EXPLORE SPACE TECH

TECHNOLOGY DRIVES EXPLORATION

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Space Technology Mission Directorate

Technology Demonstrations Overview

Objectives

- Maintain a portfolio of projects that support **STMD's Strategic Investment Plan** developed from the Agency's future mission needs
- **Partner** with organizations that provide cost sharing and technology transition or infusion opportunities
- Conduct cross cutting system-level demonstrations that **reduce risk** and/or **achieve flight readiness** of new technologies and capabilities for exploration missions, science missions, OGA's and industry use
- Enable **transition** and/or **infusion** of technologies or capabilities into NASA missions and the Nation's space enterprise

Goal -- Bridge the gap between **development and mission infusion** by maturing cross-cutting system-level technologies through demonstration in relevant operational environments. (TRL 5-7)

In late 2010, TDM was initiated as part of the NASA portfolio of technology programs. As a Level 2 Program **hosted at Marshall Space Flight Center** within the Science and Technology Office.

TDM, an uncoupled program, is the largest program in NASA's Space Technology Mission Directorate, representing **43%** of STMD's overall budget in FY21, of which **62%** is congressionally directed.

Types of Demonstrations

Spaceflight-based to mature new technologies that have been successfully demonstrated to a high-fidelity prototype that is then tested in a space environment

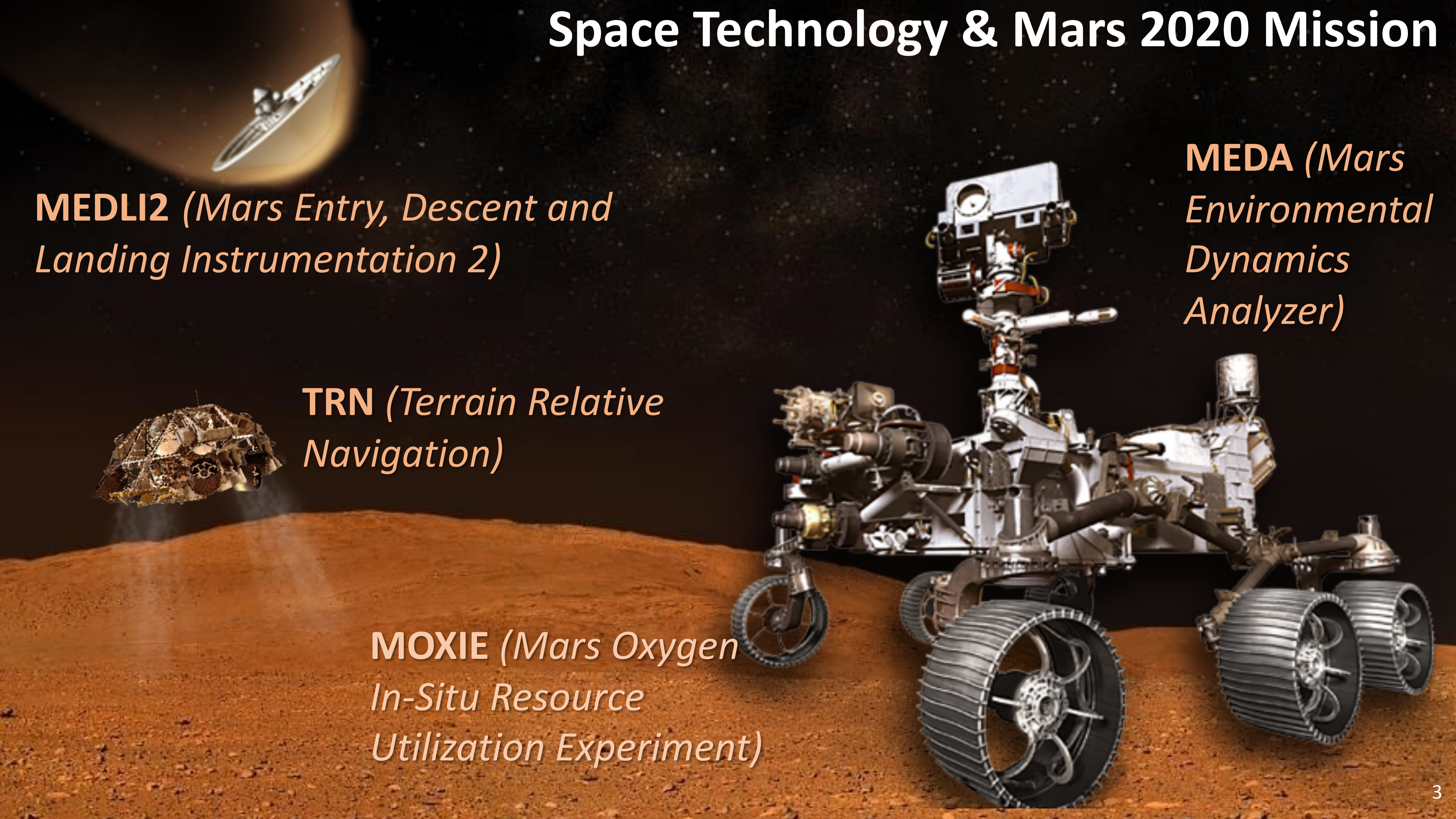
Ground-based to mature new technologies to the point of a high-fidelity prototype that may subsequently be integrated into a demonstrational or operational flight mission

TDM's budget has grown from $64.6M (FY11) to **$459.2M** (FY21).

In January 2012, TDM was approved to enter implementation and has since managed **36** projects.

In FY 21, a total of **19** technology demonstration projects were managed for STMD.

Space Technology & Mars 2020 Mission



MEDLI2 *(Mars Entry, Descent and Landing Instrumentation 2)*

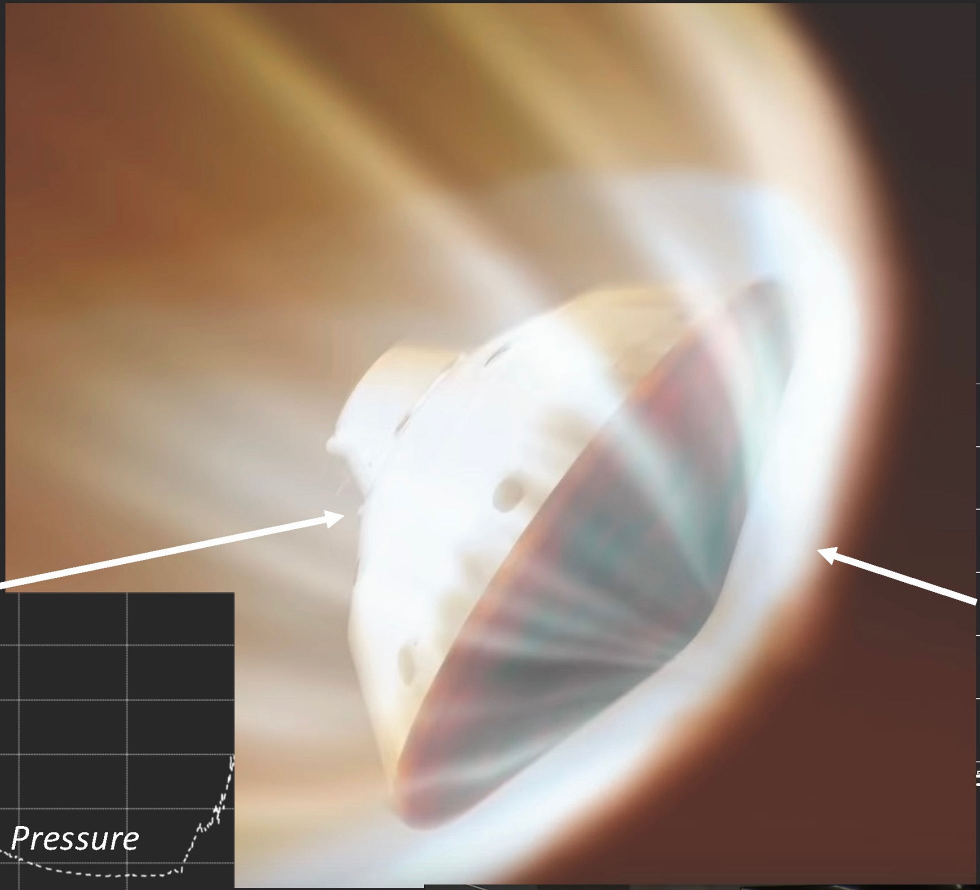
MEDA *(Mars Environmental Dynamics Analyzer)*

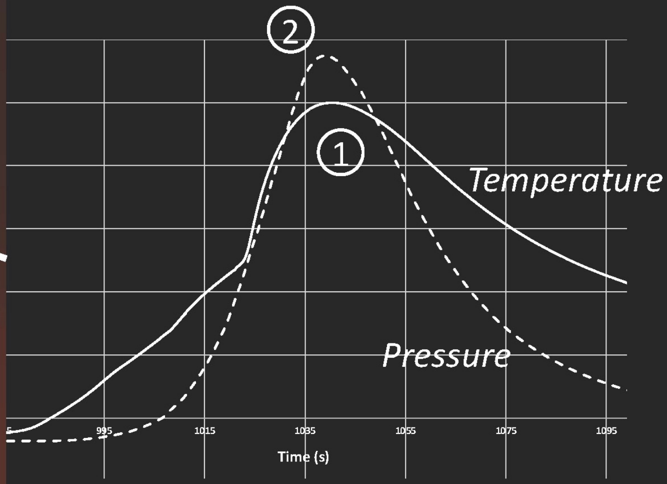
TRN *(Terrain Relative Navigation)*

MOXIE *(Mars Oxygen In-Situ Resource Utilization Experiment)*

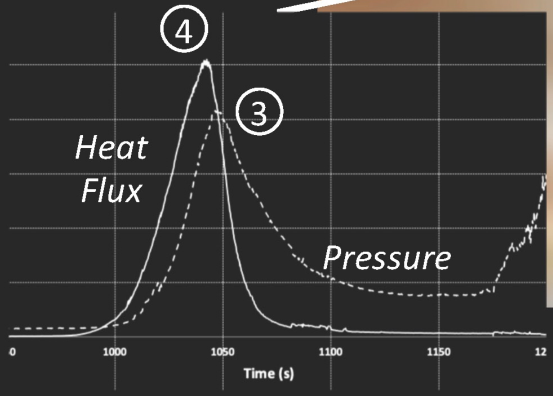
MEDLI2

Mars Entry, Descent and Landing Instrumentation 2

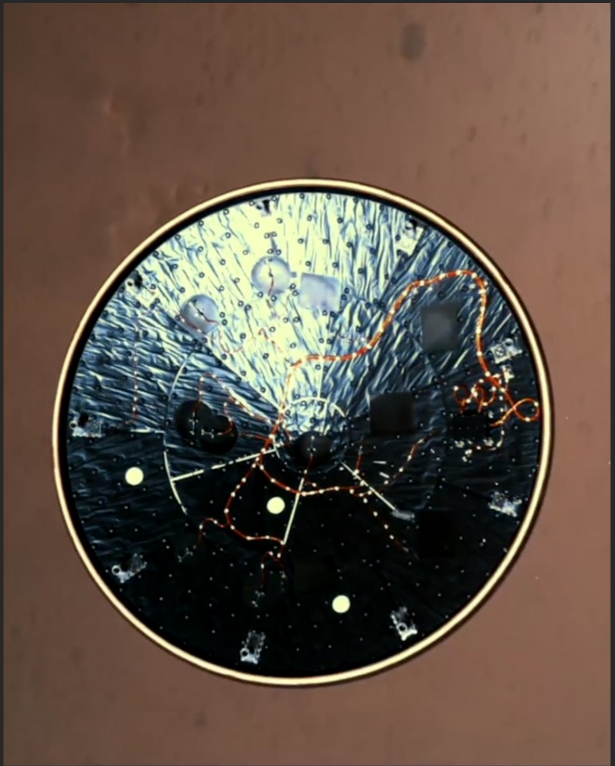




11 temperature measurements & 7 surface pressure measurements on the Heatshield (HS)

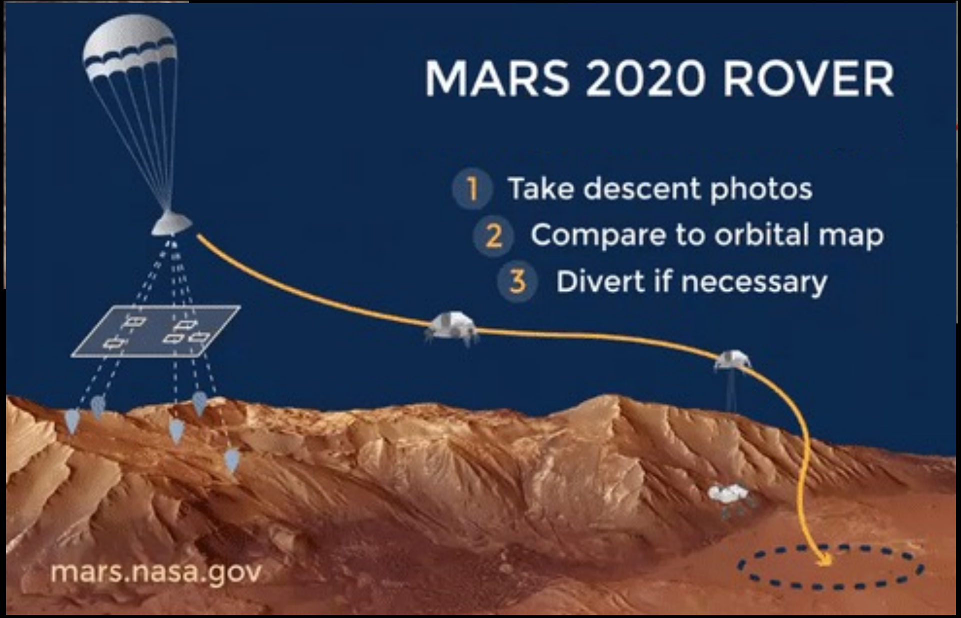


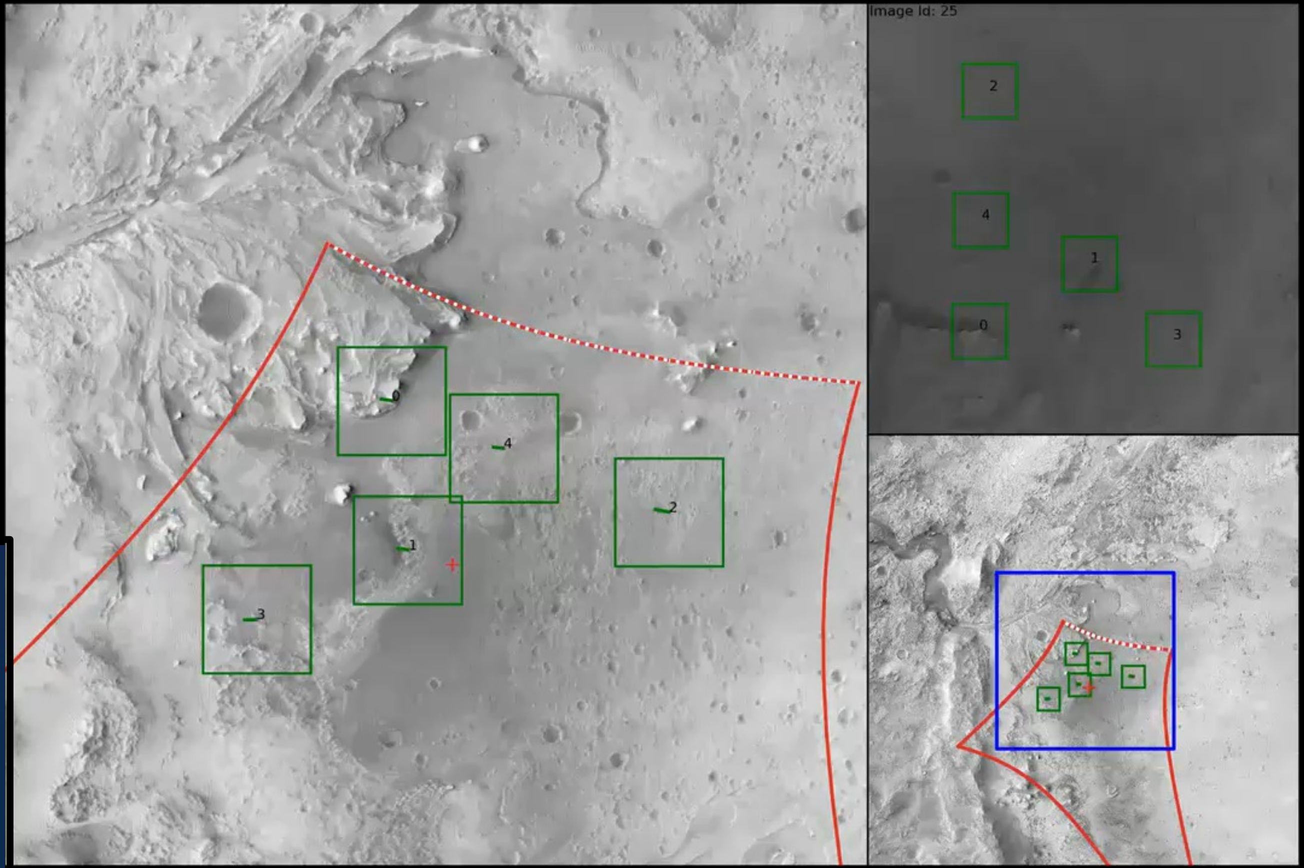
7 temperature, 3 heat flux, & 1 surface pressure measurements on the Backshell (BS)



TRN

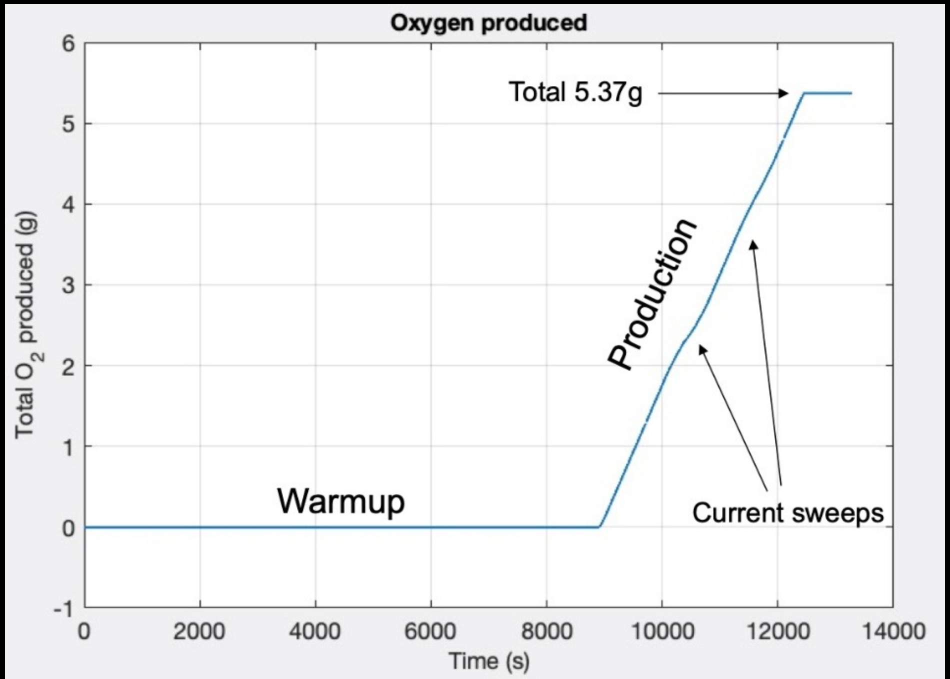
Terrain Relative Navigation





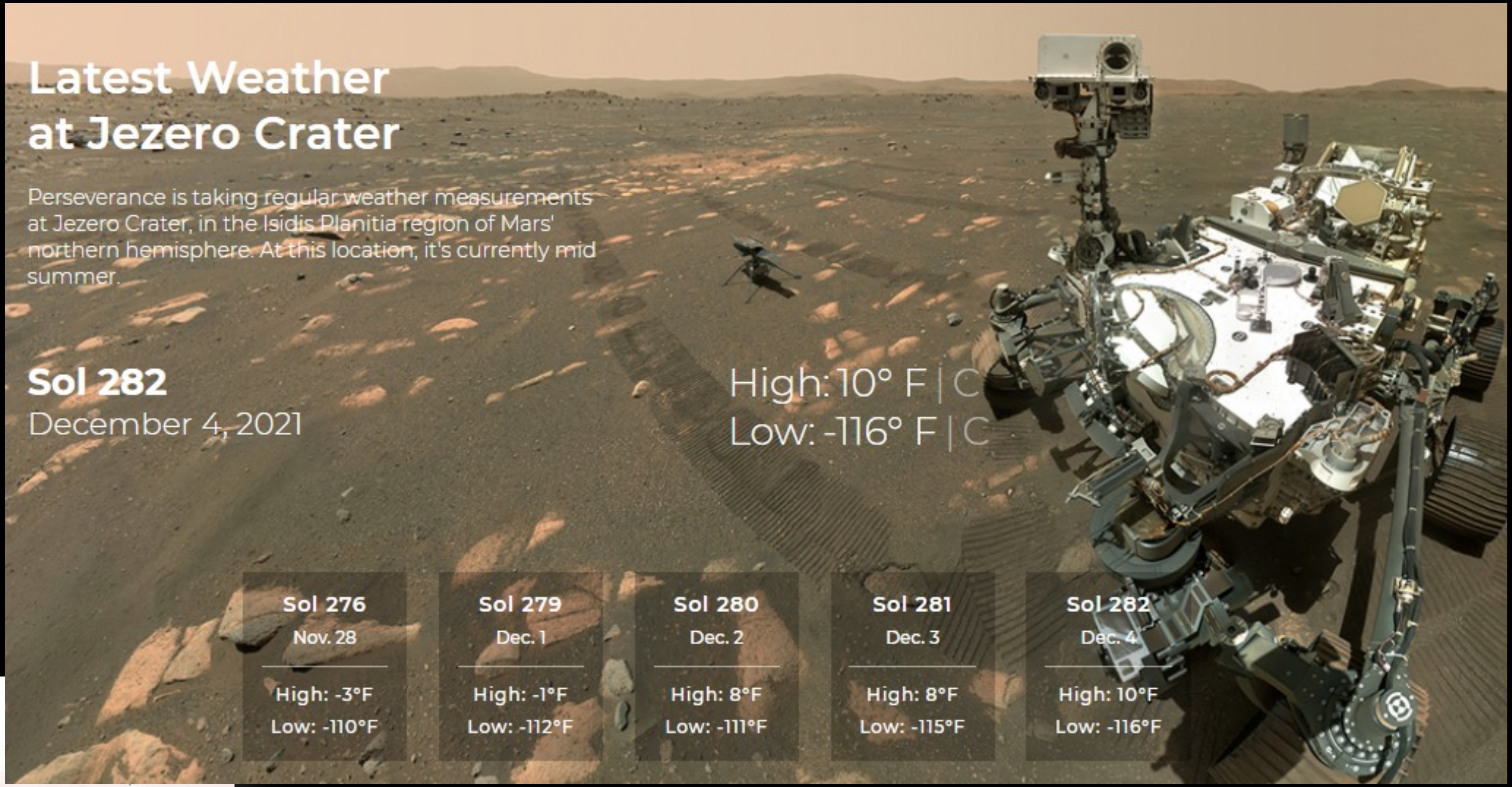
MOXIE

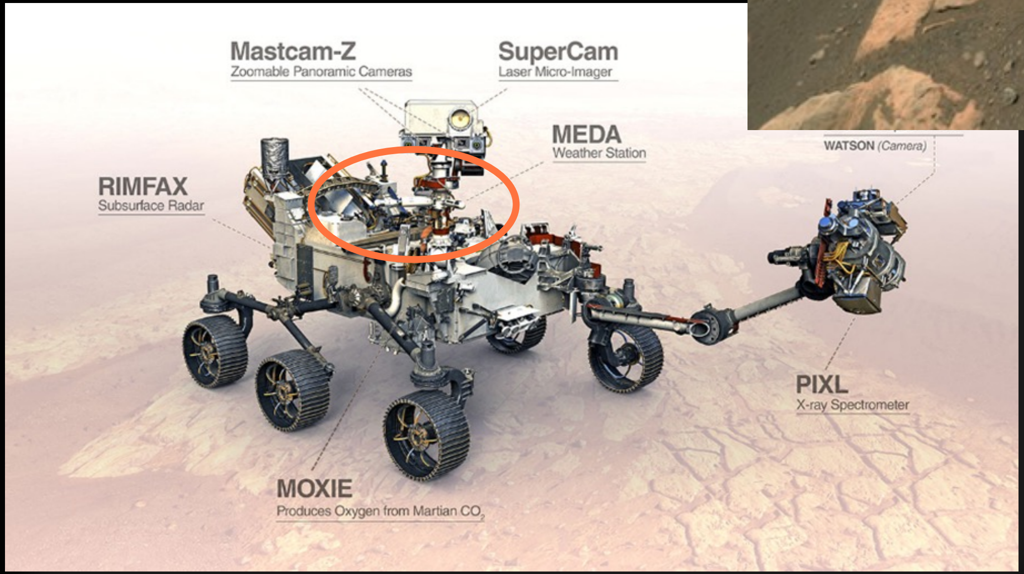
Mars Oxygen In-Situ Resource Utilization Experiment



OC #	FM-OC9	FM-OC10	FM-OC11	FM-OC12	FM-OC13	FM-OC14
Comment	1st oxygen!	1st microphone	1st daytime run	1st Temperature sweep (to determine series resistance)	1st flow sweep (to determine oxygen purity)	Generic nighttime run (intermediate density)
Sol	60	81	100	155	177	241
Total O2 (g)	5.4	7.0	7.0	9.0	8.2	6.9
Peak rate (g/hr)	6.0	8.0	8.0	6.0	6.9	7.6
Duration (min)	59	74	71	96	82	74
Time of day	Night	Night	Day	Night	Night	Night
Microphone	No	Yes	Yes	Yes	Yes	Yes
Predecessors	Aliveness test (Sol 4) RCT check (sol 13) Full health check (sol 14) Compressor sweep (sol 55)	Compressor sweep w/ microphone (sol 79)	Daytime compressor sweep w/ microphone (sol 96)	None	None	None

MEDA
Mars Environmental Dynamics Analyzer





Cryogenic Fluid Management (CFM) Technologies

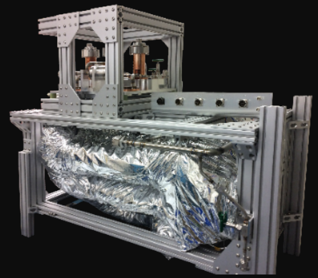
Demonstrate Technologies enabling autonomous transfer and storage of cryogenic hydrogen, capable of scaling to tens of metric tons, with negligible losses for long duration in space and on the lunar surface.

Current CFM Technology Development, Enabling Future Mission Planning:

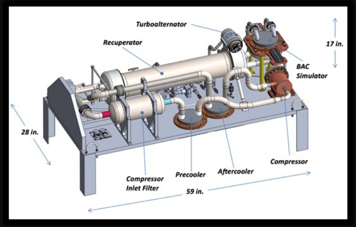
- Cryogenic thermal coatings
- Automated Cryo-couplers
- Propellant Densification
- High Vacuum Multi-Layer Insulation (IFUSI and CELSIUS)
- Unsettled liquid mass gauging
- Low Leakage Cryogenic Valves
- High Capacity Cryocooler (20K 20W)
- High Capacity Cryocooler (90K 150W)
- Storage of LH_2 Utilizing both 90K & 20K Cryocoolers (2-Stage Cooling)
- Leveraging Cryo-genic 'Demo's of Opportunity' & Tipping Point Technologies
    - CLPS Intuitive Machines Nova-C Lander (RFMG Flight & Data Buy)
    - Tipping Points (Lockheed, ULA, Eta Space, SpaceX) -- **All contracts awarded**

Technology Gaps

- LOX/Methane CFM - Zero Boil Off and Liquefaction (100's Watts @ 90K)
- Zero-g Long Duration Cryogenic Storage & Transfer (LO_2, LCH_4, LH_2)
- Advanced Cryocoolers
- Cryogenic Fluid Transfer Operations
- Zero-g Cryogenic Fluid Modeling



20W 20K Cryocooler Brassboard



150W/ 90K Cryocooler Conceptual Design

CFM Tipping Point Flight Demonstration 2021 Awarded Public Private Partnerships

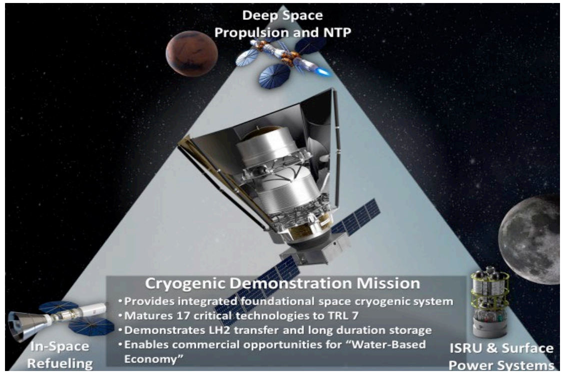
LOCKHEED MARTIN

Ground testing and 60-day flight demonstration for launch in FY24.

- Long duration storage and LH2 transfer demonstration
- Incorporates 17 critical NASA identified technologies
- Enables commercial opportunities for "water based space economy"

Project Team:

- Lockheed Martin (Prime)
- Momentus
- KT Engineering
- QualiTech
- YetiSpace
- NASA GRC, MSFC



SPACEX

Demonstration in FY23 of large-scale on-orbit cryogenic fluid transfer (more than 10 metric tons between tanks on a Starship in orbit) and management.

- Provides basis for operational use of in-space refueling technology, a key enabler for reusable, sustainable space transportation and the broader commercialization of space.

Project Team:

- SpaceX (Prime)
- NASA GRC, MSFC

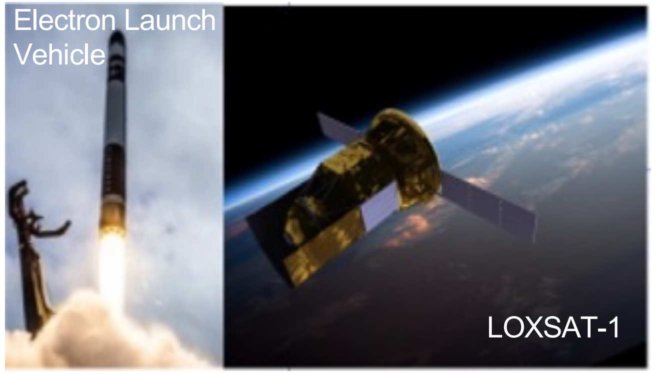
Starship's Cryogenic Propellant Transfer Capabilities will enable ambitious missions beyond LEO

ETA SPACE

Develop, launch in FY24 and fly a 9-month technology demonstration payload designed to test over 10 different CFM technologies necessary for creating practical propellent depots.

Project Team:

- Eta Space (Prime)
- Rocket Lab
- Ametek (Sun Power)
- Florida Tech
- Firefly Aerospace
- Altius Space Machines
- Yetispace
- NASA GRC, KSC, MSFC



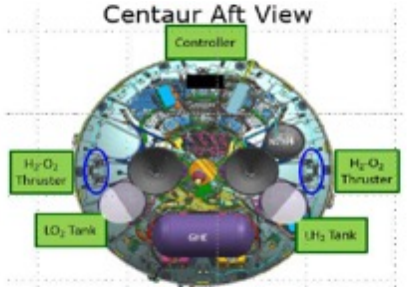
ULA

Flight demonstration in FY25 (TBR) of 3 key Cryogenic Fluid Management technologies: passive thermal control, tank pressure control, and tank to tank propellant transfer.

- Benefits include 20% increase in Vulcan Centaur launch performance, extending Centaur mission duration from hours to months and enhanced confidence in cryogenic lunar lander benefiting USG missions, including HLS and commercial payloads.

Project Team:

- ULA (Prime)
- Innovative Engineering Solutions
- Space Micro Inc.
- YetiSpace
- Dynetics
- NASA GRC, KSC, MSFC



Lockheed Martin

Cryogenic Demonstration Mission (CDM)

Project Overview:

Ground testing and flight demonstration of cryogenic LH2 transfer and long duration storage in space. CDM incorporates 17 critical technologies identified by NASA into a single system that demonstrates the transfer, storage, and pressure control of LH2 through ground testing and flight demonstration.

Critical CFM technologies to be assessed include:

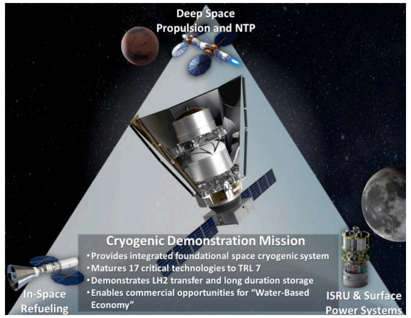
- Valves, Actuators and Components
- Helium Pressurization of an Unsettled Tank
- Main Propellent System Line Chilldown
- Liquid Acquisition Devices (LAD)
- Automated Cryo-Couplers
- Propellent Tank Chilldown
- Transfer Operations
- Flowmeters
- Low Conductivity Structures
- High Vacuum Multilayer Insulation (MLI)
- Tube-on-Shield Broad Area Cooling (BAC)
- Vapor Cooling
- Pump Based Mixing
- Thermodynamic Vent System (TVS)
- High Capacity/High Efficiency Cryocoolers 90K
- Propellent Densification
- Unsettled Liquid Mass Gauging

Project Team:

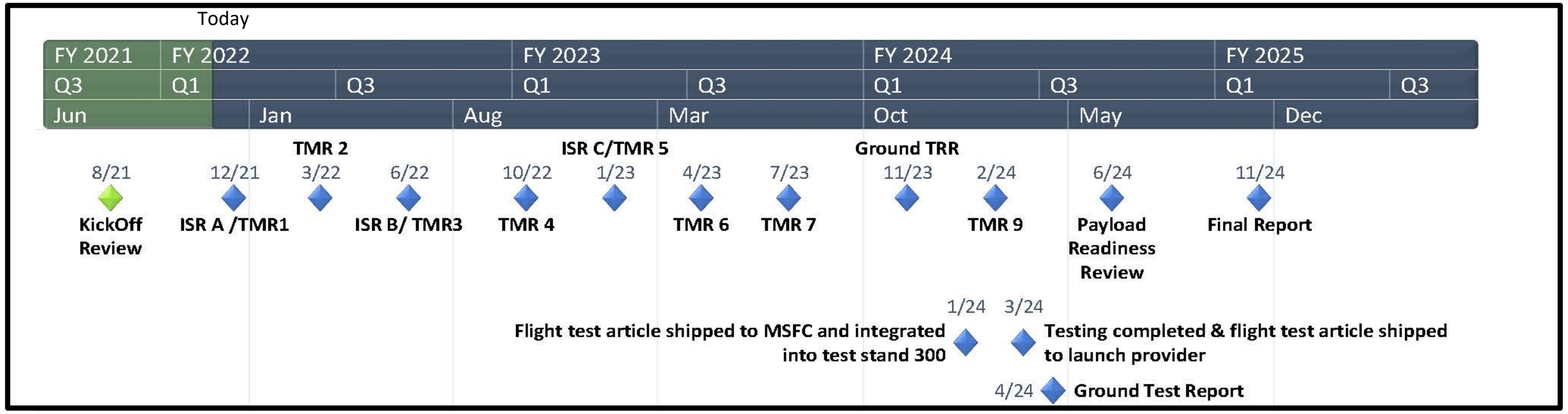
- Lockheed Martin (Prime)
- Momentus
- KT Engineering
- QualiTech
- Yetispace
- NASA GRC, MSFC

Mission Overview/ Milestones:

- 400 to 600 km orbit, 28.5 degree to Sun Sync inclination
- CDM hosted on a Momentus satellite bus
- 60-day technology demonstration, 85-day total mission



Project Timeline:



SpaceX

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

<u>Project Overview:</u>

Demonstration of large-scale on-orbit cryogenic fluid transfer (more than 10 metric tons between tanks on a Starship in orbit) and management to provide a basis for operational use of in-space refueling technology, a key enabler for reusable, sustainable space transportation and the broader commercialization of space.

<u>Project Team:</u>

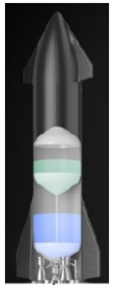
- SpaceX (Prime)
- NASA GRC, MSFC

<u>Mission Overview:</u>

- Demonstration conducted as part of a Starship flight
- Orbit insertion, header tank venting
- Coast phase (propellant settling, heating, boil-off rate and propellant stratification data collection)
- Active settling maneuver
- Autogenous pressurization and propellant transfer

<u>CFM demonstration will include:</u>

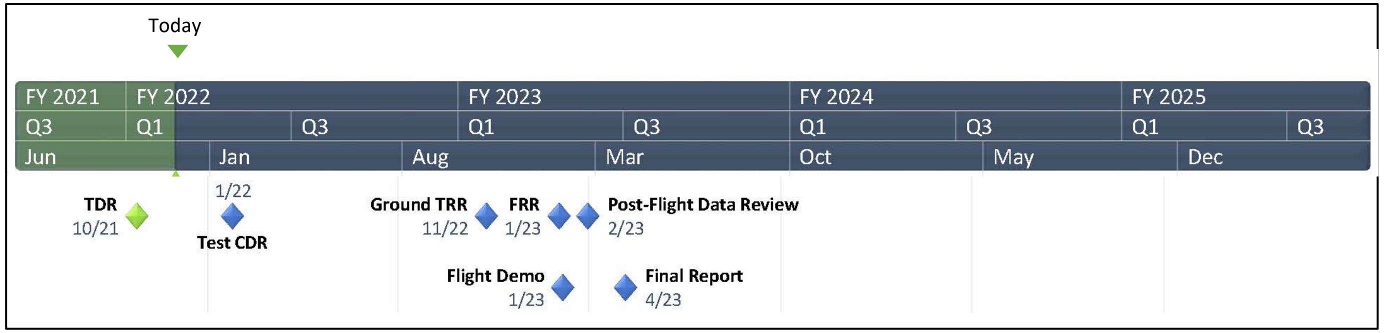
- Tank pressure control and propellant management
- Transfer line chill-down and flow-control
- Receiving tank chill-down and high fill level capability
- Demonstration of propellant storage and boil-off characterization
- Instrumentation and onboard video to characterize performance and monitor propellant fill levels and provide opportunities to improve propellant mass gauging capabilities



Starship

Starship's Cryogenic Propellant Transfer Capabilities will enable ambitious missions beyond LEO

<u>Project Timeline:</u>



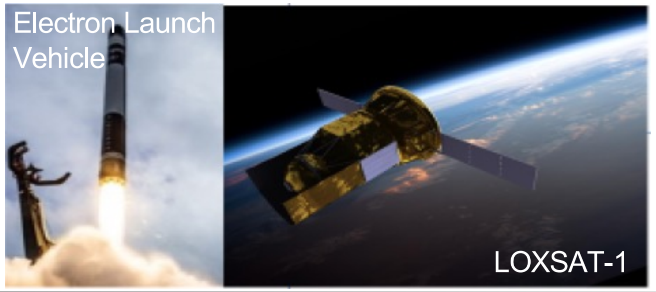
Eta Space
LOXSAT 1

Project Overview:
Develop, launch and fly a 9-month technology demonstration payload designed to test over 10 different CFM technologies necessary for creating practical propellent depots.

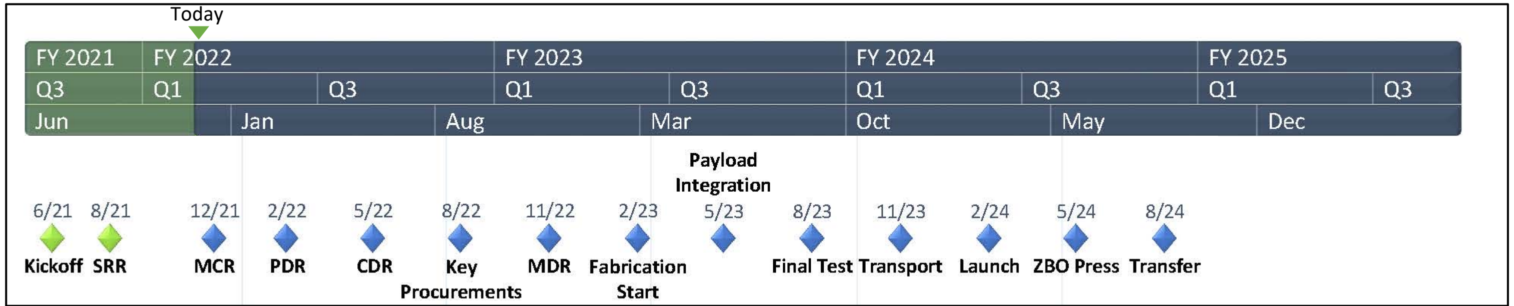
CFM Technologies Include:
LOXSAT 1 will test a suite of CFM technologies previously developed and ground tested. CFM technologies include:
- Active and passive thermal control
- Cryogenic chill down and transfer
- Pressure control
- Ground densification
- Fluid surface visualization tools
- Autogenous vs. helium pressurization
- Liquid acquisition devices (LAD)
- Zero boil off (ZBO) with pump mixing
- High capacity 90K cryocoolers
- Ground to flight insulation
- Low conductivity supports
- Zero-g chill down and transfer
- Cryogenic quick disconnects
- Ground densification for thermal energy storage

Project Team:
- Eta Space (Prime)
- Rocket Lab
- Ametek (Sun Power)
- Florida Tech
- Firefly Aerospace
- Altius Space Machines
- Yetispace
- NASA GRC, KSC, MSFC

Mission Overview:
- 500 km Sun synchronous orbit
- LOXSAT 1 hosted on a dedicated Photon satellite bus
- Minimum 9 month mission



Project Timeline:



United Launch Alliance (ULA)

Cryogenic (H_2/O_2) Smart Propulsion Flight Demonstration

Project Overview:

Flight demonstration of 3 key Cryogenic Fluid Management technologies including passive thermal control, tank pressure control, and tank to tank propellant transfer.

Benefits include 20% increase in Vulcan Centaur launch performance, extending Centaur mission duration from hours to months and enhanced confidence in Dynetics cryogenic lunar lander benefiting USG missions, including HLS and commercial payloads.

Project Team:

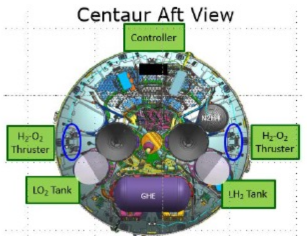
- ULA (Prime)
- Innovative Engineering Solutions
- Space Micro Inc.
- Yetispace
- Dynetics
- NASA KSC, MSFC, GRC

Mission Overview:

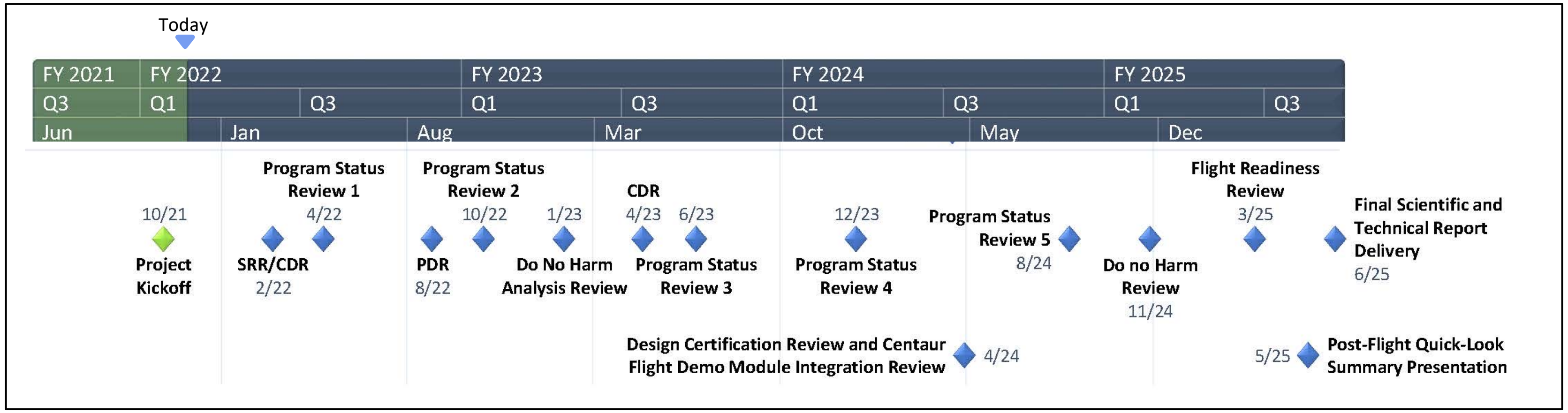
- Demonstration occurs after primary spacecraft is separated; demonstration hardware integrated with Centaur V
- Demonstration is a multi-month on-orbit duration

CFM technologies to be demonstrated include:

- Tank Pressure Control (Short duration precision autogenous tank pressure control demonstration)
- Tank-to-Tank Transfer (Tank-to-Tank LO2 and LH2 transfer)
- Passive Thermal Control (Low LO2 and LH2 boiloff over an extended duration)



Project Timeline:



CFM Strategy & Forward Path

- Execute Tipping Points to Fly CFM Technologies
  - A significant number of technology advancements will be achieved through Tipping Point flights
  - Key technology gaps needed for Mars Mission will remain
    – High capacity cryo-coolers, 2-stage cooling, unsettled cryo-transfer, etc.

- Prove out utilization of 90K & 20K Cryo-Cooler (2-Stage Cooling) to Store LH_2
  - Analytically Shown to Save Mass & Power for Mars Missions
  - Once Proof-of-Concept Is Complete in FY22, Transition Technology Effort into Delivering Flight-Rated High-Capacity Cryo-Coolers

- Continue Ground Development of Ancillary CFM technologies
  - Cryo-Coupler, Valves, Low Conductivity Structures, Solar White
  - Support Landers, Modeling and Other/Seedlings

- Continue Leveraging 'Demos of Opportunity' to Understand Fluid Behavior and Technology Advancement
  - Pressure control methods & Mass Gauging
  - Liquid Acquisition and Cryo Fluid behavior in low-g/micro-g
  - Detailed data for storage, line and tank chill-down model anchoring

- Fly CFM DEMO mission in late 2020's with some version of high-capacity active cooling
  - Would occur after Tipping Point flights, but before Mars flight in 2030's


Technology Drives Exploration