CONCEPT DESIGN OF CRYOGENIC PROPELLANT
STORAGE AND TRANSFER FOR SPACE EXPLORATION

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CPST Goal and Objectives

**CPST Goal Statement:** Advance cryogenic propellant systems technologies for infusion into future extended in-space missions.

**Objectives**

- Store cryogenic propellants in a manner that maximizes their availability for use regardless of mission duration
- Efficiently transfer conditioned cryogenic propellant to an engine or tank situated in a microgravity environment
- Accurately monitor and gauge cryogenic propellants situated in a microgravity environment
CPST Project Organization

Technology Lead

CPST Project
- Project Manager
- Deputy Project Manager
- Chief Engineer

Project Integration
- Schedule, Resources, CM

Software/Avionics

S&MA Technical Authority

CPST Systems Engineer

S&MA

Procurement

CFS Mission Manager

- CFS Payload
- Technology Maturation
- Spacecraft

CPST Integration and Test Manager

- Launch Vehicle
- System Integration
- Test and Verification

Launch Services Provider POC

CPST Mission Operations Manager

- Flight Ops
- Mission Data Processing
- Ground Ops

IAC-I2,D3,3,2,x14163
Mission Overview

Flight Demonstration System Mission Architecture

Launch Vehicle

Launch Control

Remote Researchers

Operations Center

Low Earth Orbit

Flight Laboratory

Space Communications Asset

Ground Communications Asset

Ground Infrastructure
## Mission Timeline

<table>
<thead>
<tr>
<th>Mission Demonstration</th>
<th>Month</th>
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<tbody>
<tr>
<td>Spacecraft &amp; CFM Demo Systems Checkout</td>
<td>1</td>
</tr>
<tr>
<td>LH2 Storage Tank Passive CFM Demo</td>
<td></td>
</tr>
<tr>
<td>LH2 Storage Tank Active CFM Demo</td>
<td>3</td>
</tr>
<tr>
<td>LH2 Transfer Demos</td>
<td>4 6</td>
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</tbody>
</table>

**Storage Tank Passive CFM Demos include:**
- Determination of passive thermal control performance
- Settled mass gauging
- Unsettled mass gauging
- Low-conduction structural concepts

**Storage Tank Active CFM Demos include:**
- Determination of active thermal control performance
- Settled mass gauging
- Unsettled mass gauging
- Low-conduction structural concepts

**Propellant Transfer Demos include:**
- Pump-fed propellant transfer
- Pressure-fed propellant transfer
- Settled propellant transfer
- Unsettled propellant transfer
- Transfer Tank and Transfer system conditioning
- Transfer rate measurement and vapor detection
- Settled and unsettled liquid acquisition
- Tank expulsion demos

**Tanks Sized to Provide (at least):**
- 6 Month Storage Demo for LH2
- 2 Transfer Demo Series for LH2

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CPST NASA Point of Departure Concept Recommended Technologies

Needs
- Create the innovative new space technologies for our exploration, science, and economic future

Goals
- Advance cryogenic propellant systems technologies for infusion into future extended in-space mission

Objectives
- Store cryogenic propellants in a manner that maximizes their availability for use regardless of mission duration
- Efficiently transfer conditioned cryogenic propellant to an engine or tank situated in a microgravity environment
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Technologies

LH2 Storage
- Active thermal control: Broad Area Cooling (tubes on tank or tubes on shield)
- Active thermal control: cryo-coolers (90K)
- Passive storage: reduced penetration heat leak through MLI
- Passive storage: low conductivity structural attachments
- Tank Pressure Control: thermodynamic vent system (TVS)
- Tank Pressure Control: mixing pumps

LH2 Acquisition
- Liquid Acquisition Devices (LADs)

LH2 Transfer
- Transfer Valves
- Transfer Pump
- Line and Tank Chill-down

LH2 Quantity Gauging
- Capacitance Probe
- Wet-Dry Sensor (Cryotracker)
- Radio Frequency (settled/unsettled)

RF Gauge Test Rig

TVS components (installed in test tank)
Pulse-tube cryocooler

Screen Channel Capillary LAD
**CPST Technology Readiness Levels**

* Items with two TRLs listed are where there is a propellant dependence (hydrogen/oxygen)

<table>
<thead>
<tr>
<th>CPST Technology</th>
<th>TRL Now</th>
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</thead>
<tbody>
<tr>
<td>1 Active Thermal Control: Cryocoolers w/ tube-on-shield heat collection</td>
<td>4</td>
</tr>
<tr>
<td>2 Thick Multilayer Insulation with Foam Substrate</td>
<td>4/6</td>
</tr>
<tr>
<td>3 Low Conductivity Structures: High Strength Composite Struts</td>
<td>4/6</td>
</tr>
<tr>
<td>4 Micro-G Pressure Control: Thermodynamic Vent System</td>
<td>5</td>
</tr>
<tr>
<td>5 Micro-G Pressure Control: Mixing Pumps</td>
<td>5</td>
</tr>
<tr>
<td>6 Unsettled Liquid Acquisition Devices</td>
<td>4/5</td>
</tr>
<tr>
<td>7 Micro-G Transfer Line Chilldown</td>
<td>4</td>
</tr>
<tr>
<td>8 Pressurization Systems</td>
<td>5</td>
</tr>
<tr>
<td>9 Settled Mass Gauging: Wet/dry silicon diode sensors</td>
<td>5</td>
</tr>
<tr>
<td>10 Unsettled Mass Gauging: Radio Frequency Gauging</td>
<td>5</td>
</tr>
<tr>
<td>11 Micro-G Tank Chilldown</td>
<td>5</td>
</tr>
<tr>
<td>12 Automated Leak Detection</td>
<td>5</td>
</tr>
</tbody>
</table>

• First 11 items address primary mission objectives
  • Leak detection is a secondary objective
• TRL highlighted in yellow indicates TRL is currently being advanced through the Technology Maturation portion of the project
  • Project goal is to have candidate technologies at TRL = 5 before mission authority to proceed (ATP)
## CPST Technology Maturation Activities

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH2 Reduced Boil-off Active Cooling Thermal Demonstration</td>
<td>Demonstration of a flight representative active thermal control system for Reduced Boil-Off (RBO) storage of LH2 for extended duration in a simulated space thermal vacuum environment</td>
</tr>
<tr>
<td>LH2 Reduced Boil-off Broad Area Cooling Shield/MLI Structural Integrity</td>
<td>Assess the structural performance of an MLI / BAC shield assembly subjected to launch environmental representative loads</td>
</tr>
<tr>
<td>Composite Strut Thermal Performance in LH2</td>
<td>Measurement of heat leak due to composite struts integrated with MLI.</td>
</tr>
<tr>
<td>Liquid Acquisition Device (LAD) Outflow &amp; Line Chill</td>
<td>Quantify the LAD stability (no LAD breakdown) due to transfer line chill down transient dynamic pressure perturbations during outflow</td>
</tr>
<tr>
<td>MLI Penetration Heat Leak Study</td>
<td>Measurement of heat leak due to struts penetration integrated with MLI.</td>
</tr>
<tr>
<td>Active Thermal Control Scaling Study</td>
<td>Conduct study to show relevancy of CPST-TDM active thermal control flight data to full scale CPS or Depot application</td>
</tr>
<tr>
<td>Thick MLI Extensibility Study</td>
<td>Assess optimum approach for attachment of thick (40-80 layer) MLI to very large tanks</td>
</tr>
<tr>
<td>Analytical tools</td>
<td>Continue development of tools to be validated by CPST</td>
</tr>
<tr>
<td>Pathfinder Integrated System Test (GTA)</td>
<td>Demonstrate flight-scale system operations &amp; interactions; demo tank manufacturing; early software development</td>
</tr>
<tr>
<td>Instrumentation Advancement</td>
<td>Mature Radio Frequency Mass Gauge flight avionics and leak detection sensor system for vacuum environment</td>
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NASA Internally Developed Point of Departure (POD) Mission Concept

NASA conducted an internal conceptual design study in 2011 with the objectives of

- defining a preliminary design concept to enable initial assessments of mission viability
- enabling early project formulation activities

POD Salient Features
- Free flying spacecraft separate bus and cryogenic payload
- Downs-selected to flying a single fluid (LH2)
- A smaller secondary tank is included for propellant transfer demonstration
- Carries the full technology suite described earlier
- Loaded with LH2 on the PAD with a T0 disconnect
Five contractor mission concept studies were conducted to augment the Government POD study

- Analytical Mechanics Associates, Ball Aerospace, Boeing, Lockheed Martin, and United Launch Alliance

- The overall objectives of the mission studies were the same as used for the NASA internal POD study

- Cost constraint was a primary challenge and the mission concepts brought various options into the trade space including:
  - Launch: dedicated launch vs. rideshare or dual manifest
  - Spacecraft Bus Function: payload/bus configuration vs. integrated bus functions
  - Loading propellants into the payload: ground loading vs. preloaded vacuum jacketed tanks vs. propellant scavenging from an upper stage

- Technology demonstration included in the concepts were overall similar to NASA POD, with some unique options

- Single fluid and two fluid options were provided by the contractors
## CPST Project Notional Schedule

<table>
<thead>
<tr>
<th></th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14</th>
<th>FY 15</th>
<th>FY 16</th>
<th>FY 17</th>
<th>FY 18</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Program Milestones</strong></td>
<td>KDPA</td>
<td>ASM</td>
<td>KDPB</td>
<td>KDPC</td>
<td>KDPE</td>
<td>KDPF</td>
<td></td>
</tr>
<tr>
<td><strong>Project Milestones</strong></td>
<td>MCR</td>
<td>SPR</td>
<td>Contract SRR/MDR</td>
<td>PDR</td>
<td>CDR</td>
<td>SIR</td>
<td>FRR</td>
</tr>
<tr>
<td><strong>Technology Development</strong></td>
<td>Penetration Heat Leak TDR</td>
<td>LH₂ Active Cooling TDR</td>
<td>LAD Outflow and Line Chill TDR</td>
<td>MLI/BAC Shield Vibration TDR</td>
<td>LO₂ Active Cooling TDR</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GTA</strong></td>
<td>Storage Tank Ready for Integration</td>
<td>Integrated Hardware Assembly and C/O Complete</td>
<td>GTA Installation in TS-300 Complete</td>
<td>Test Preparations Complete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RF Mass Gauge (GFE to contract)</strong></td>
<td>RFMG PDR</td>
<td></td>
<td>RFMG CDR</td>
<td></td>
<td>RFMG Delivery</td>
<td></td>
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- Launch 12/16
- Mission Review
- De-Commissioning Complete

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CPST Summary

• NASA is planning to fly a Cryogenic Propellant Storage and Transfer (CPST) technology demonstration mission mission in late 2016 (TBR).

• Mission Concept Review (MCR) and Acquisition Strategy Meeting were recently completed.
  – Based on a NASA in-house mission concept and five contractor developed mission concepts, mission feasibility was demonstrated.

• Preparation for System Requirements Review (SRR) underway.

• Technology Maturation activities to raise candidate technologies to TRL 5 are near completion, by end of CY2012.
CPST Points of Contact

Project Manager: Susan Motil; susan.m.motil@nasa.gov

Chief Technologist: Mike Meyer; michael.l.meyer@nasa.gov

Chief Engineer: Bill Taylor; william.j.taylor@nasa.gov
Cryogenic Propellant Storage and Transfer Functions that CPST Can Demonstrate

**Thermal Control**
- Insulation (launch environments and in-space)
- Vapor or actively cooled shields
- Low conductivity/ cooled support structure

**Pressurization**
- Cold helium
- Autogenous

**Vent or to vapor cooled shields**

**Pressure Control**
- Zero-g venting (thermodynamic vent and heat)

**Liquid Acquisition**
- Capillary retention devices LADs vanes, etc.

**Propellant Gauging**
- Settled propellant/level sensors
- High accuracy micro-g techniques

**Propellant Transfer**
- Settled/unsettled
- No-vent fill