Composites (PSCs)
  – Low-Temperature Shape Memory Alloy Systems for Broad-Area Thermal Management
Cryostat Insulation Test Instruments

- Cryostat-100, Cylindrical – Absolute
- Cryostat-200, Cylindrical – Comparative
- Cryostat-400, Flat Plate – Comparative
- Cryostat-500, Flat Plate – Absolute
- Macroflash (Cup Cryostat), Flat Plate - Comparative
- Cryogenic Moisture Uptake Apparatus
- Transient Thermal Tester
- 1000-liter Tank Cryostat (LH₂ or LN₂)
- Cryogenic Pipeline Test Apparatus
- Patents:
  - *Methods of Testing Thermal Insulation and Associated Test Apparatus*, US Patent 6,742,926
  - Additional patents pending

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Liquid Oxygen Ground Operations Demonstration Project (GODU-LO$_2$)

Objectives:
- Rapid propellant (cryofuel) loading concept demonstrations.
- Autonomous control and data monitoring system development.
- Testbed for development of many technologies and innovations, such as:
  - Fault tolerance of failed control valves and sensors.
  - Software to monitor overall health and status of propellant loading system.
  - Component (valves and pumps) sealing system designs.
  - Cryogenic composite tank structural/thermal monitoring.
  - Novel sensors applications and use in real world environments.

Features:
- Up to 800 GPM flow rate and 225 PSI.
- Four cryogenic pumps are fed from a 6,000 gallon liquid nitrogen supply tank.
- Pumps have varying flow capacities from 25 up to 450 GPM.
- Complexity and component count is comparable to full scale launch pad transfer system.
- Modular and re-configurable for a wide range of different vehicle or R&D requirements.

Overall view of the Simulated Propellant Loading System located at the CryoTestLab
ISO Work – LN₂ Vapor Work

Objective:
• Evaluate the effects of LN₂ vapor on “simulated insulation sample”.

Test Hardware
• Various “nozzles”
• Data acquisition system (DAQ)
• 6,000 gallon LN₂ storage tank
• Simulated insulation sample (enclosure)
ISO Work – LN$_2$ Vapor Work (cont)

Test Hardware
• Simulated insulation sample (enclosure)

Sample enclosure  Test run (vapor cloud)  Test run (1m distance)
ISO Work – LN₂ Vapor Work (cont)

All Thermocouples

- Cool-down of Nozzle at 1 m.
- Two-Phase Flow at 1 m.
- Full Liquid Flow at 0.5 m.
- Full Liquid Flow at 1 m.

Temperature (°C)

Test Time (min)

TC1, TC2, TC3, TC4, TC5, TC6, TC7, TC8, TC9, TC10, TC11, TC12, TC13, TC14, TC15

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Conclusion

• Cryogenics is globally and fundamentally linked to energy generation, storage, and usage.
• Two keys to safe and cost-efficient (on mass-efficient) storage, transfer, and application of cryogens:
  – Integrated refrigeration systems technology (active systems)
  – Thermal insulation systems technology (passive systems)
• New high efficiency designs, methodologies, and materials (active + passive) are being developed.
• Vital collaborations are with industry and academic research institutions for a wide range of applications, both commercial and government.

*Through measurement to knowledge; through knowledge to product.*
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Examples of the variation of effective thermal conductivity ($k_e$) with cold vacuum pressure are shown for different cryogenic insulation systems. The boundary temperatures are approximately 78 K and 293 K, the residual gas is nitrogen, and the total thicknesses are typically 25-mm.\textsuperscript{1}

Ground Operations Demonstration Unit for Liquid Hydrogen (GODU-LH$_2$)

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Integrated Refrigeration Objectives
GODU-LH$_2$

• Demonstrations:
  ✓ Zero loss storage and transfer of LH$_2$ on a large scale
  ✓ Hydrogen liquefaction using close cycle helium refrigeration
  ✓ Hydrogen densification in storage tank and loading of flight tank

• Secondary objectives:
  ✓ Creating a densified hydrogen servicing capability
  ✓ Maintaining critical cryogenic design and operations skills
  ✓ Demonstrating low-helium usage operations
  ✓ Validating modern component technologies

• Potential Advantages of IRAS LH$_2$ Systems:
  ✓ Cost savings (less boiloff)
  ✓ More autonomy in operations (less downtime)
  ✓ Improved safety and reliability (enthalpy margin)
Integrated Refrigeration and Storage (IRAS) System for GODU-LH$_2$

- **Vacuum-Jacketed Tank Features:**
  - 125 m$^3$ (33,000 gal) capacity, 22 m (70 ft) length, 3 m (10 ft) diameter
  - Vacuum-jacketed with foil/paper MLI
  - Modified 600-mm diameter manway for helium and instrumentation feedthrough
  - Internal stiffening rings for sub-atmospheric pressure operation

- **Heat Exchanger Features:**
  - Cold helium, end-to-end flow balanced
  - Modular self-supporting system with 300 m of 6-mm diameter stainless steel tubing
  - Cold helium in-line process temperature sensors (4 silicon diodes)
  - Three temperature rakes to measure vertical and horizontal gradients (20 silicon diodes)
GODU-LH$_2$ Future Uses

• LH$_2$ Integrated Refrigeration and Storage system is fully operational at Kennedy Space Center.
• Upon completion of the GODU-LH$_2$ project, the system will be available for other uses:
  – Servicing on upper stages or test stands with densified hydrogen
  – Hydrogen distribution applications
  – Cryostat-900 and high efficiency transfer lines
  – Fuel cell and electrolysis research
  – Spacecraft loading ground support equipment
  – Superconductivity applications
Advanced Cryogenic Storage & Transfer

• End-to-end system architectures for rapid and reliable operations
• Composite materials development with real-world prototype combined functional testing: structural, vibration, and thermal.
• Autonomous control and system health monitoring
• Modular, semi-flexible piping systems
• Zero-loss transfer of Liquid Hydrogen
• Supporting Technology for Safe Operations (NASA-KSC Patents):
  – Color-changing tape for hydrogen gas leak detection
  – Aerogel blended polymers (AeroPlastic) for sealing components
  – Aerogel foam composites (AeroFoam) for cryogen storage
  – Aerogel fiber panel composites (AeroFiber) for structures and thermal protection systems
  – Layered composite insulation system for extreme environments (LCX)
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