National Aeronautics and Space Administration

Mastering Cryogenic Pr bellants

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Presente t the
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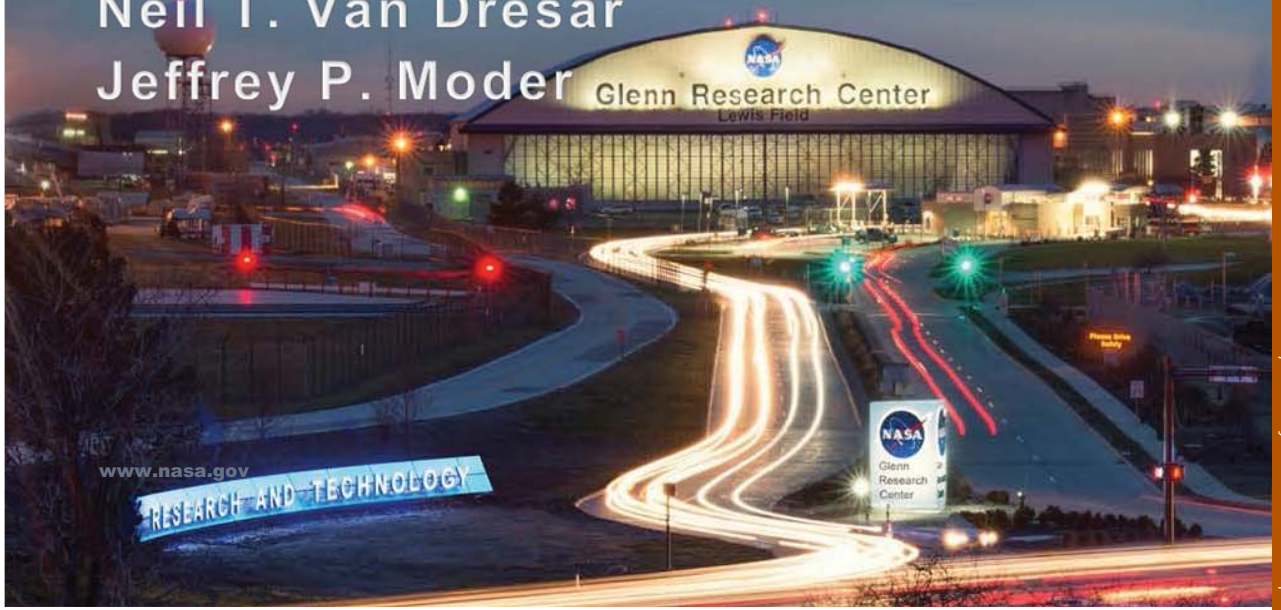
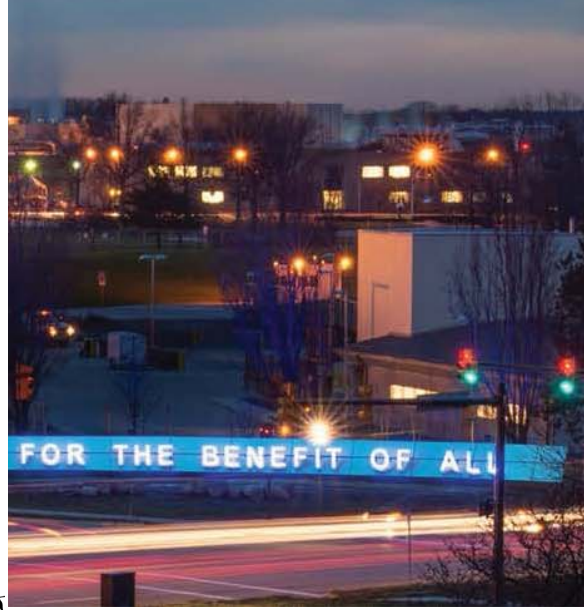




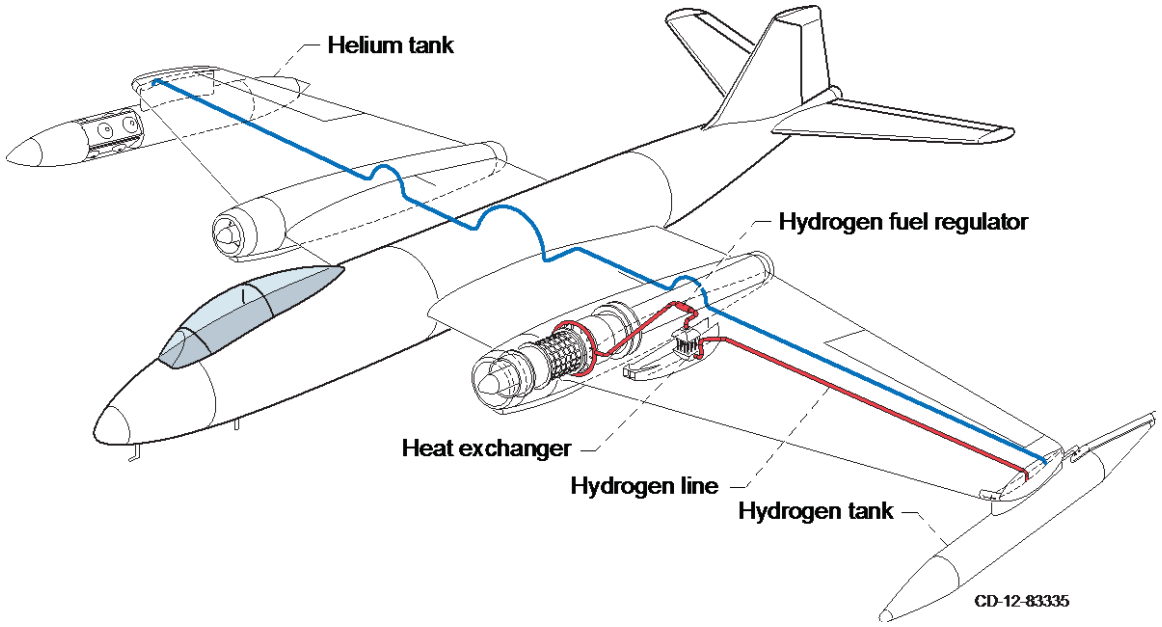
Project Bee (1955-1959)

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

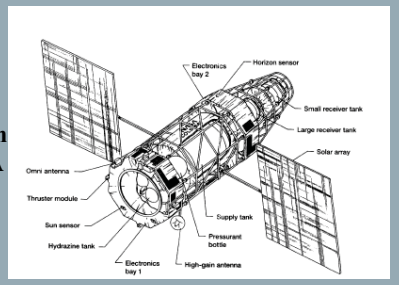
Flight test demonstrated feasibility and safety



GRC Cryogenic Fluid Management Accomplishments

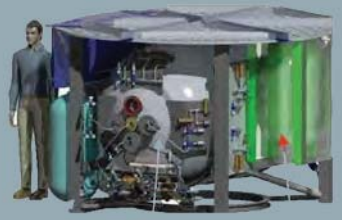
1962-> Centaur LO2/LH2 stage development

COLD-SAT Experiment Experiment Design completes Phase A (1990)

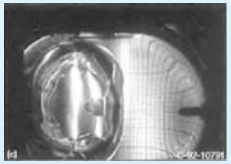


LH2 Zero Boil-off storage feasibility demonstrated (1998)

2010 Methane Lunar Surface Thermal Control Test demonstrate advanced MLI

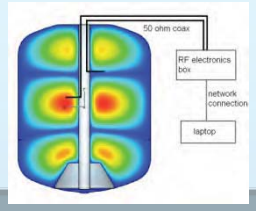


Cryogenic Propellant Storage and Transfer (CPST) Demonstration completes SRR/MDR (2014)



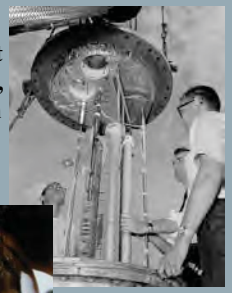
Shuttle Experiments: Tank Pressure Control Experiment (1992), Vented Tank Resupply Experiment (1996)

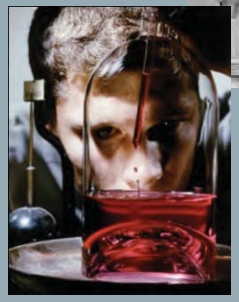
Liquid acquisition, gauging, pressure control, and modeling matured (2005)



2010-2013 CFM technology matured for flight demonstration

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

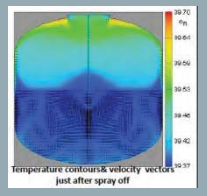




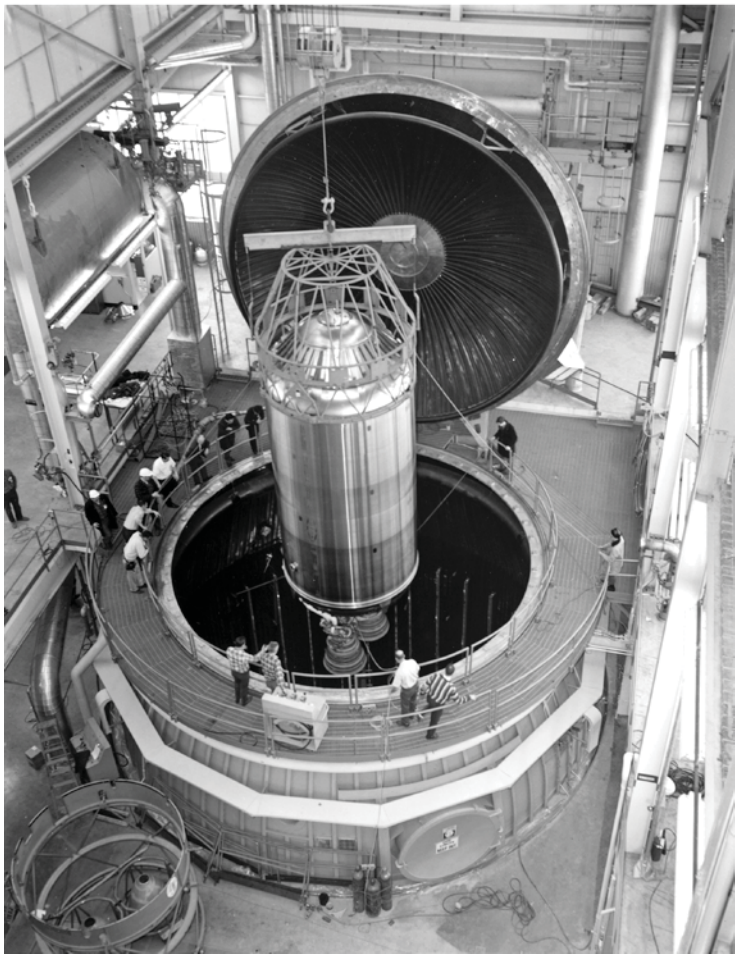
1988-1994: NASP Slush H2 Technology Program. >200,000 gallons of SLH2 produced

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



Centaur



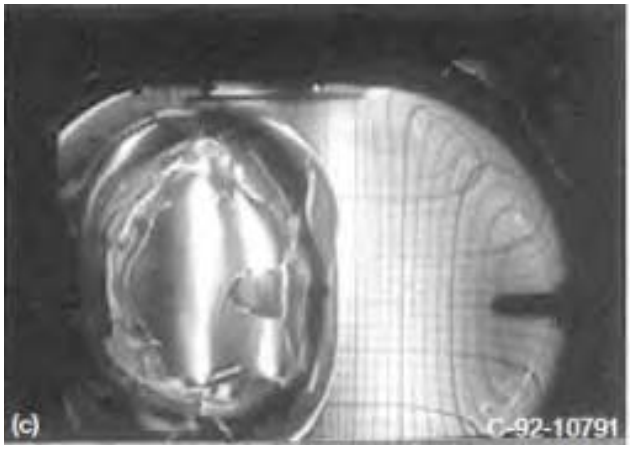
1960s - Centaur stage being lowered into Spacecraft Propulsion research Facility for integrated CFM and hot-fire testing

Subscale experiments and full scale demonstration flights addressed:

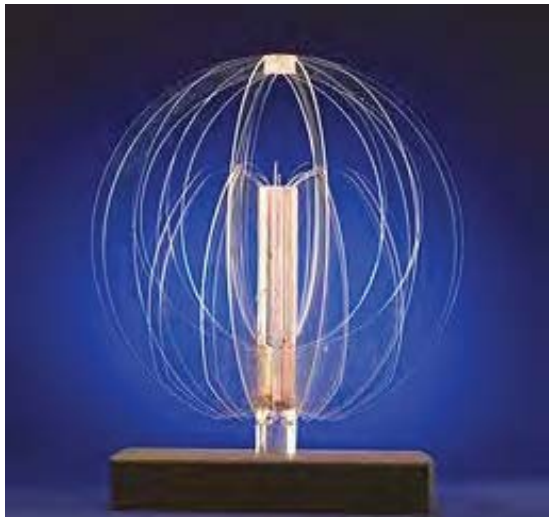
- Propellant slosh
- Propellant settling
- Short term storage/pressure control

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

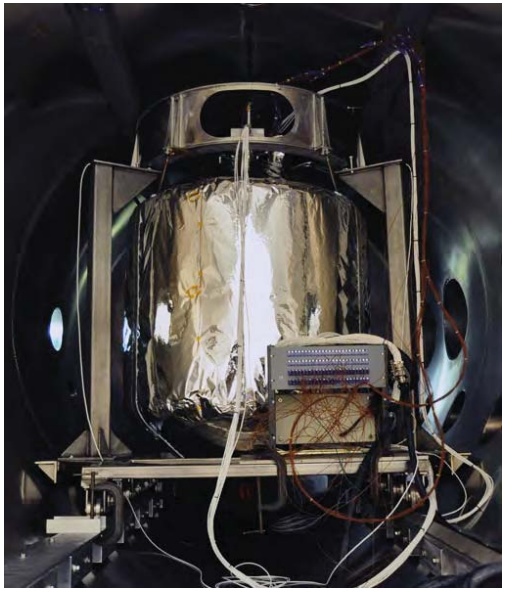
Analysis and simulation
- Correlations
- Lumped element modeling
- Full physics computational fluid dynamics
- Analysis of unsettled cryogen storage
- Analysis of transfer line and tank chill and fill processes

Broad suite of cryogens
- Liquid oxygen
- Liquid hydrogen
- Liquid methane
- Liquid nitrogen

Recent Highlights

CPST Engineering Development Unit - Fabrication and Testing

CFM Flight Payload Concept



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