Mastering Cryogenic Propellants

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Project Bee (1955-1959)

USAF: Is it practical to use LH$_2$ in an airplane?
NACA Lewis conducts Project Bee
- B-57B modified to permit one engine to burn JP-4 or H$_2$
Flight test demonstrated feasibility and safety
GRC Cryogenic Fluid Management Accomplishments

COLD-SAT Experiment Design completes Phase A (1990)

1962–> Centaur LO2/LH2 stage development

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Pioneering cryogenic propellant properties, behavior, and instrumentation studies 1960s-70s

Shuttle Experiments: Tank Pressure Control Experiment (1992), Vented Tank Resupply Experiment (1996)

LH2 Zero Boil-off storage feasibility demonstrated (1998)

Liquid acquisition, gauging, pressure control, and modeling matured (2005)

2010 Methane Lunar Surface Thermal Control Test demonstrate advanced MLI

Cryogenic Propellant Storage and Transfer (CPST) Demonstration completes SRR/MDR (2014)

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1996–2001: Propellant densification development culminates in X-33 GSE

2004 Creek Road Cryogenic Complex opens; Over 50 test programs conducted to mature CFM technology in next 10 years

2010–2013 CFM technology matured for flight demonstration

1988–1994: NASP Slush H2 Technology Program. >200,000 gallons of SLH2 produced
Centaur

Subscale experiments and full scale demonstration flights addressed:
- Propellant slosh
- Propellant settling
- Short term storage/pressure control

1960s - Centaur stage being lowered into Spacecraft Propulsion research Facility for integrated CFM and hot-fire testing

1990s - Liquid hydrogen tank in test at the Cryogenic Propellant Tank Facility (K-Site): fill, pressurization/venting, slosh
Flight Experiments

Tank Pressure Control Experiment (TPCE)

Vented Tank Resupply Experiment (VTRE)

Zero Boil-off Tank Experiment (ZBOT)

Liquid Motion Control Experiment (LME)
Cryogenic Fluid Management Facilities

Spacecraft Propulsion research Facility (B-2) at Plum Brook Station (PBS)

Small Multipurpose Research Facility (SMiRF) at Lewis Field

Cryogenic Propellant Tank Facility (K-Site) (PBS)

Not Pictured:
- Cryogenic Components Laboratory (CCL) (PBS)
- “Cell 7” at Lewis Field
Recent Highlights

Since 2003, Technology Development Projects have enabled maturation of technologies for:

**Efficient long duration cryogen storage**
- Advanced multilayer insulation
- Mixing and thermodynamic venting for pressure control
- Active Thermal control

**In-space cryogenic propellant transfer**
- Unsettled liquid acquisition
- Transfer line chill-down

**Cryogenic propellant gauging**
- Evaluation of alternative liquid level sensors
- Radio frequency mass gauging

**Analysis and simulation**
- Correlations
- Lumped element modeling
- Full physics computational fluid dynamics
- Analysis of unsettled cryogen storage
- Analysis of transfer line and tank chill and fill processes

**Broad suite of cryogens**
- Liquid oxygen
- Liquid hydrogen
- Liquid methane
- Liquid nitrogen
Recent Highlights

CFM Flight Payload Concept

CPST Engineering Development Unit - Fabrication and Testing

Vibro-acoustic Testing of MLI and BAC

LOX ZBO Demonstration
Summary

• CFM technologies have matured at a slow pace compared to other aerospace technologies
• During the last ten years considerable progress has been achieved in:
  • Technology Development
  • Modeling
  • System Performance
• NASA future architectures and roadmaps require a robust CFM approach