



**NASA STMD Cryogenic Fluid Management Portfolio Project Office**  
**NASA Cryogenic Fluid Management Flight Demonstration Summary:**  
**Lockheed Martin 2020 Tipping Point #646**  
**2023 Cryogenic Engineering Conference**

July 2023

**William Pratt and Danielle Richey, Lockheed Martin**

**Jack Chapman and R. Jeremy Kenny, NASA MSFC**

**Wesley Johnson and Ryan Grotenrath, NASA GRC**

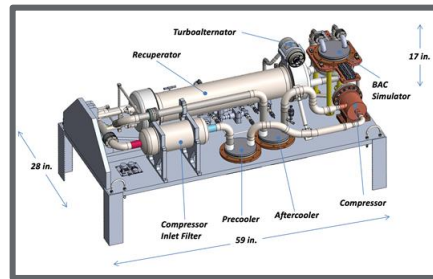
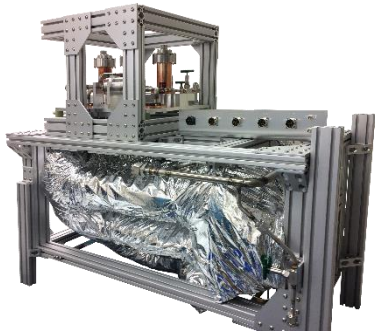
# CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT

Demonstrate Technologies enabling autonomous transfer and storage of cryogenic hydrogen, capable of scaling to tens of metric tons, with negligible losses for long duration in space and on the lunar surface.

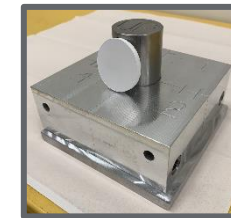
## Technology Gaps

- LOX/Methane CFM - Zero Boil Off and Liquefaction (100's Watts @ 90K)
- Zero- Long Duration Cryogenic Storage & Transfer (LO<sub>2</sub>, LCH<sub>4</sub>, LH<sub>2</sub>)
- Advanced Cryocoolers
- Cryogenic Fluid Transfer Operations
- Zero-g Cryogenic Fluid Modeling

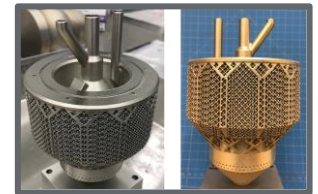
- Cryogenic thermal coatings
- Automated Cryo-couplers
- Propellant Densification
- High Vacuum Multi-Layer Insulation
- Unsettled liquid mass gauging
- Low Leakage Cryogenic Valves & Components
- High Capacity Cryocooler (20K / 20W)
- High Capacity Cryocooler (90K / 150W)
- Storage of LH<sub>2</sub> Utilizing both 90K & 20K Cryocoolers
- Leveraging Cryogenic 'Demo's of Opportunity' & Tipping Point Technologies
  - CLPS Intuitive Machines Nova-C Lander (RFMG Flight & Data Buy)
  - Tipping Point (Lockheed, ULA, Eta Space, SpaceX) Contracts Awarded
  - **Currently in execution**
- Fly CFM Demonstration mission in late 2020's with some of high-capacity active cooling
  - Occurs between Tipping Point & long-duration Mars flight in 2030's.
  - **Currently being studied**



RGCT Transfer Line Chilldown Test

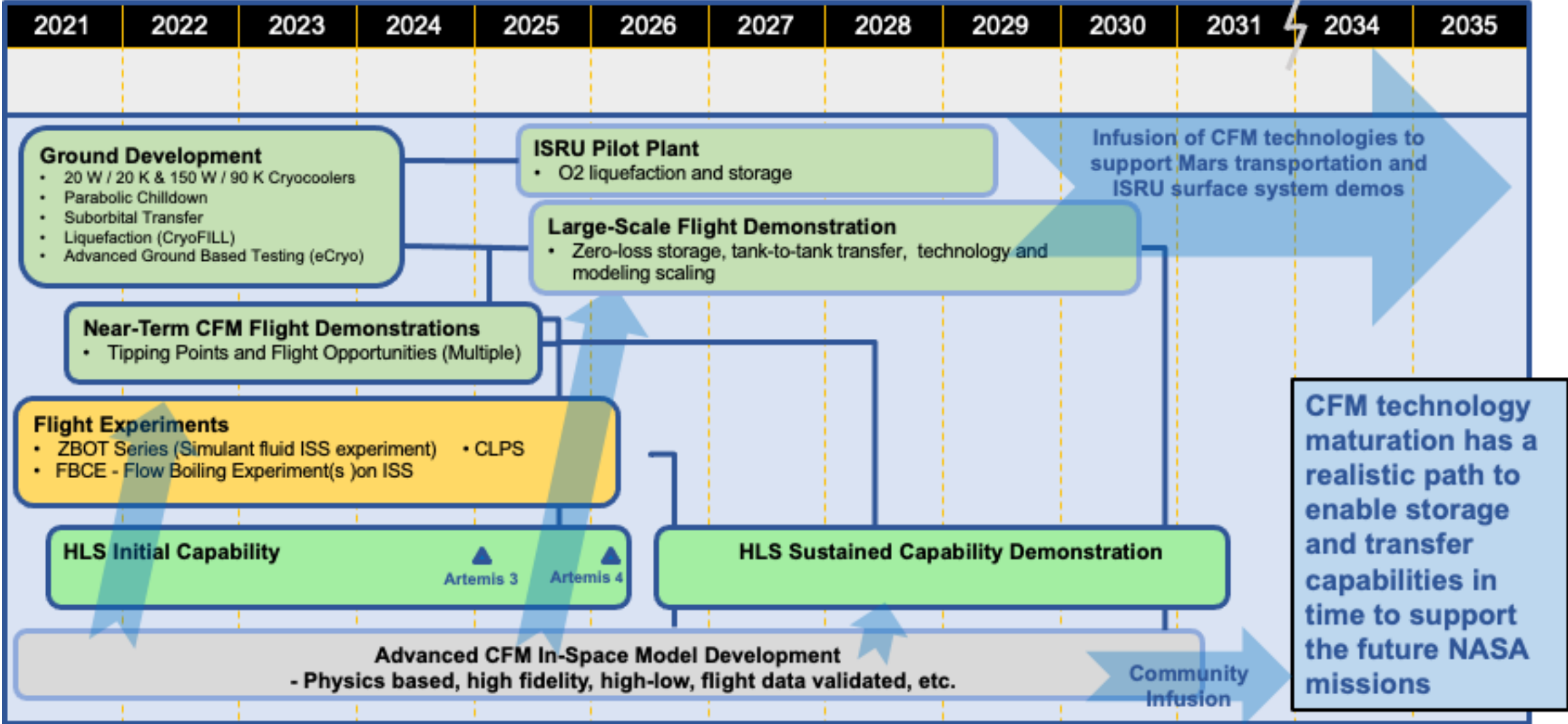


Solar White: One Inch Diameter Yttrium Oxide (Y2O3) Rigid Tile Sample Sitting on Sample Mold



Thermo-dynamic Vent

# NOTIONAL CFM DEVELOPMENT ACTIVITIES (DATES ARE EVOLVING)



■ STMD Technology Development  
 ■ SMD Foundational Experiment  
 ■ HEOMD Mission  
 ■ Modeling Efforts

# CDM PAYLOAD OVERVIEW

## Cryogenic Demonstration Mission (CDM)

*Lockheed Martin led mission for cryogenic fluid management systems*

### NASA STMD 2020 TIPPING POINT

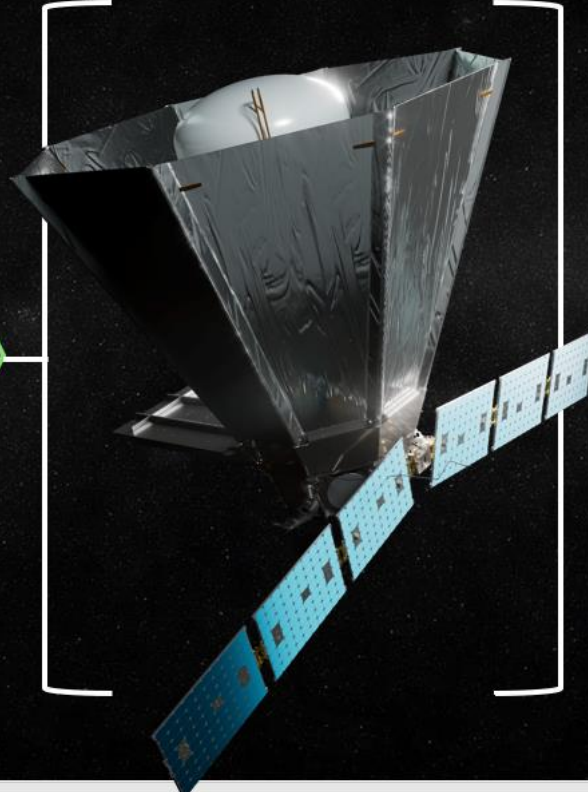
- In-space demonstration using liquid hydrogen
- Testing more than 12 cryogenic fluid management technologies
- Collaboration with Marshall Spaceflight Center and Glenn Research Center

# CDM TECHNOLOGY AREAS

## CDM Program Overview



*Integrated cryogenic hydrogen storage & transfer in a single automated spacecraft*



### ON-ORBIT TECHNOLOGY DEMONSTRATION MISSION

- Integrates foundational CFM technologies into a single automated spacecraft
- Advances each technology to at least TRL 7
- Prepares for future integration into large-scale CFM systems

# CDM MISSION RELEVANCE

## Mission Relevance

### *Building a Foundational Space Cryogenic System for Exploration*

- Robotic Deep Space Exploration
- Human Exploration
- Planetary Surface Systems
- In-Space Refueling

Copyright © 2022 by Lockheed Martin Corporation. All Rights Reserved.





[www.nasa.gov](http://www.nasa.gov)

# 2020 TIPPING POINT CONTRACTS – ‘RIDESHARE CFM FLIGHT DEMOS’

## SpaceX

### On-Orbit Large-Scale Cryogenic Propellant Management and Transfer Demonstration

Overview: Demonstration of large-scale on-orbit cryogenic fluid transfer (> 10 metric tons) between tanks on a Starship in orbit and management to provide a basis for operational use of in-space refueling technology.

#### Mission Overview:

- Demonstration conducted as part of a Starship flight
- Active settling maneuver
- Settled transfer between main propellant tank and header tank located in the nosecone.
- ~1 day mission duration

Projected Flight: 2023



*Starship  
Launch  
Vehicle*

## ULA

### Cryogenic (H<sub>2</sub>/O<sub>2</sub>) Smart Propulsion Flight Demonstration

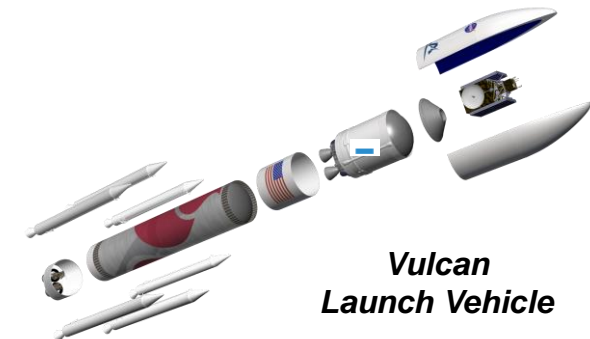
Overview: Flight demonstration of key CFM technologies:

- passive thermal control,
- tank pressure control,
- tank-to-tank propellant transfer

#### Mission Overview:

- Demonstration occurs after primary spacecraft is separated; demonstration hardware integrated with Centaur V
- ~1 day on-orbit duration

Projected Flight: 2025



*Vulcan  
Launch Vehicle*



# 2020 TIPPING POINT CONTRACTS – ‘PAYLOAD CFM FLIGHT DEMOS’

## Eta Space

### Liquid Oxygen Flight Demonstration (LOXSAT-1)

Overview: Develop, launch and fly a technology demonstration payload designed to test multiple CFM technologies necessary for creating practical propellant depots.

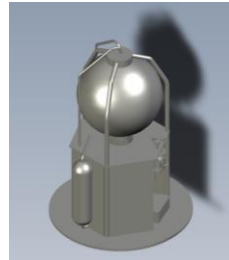
#### Mission Overview:

- Flight demonstration based on:
  - Zero fluid loss storage in LEO environment
  - Control of fluid position and thermodynamic state
  - Control of tank pressure using autogenous and helium pressurization
  - Tank-to-tank fluid transfer
- LOXSAT 1 hosted on a dedicated Rocket Lab Photon satellite bus
- ~ 9 month mission

Projected Flight: 2024



*Rocket Lab Electron Launch Vehicle*



*Eta Space LOXSAT-1 Payload*

## Lockheed Martin

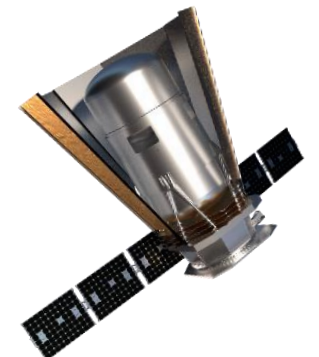
### Cryogenic Demonstration Mission (CDM)

Overview: Ground testing and flight demonstration of cryogenic LH2 transfer and long duration storage in space. CDM incorporates CFM technologies into a single system that demonstrates the transfer, storage, and pressure control of LH2 through ground testing and flight demonstration.

#### Mission Overview:

- Demonstrate passive and active LH2 storage
- Demonstrate transfer of LH2 between a storage tank and receiver
- ~ 2 month mission demonstration

Projected Flight: 2025



*Lockheed Martin CDM Payload*

