CONCEPT DESIGN OF CRYOGENIC PROPELLANT STORAGE AND TRANSFER FOR SPACE EXPLORATION

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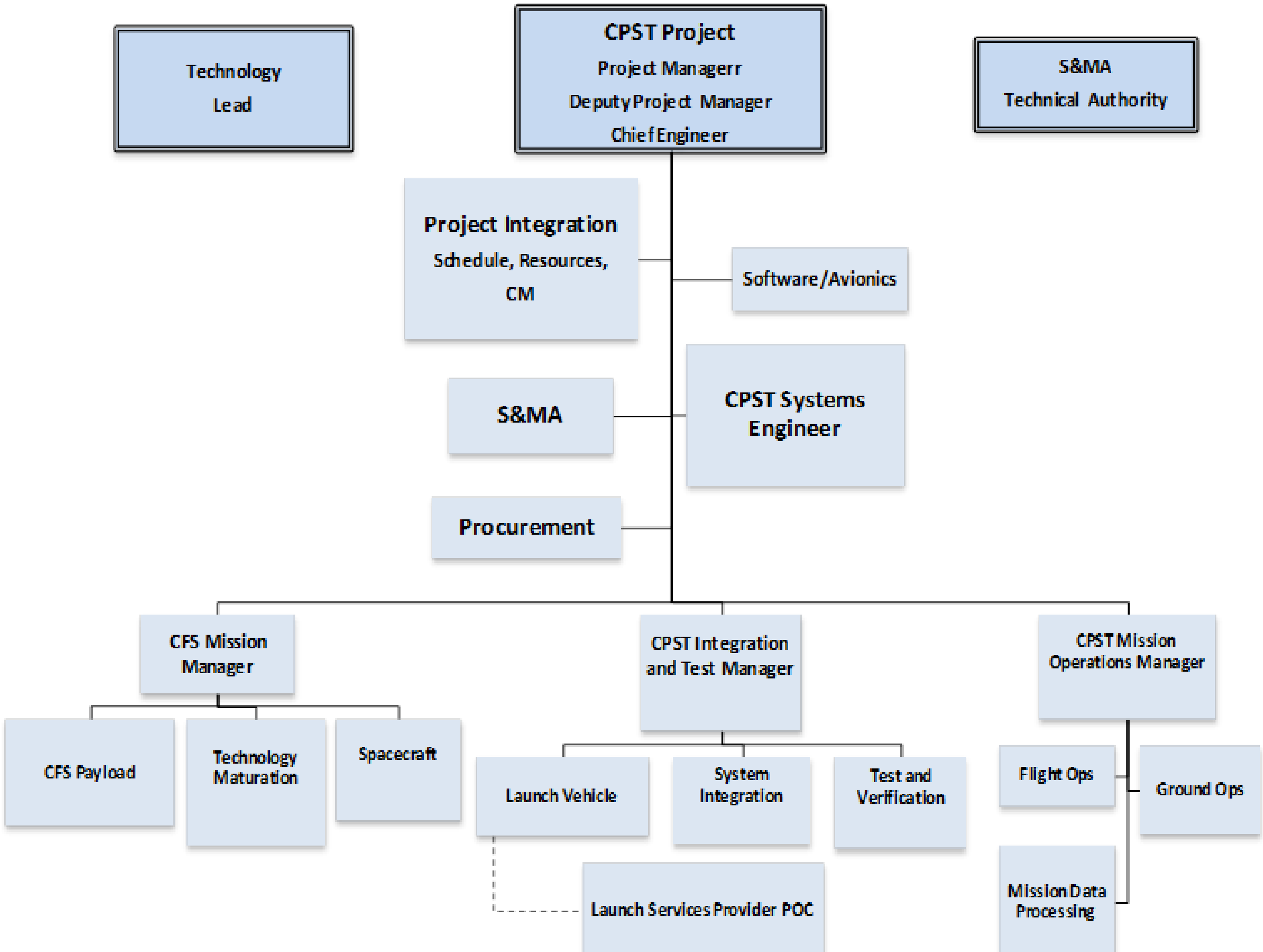
CPST Goal and Objectives

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

Objectives

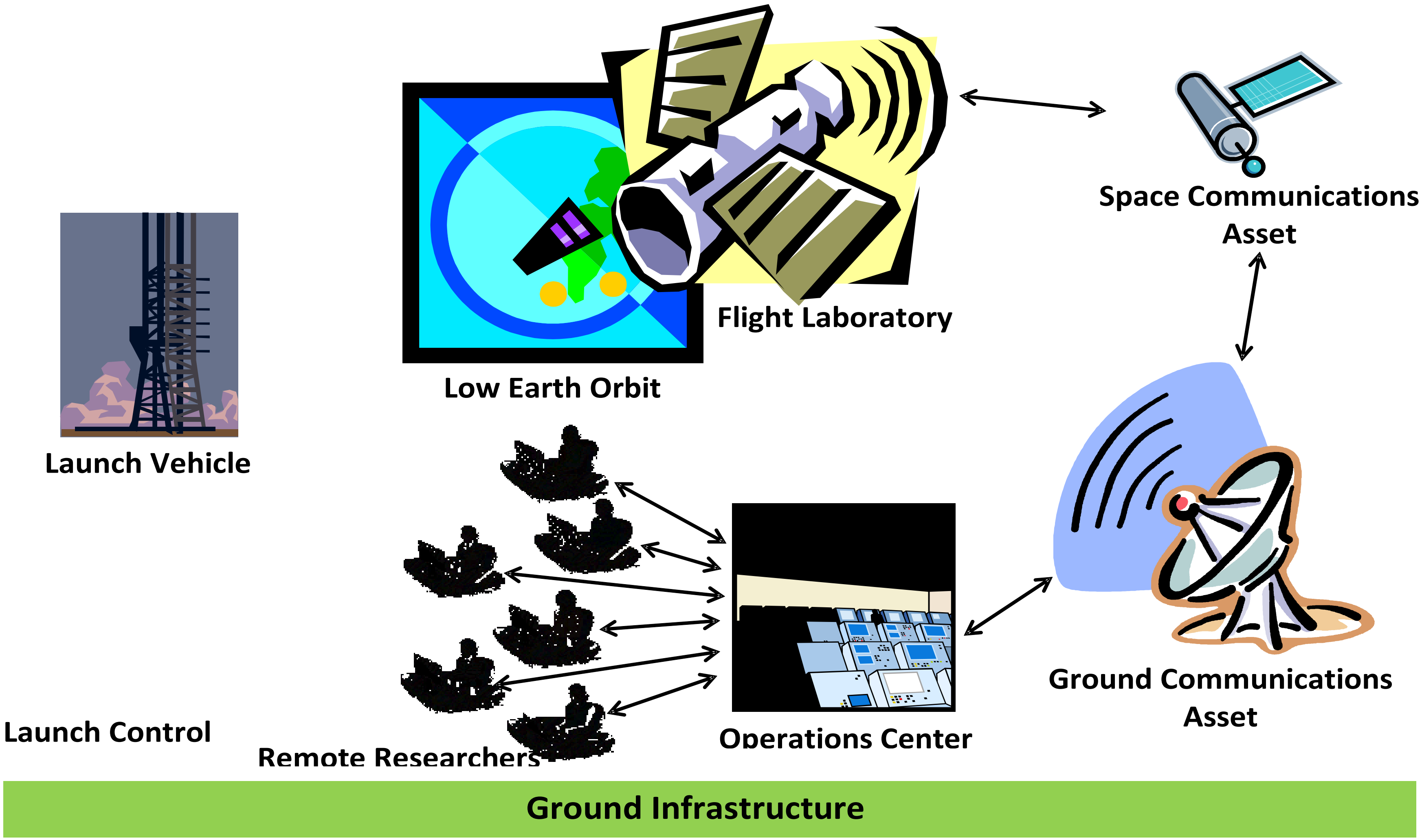
- Store cryogenic propellants in a manner that maximizes their availability for use regardless of mission duration
- Efficiently transfer conditioned cryogenic propellant to an engine or tank situated in a microgravity environment
- Accurately monitor and gauge cryogenic propellants situated in a microgravity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

CPST Project Organization

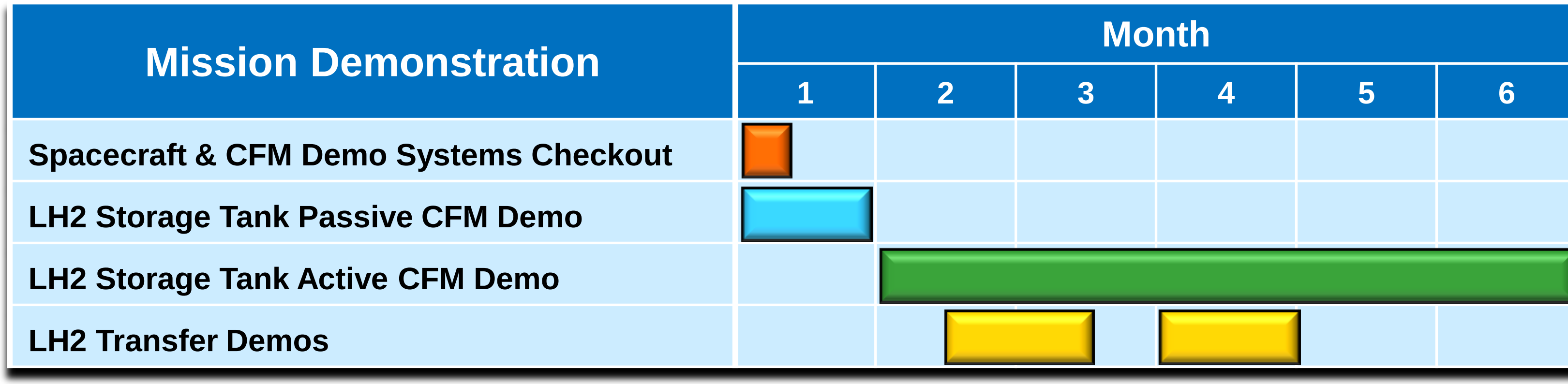


Mission Overview

Flight Demonstration System Mission Architecture



Mission Timeline



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

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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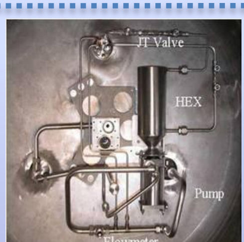
Technologies



TVS components (installed in test tank)

Pulse-tube cryocooler

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)

Screen Channel Capillary LAD

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

CPST Technology Readiness Levels

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

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

- 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

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

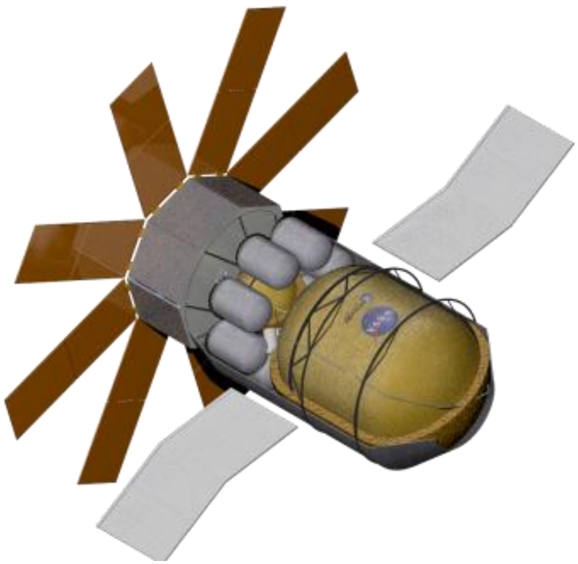
NASA Internally Developed Point of Departure (POD) Mission Concept

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



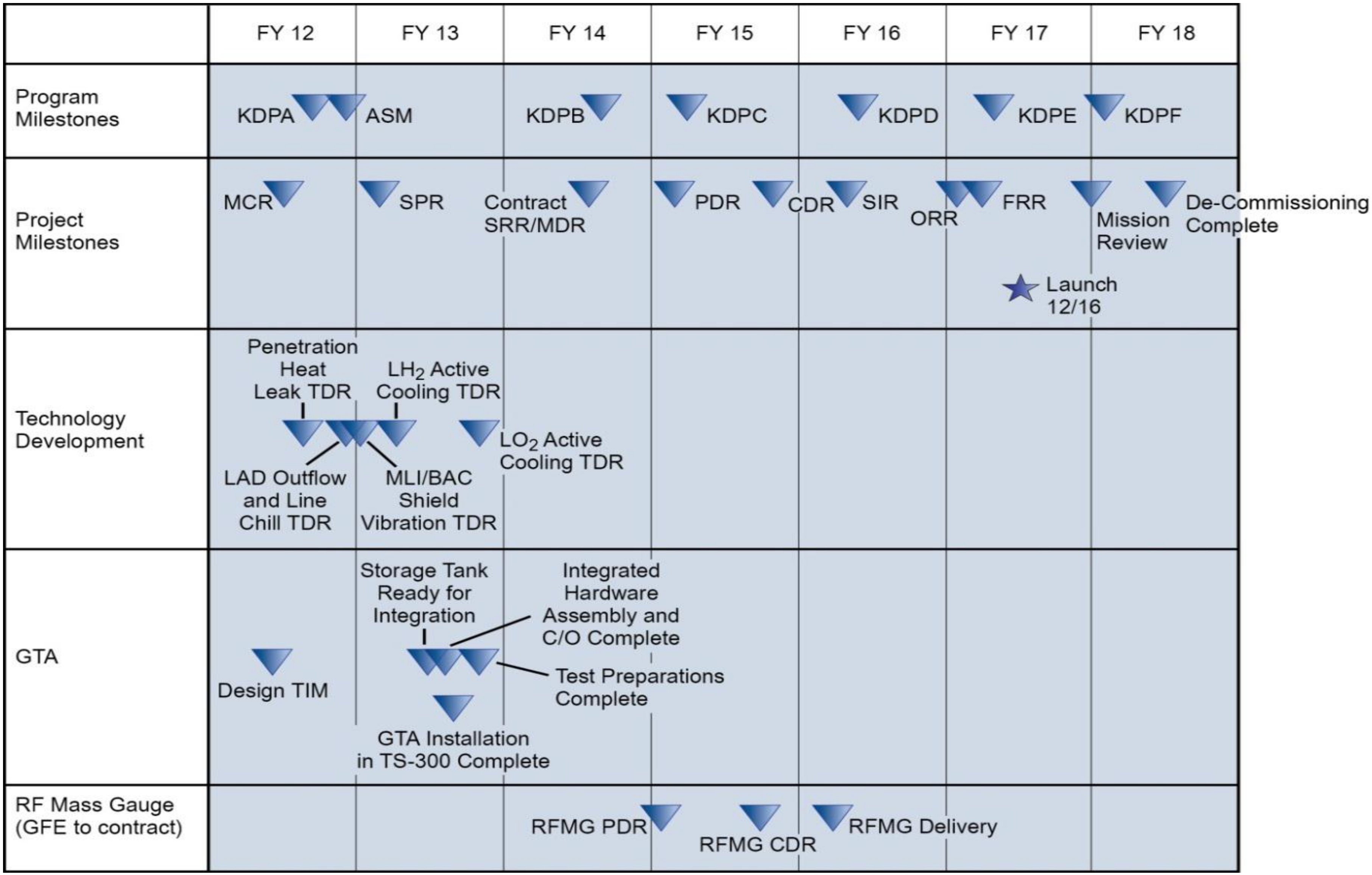
Contractor Developed Mission Concepts

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

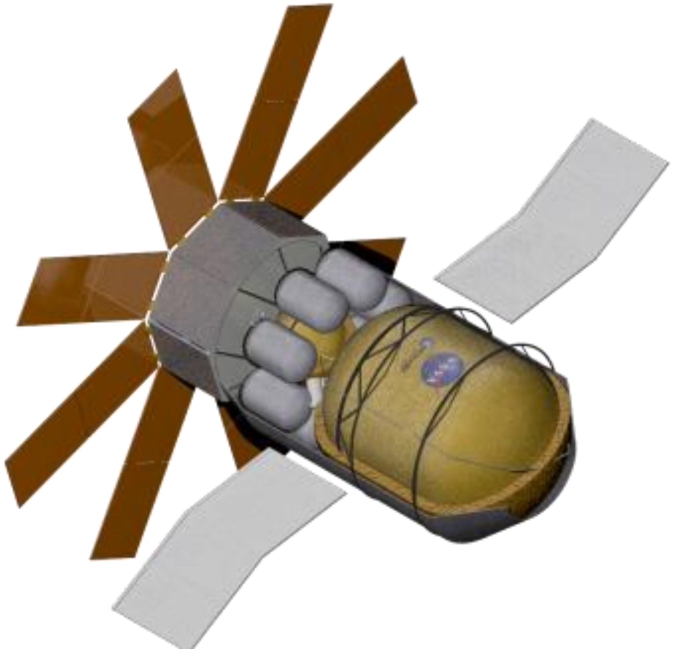
- The overall objectives of the mission studies were the same as used for the NASA internal POD study
- Cost constraint was a primary challenge and the mission concepts brought various options into the trade space including:
  - Launch: dedicated launch vs. rideshare or dual manifest
  - Spacecraft Bus 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



CPST Summary

- NASA is planning to fly a Cryogenic Propellant Storage and Transfer (CPST) technology demonstration 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

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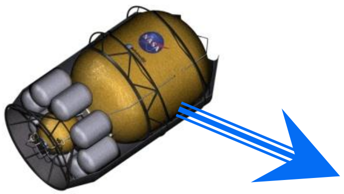
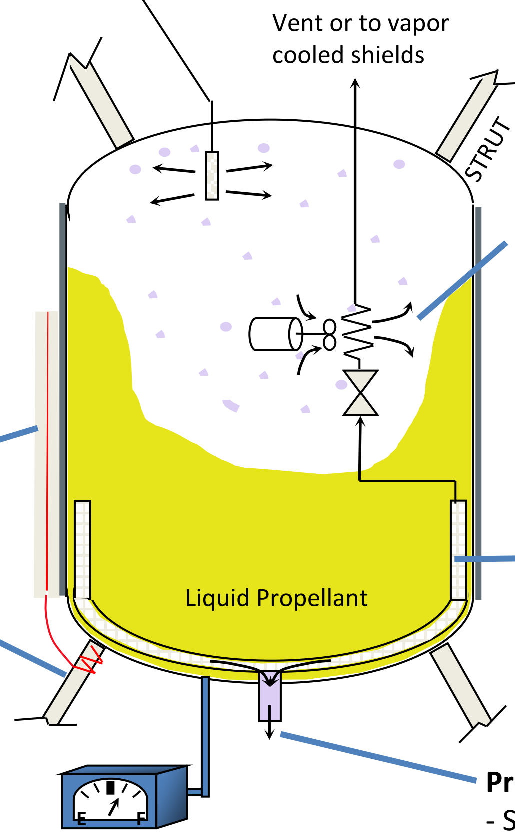
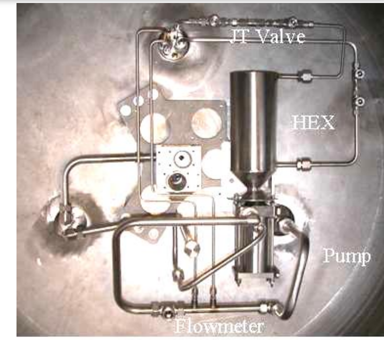
Cryogenic Propellant Storage and Transfer Functions that CPST Can Demonstrate

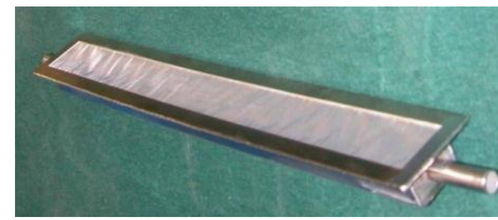


Pressurization
- Cold helium
- Autogenous





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



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

Liquid Acquisition
- Capillary retention devices LADs vanes, etc.

Propellant Transfer
- Settled/unsettled
- No-vent fill

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