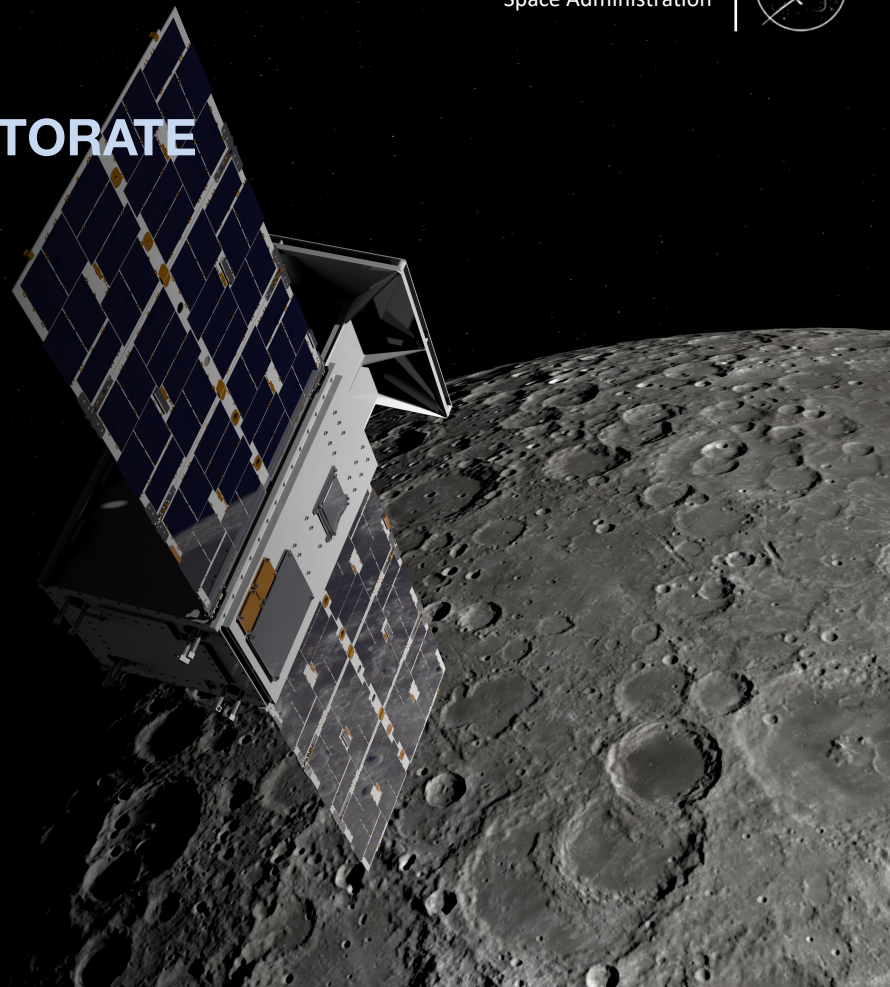
National Aeronautics and
Space Administration

SPACE TECHNOLOGY MISSION DIRECTORATE
SMALL SPACECRAFT TECHNOLOGY

ROGER HUNTER
Program Manager
Small Spacecraft Technology Program

KEYNOTE
4S SYMPOSIUM
VILAMOURA, PORTUGAL
20 MAY 2022



2022-2023 Launch Schedule

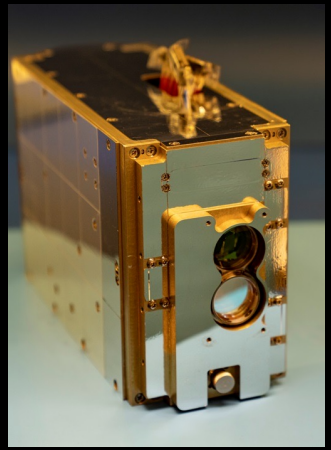
Technology Demonstrations	Launch Timeframe
Pathfinder Technology Demonstrator-3: *Payload: TBIRD 200GB Laser Communications*	May 25, 2022
CPOD: *CubeSat Proximity Operations Demonstration*	May 25, 2022
CAPSTONE: *Cislunar Autonomous Positioning System Tech Ops and Navigation Experiment*	May 31, 2022 (NET)
CLICK A: *CubeSat Laser Infrared CrossLinK*	Jun. 2022 (NET)
Starling: *Demonstration of Autonomous Swarm Technologies*	Summer 2022
PACE-2: *Payload Accelerator for CubeSat Endeavors*	Oct. 2022
ACS3: *Advanced Composite Solar Sail System*	Nov. 2022
Lunar Flashlight: *Mapping of Water and Volatiles at the Lunar Surface*	Late 2022
Pathfinder Technology Demonstrator-4: *Payload: LISA-T High-Power Deployable Solar Array Antenna*	Jan. 2023 (NET)
CLICK B/C: *CubeSat Laser Infrared CrossLinK*	Jun. 2023 (NET)
DiskSat*: A "Two-Dimensional" Bus Architecture*	2024

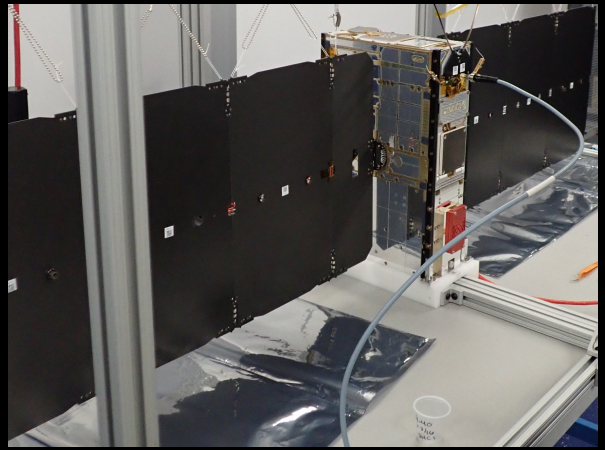
Pathfinder Technology Demonstrator 3 – TeraByte InfraRed Delivery (TBIRD)
Launch: May 25, 2022

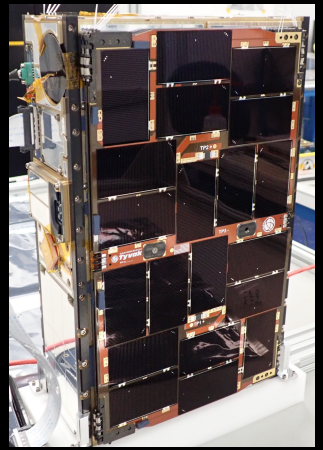
Mission Objective

The TeraByte InfraRed Delivery (TBIRD) will demonstrate optical communications downlink at 200 gigabits per second - the fastest the aerospace industry has ever seen.

Pathfinder Technology Demonstrator-3







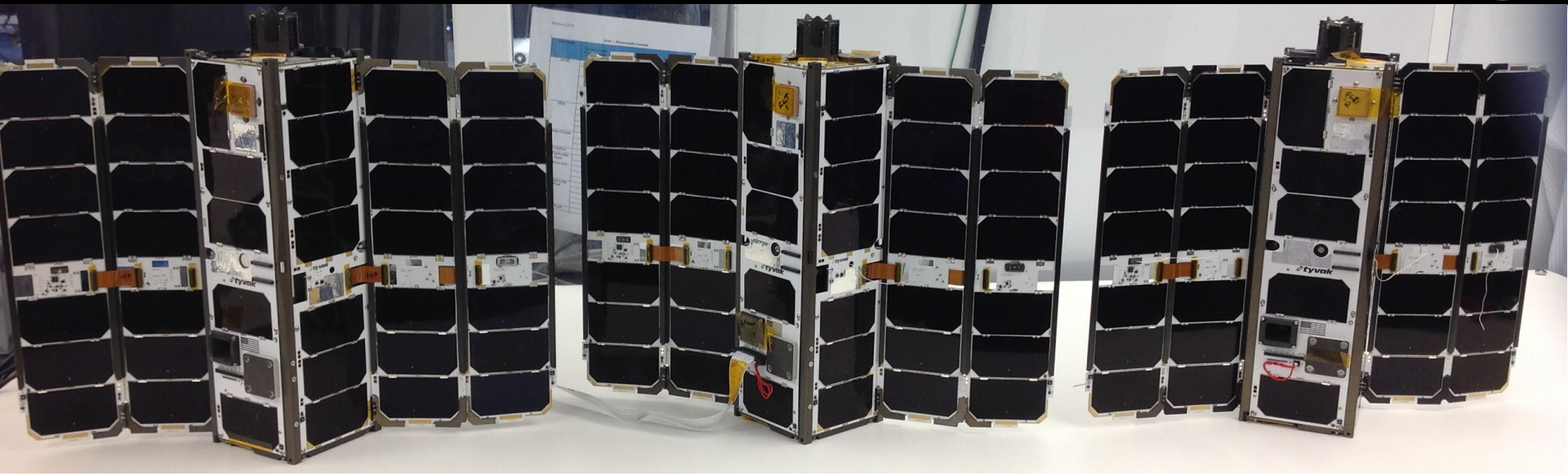
Partners: PTD-Mission Series

- NASA's Ames Research Center in California's Silicon Valley manages the PTD mission series.
- NASA's Small Spacecraft Technology program within the agency's Space Technology Mission Directorate is sponsoring the PTD mission series. The program is based at Ames.
- Terran Orbital Corporation of Irvine, California is developing the PTD spacecraft bus and performing payload integration and mission operations for each mission.

Partners: PTD-3

- The Massachusetts Institute of Technology's Lincoln Laboratory in Cambridge, Massachusetts is developing the optical communications system to be demonstrated on the PTD-3 mission. This technology is funded by NASA's Space Communications and Navigation (SCaN) program.
- NASA's Goddard Space Flight Center in Greenbelt, Maryland manages the TBIRD project, in addition to multiple other optical communications projects, demonstrating NASA's optical capabilities for future missions.

CubeSat Proximity Operations Demonstration - Launch: May 25, 2022



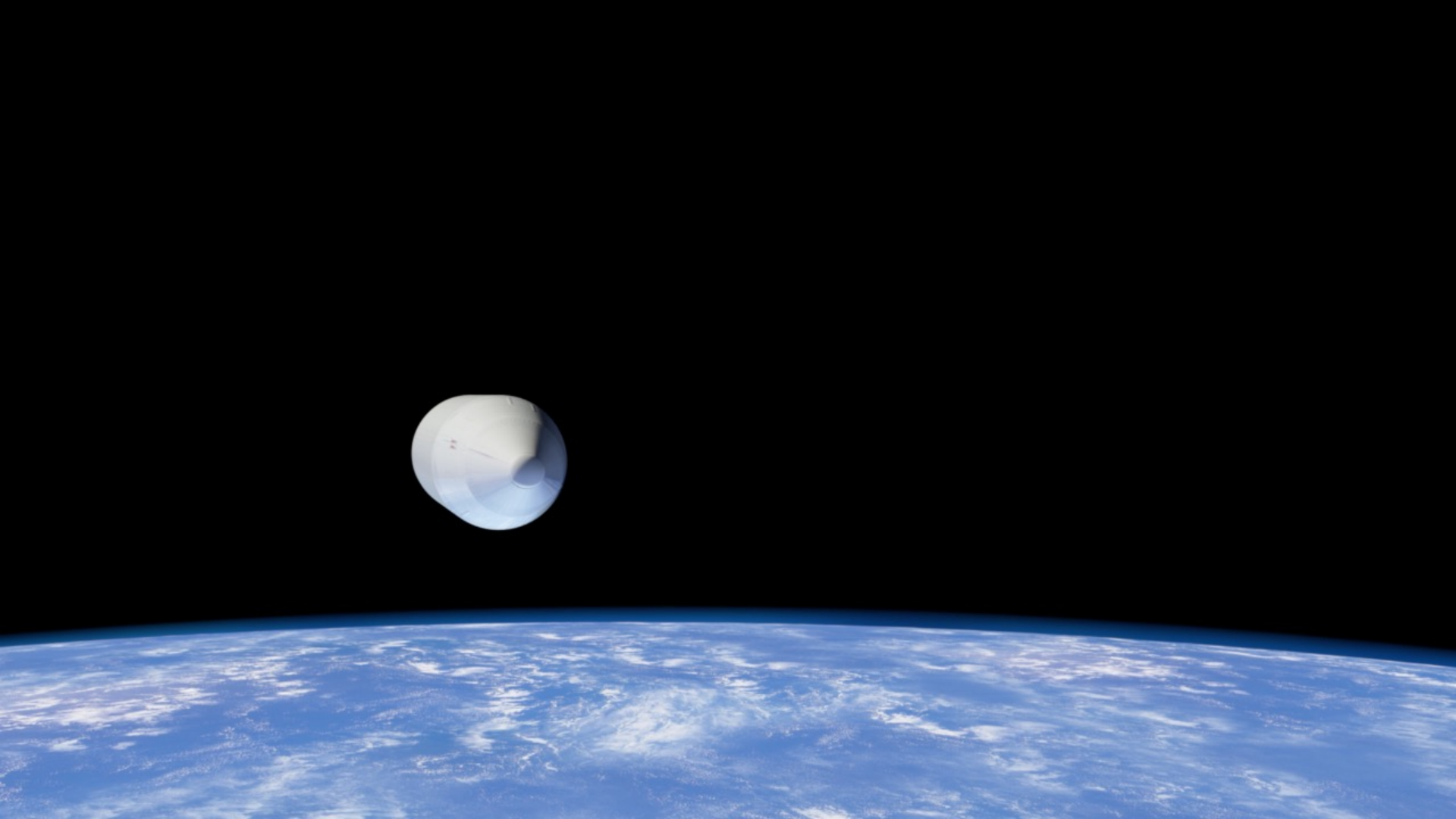
Mission Objectives

- CubeSat Proximity Operations Demonstration (CPOD) project will demonstrate rendezvous, proximity operations and docking (RPOD) using two 3U CubeSats.
- The two CPOD spacecraft will demonstrate relative station keeping.
- Docking will employ the use of a novel universal docking device, imaging sensors, and a multi-thruster cold gas propulsion system.

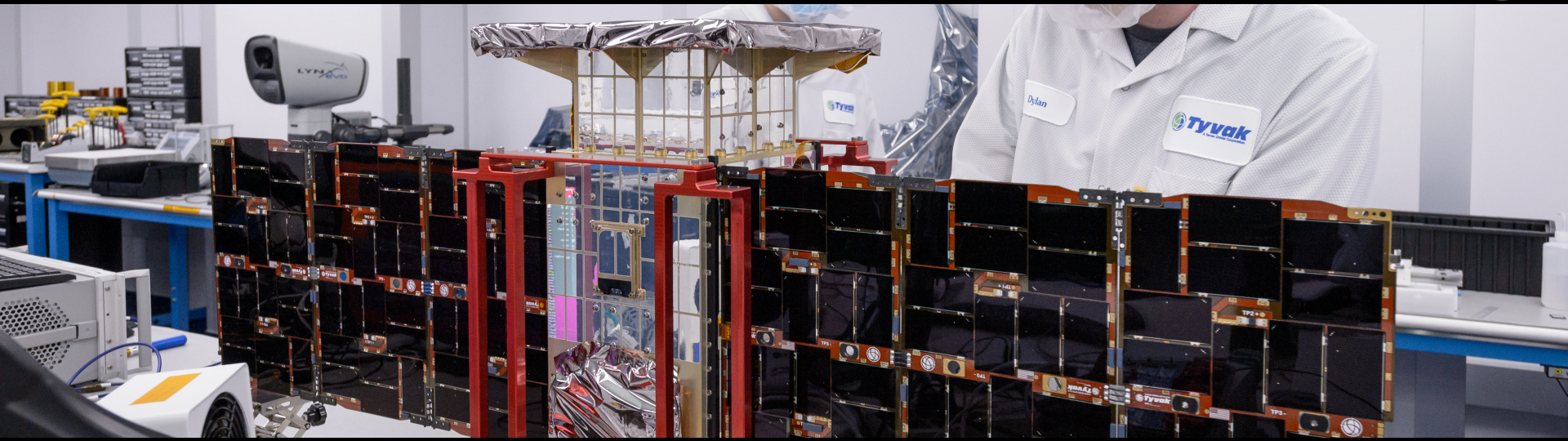
CubeSat Proximity Operations Demonstration

Partners:

- NASA's Small Spacecraft Technology program based at NASA's Ames Research Center in Silicon Valley and within the Space Technology Mission Directorate manages and funds the CPOD mission.
- Terran Orbital Corporation of Irvine, California leads the CPOD mission.



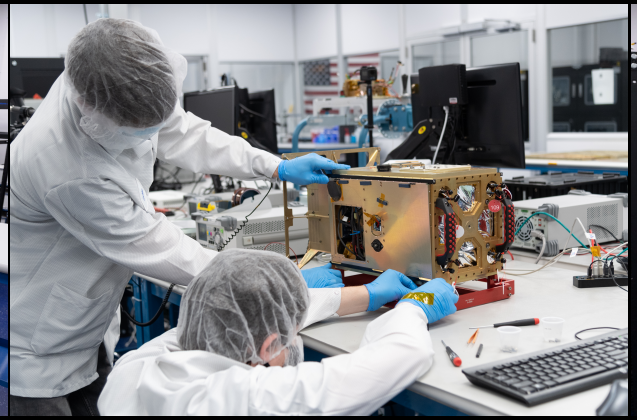
CAPSTONE - Launch Timeframe: NET May 31, 2022



Mission Objectives

- Verify the characteristics of a cis-lunar near rectilinear halo orbit for future spacecraft
- Demonstrate entering and maintaining this unique orbit that provides a highly-efficient path to the Moon's surface and back
- Demonstrate spacecraft-to-spacecraft navigation services that allow future spacecraft to determine their location relative to the Moon without relying exclusively on tracking from Earth
- Lay a foundation for commercial support of future lunar operations
- Gain experience with small dedicated launches of CubeSats beyond low-Earth orbit.

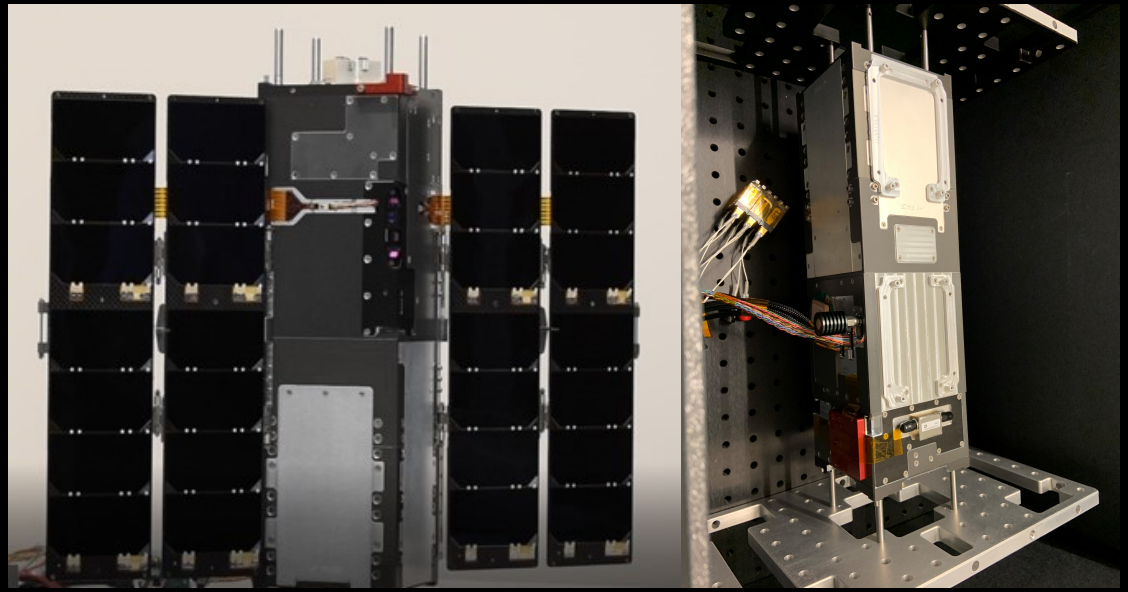
CAPSTONE


Partners

- Advanced Space of Westminster, Colorado, is developing and operating CAPSTONE.
- Terran Orbital Corporation, of Irvine, California, is building the CubeSat platform.
- Stellar Exploration, Inc. of San Luis Obispo, California, is providing CAPSTONE's propulsion system.
- Rocket Lab of Long Beach, California, is providing launch services. The launch is managed by NASA's Launch Services Program at NASA's Kennedy Space Center in Florida.
- NASA's Small Spacecraft Technology program within the agency's Space Technology Mission Directorate is managing the CAPSTONE project.
- NASA's Advanced Exploration Systems within the agency's Exploration Systems Development Mission Directorate is funding the launch and supporting mission operations.
- The development of CAPS is supported by NASA's Small Business Innovation Research (SBIR) program.
- NASA's Goddard Space Flight Center in Greenbelt, Maryland, manages LRO.

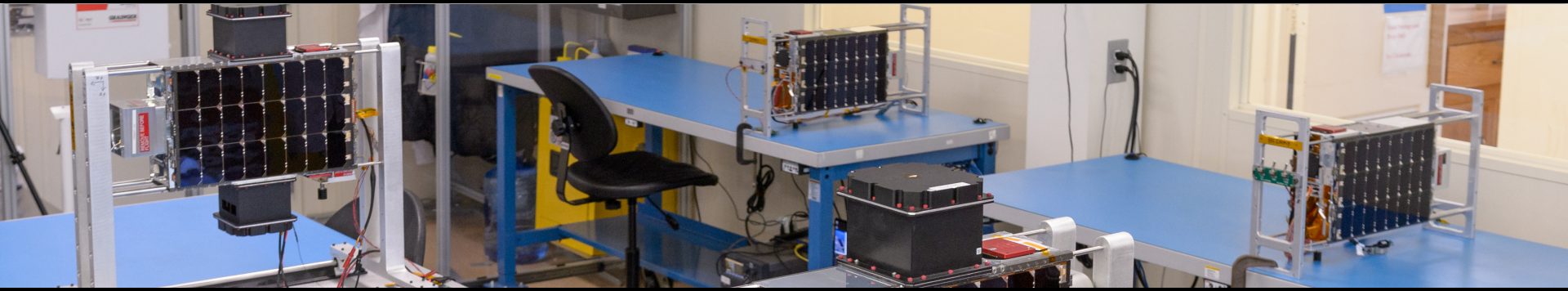
CubeSat Laser Infrared CrosslinK A – Launch Timeframe: June 2022



Mission Objectives

- The key objective of this risk reduction testing is to demonstrate the fine steering mirror control system's high precision pointing performance which enables the use of a lower power laser in CLICK B/C.
- The key performance metric of CLICK A is to establish a greater than 10 Mbps data downlink from the CLICK A spacecraft from an altitude of approximately 400 kilometers, to a 30-centimeter telescope on the ground.

Starling 1.0 - Launch Timeframe: Summer 2022

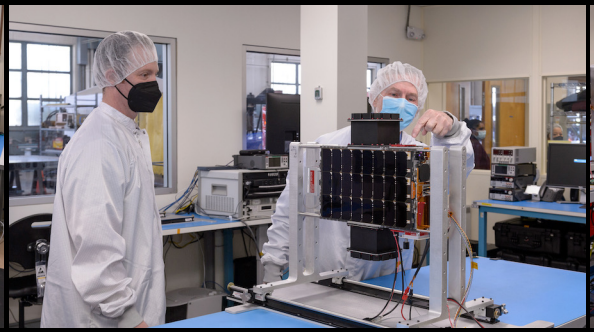
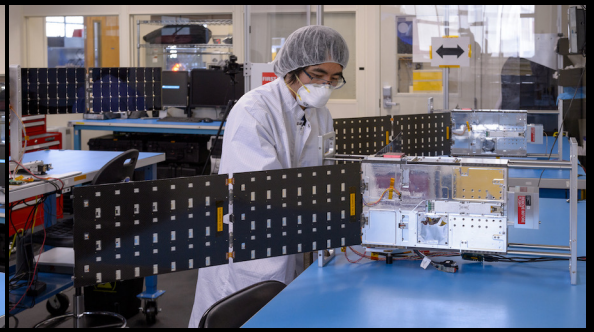


Mission Objectives

Starling will demonstrate technologies to enable multipoint science data collection by small spacecraft flying in swarms. The intent is to test each technology to understand what works, what are the limitations, and what is still needed in terms of swarm technology development. These technologies include:

- **Network communication protocols:** *(MANET – Crosslink/Networking)* – Autonomously map the network topology approach
- **Cluster flight control algorithms:** *(ROMEO – Onboard Cluster Flight Control)* - Autonomously maintain relative vehicle positions (e.g., GPS, ADCS, Prop)
- **Autonomous reactive operations software:** *(DSA – Distribute Spacecraft Autonomy)* - Autonomously reconfigure in response to external sensor data
- **Relative navigation algorithms:** *(StarFOX –Relative Navigation)* - Continuously estimate relative vehicle positions using standard spacecraft components

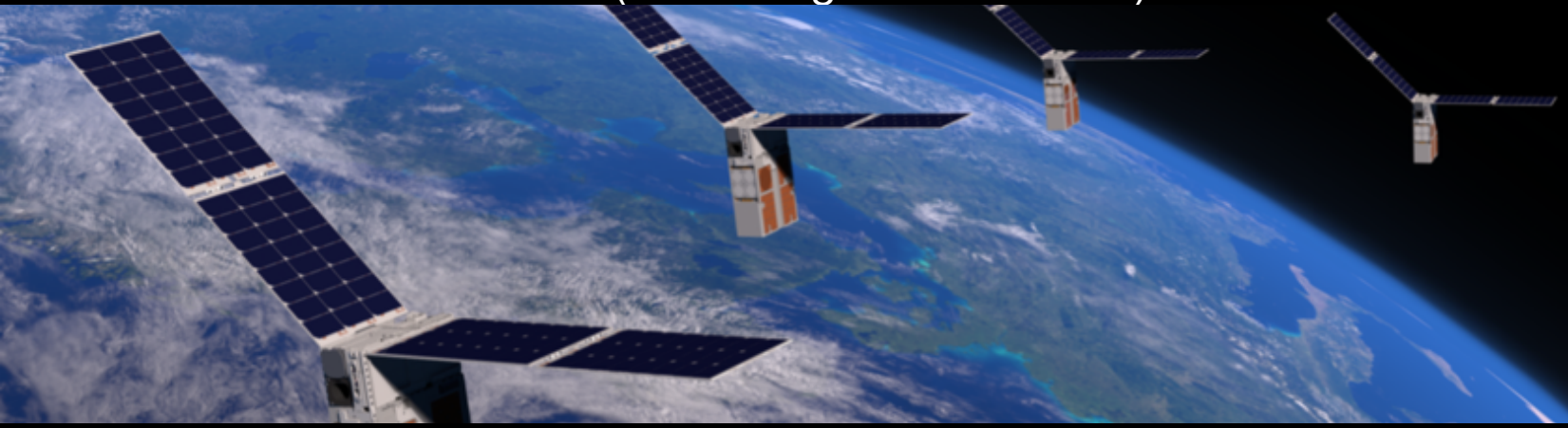
Starling 1.0

Partners

- NASA's Small Spacecraft Technology program within the Space Technology Mission Directorate funds and manages the Starling mission.
- NASA's Ames Research Center in Silicon Valley, California, leads the Starling project, providing payload avionics and software, spacecraft integration and test, and mission operations.
- Blue Canyon Technologies of Boulder, Colorado, is designing and manufacturing the spacecraft buses and providing mission operations support.
- Emergent Space Technologies of Laurel, Maryland, is providing the cluster flight application software for ROMEO.
- CesiumAstro of Austin, Texas, is providing the crosslink radios and antennas for the MANET experiment.
- Stanford University's Space Rendezvous Lab in Stanford, California, is developing the StarFOX experiment.
- NASA's Game Changing Development program within the Space Technology Mission Directorate provides funding for the DSA experiment.
- Firefly Aerospace, Inc., of Austin, Texas, and Nanoracks, LLC of Webster, Texas, are providing launch and integration services, respectively. The launch is managed by NASA's Launch Services Program at NASA's Kennedy Space Center in Florida.
- L3Harris Technologies, Inc., of Melbourne, Florida is providing ground software support for spacecraft navigation and maneuver planning.

Starling 1.5 - Extended Operations for Starling 1.0
(Launching Summer 2022)



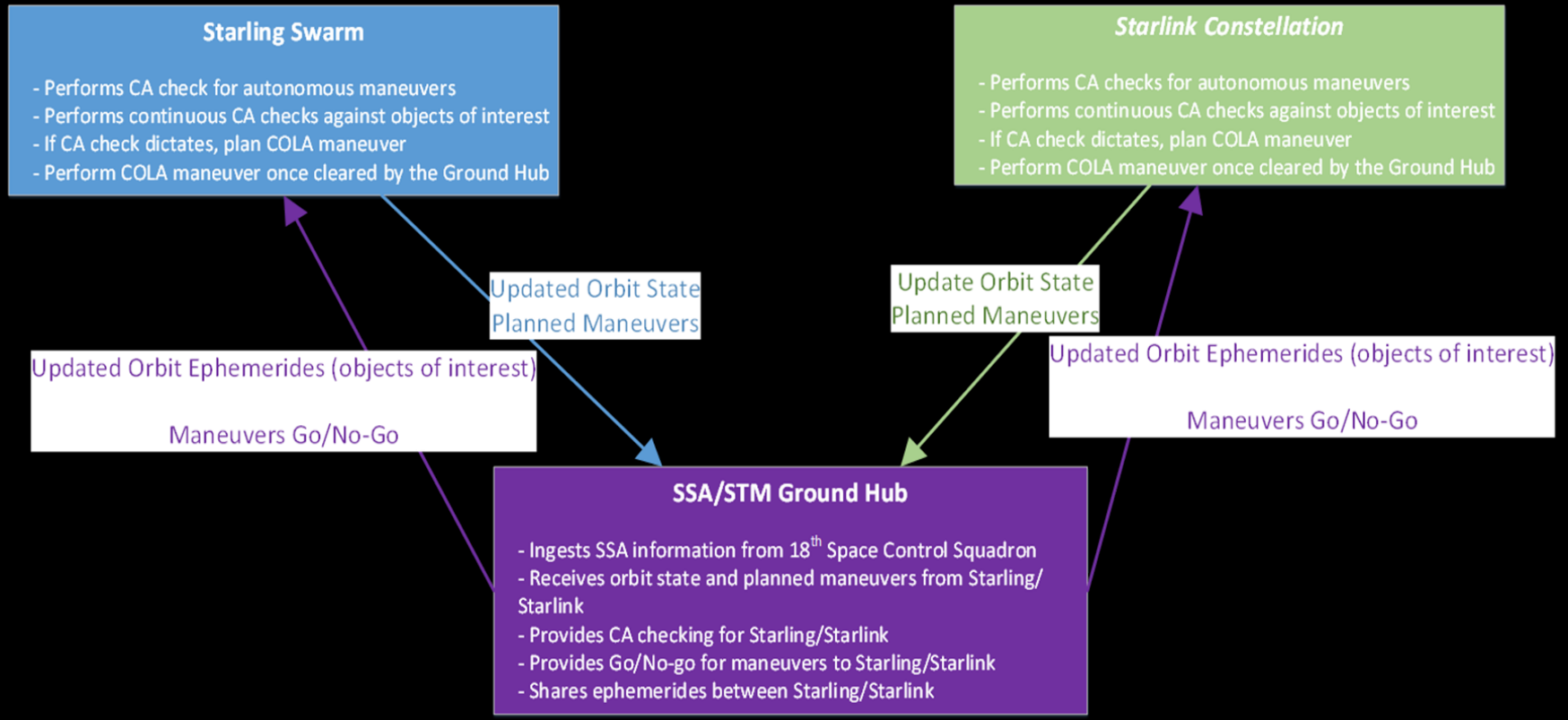
Mission Objectives

Starling 1.5 will demonstrate enhanced space traffic management between different owner/operators of low-Earth orbit spacecraft. Starling 1.5 is a mission extension of the Starling technology demonstration expected to launch summer of 2022. The project is partnered with SpaceX's Starlink constellation to demonstrate coordinated conjunction assessment (CA) and collision avoidance (COLA). Starling 1.5's objectives are:

- Demonstrate onboard CA for Starling's planned maneuvers
- Demonstrate continuous CA checking of passive and active/maneuvering objects
- Demonstrate a ground-based space situational awareness / space traffic management hub that facilitates on-orbit autonomous CA/COLA
- Demonstrate COLA maneuver of Starling spacecraft in response to an onboard CA detection

Starling 1.5 Concept of Operations

- Onboard planned maneuvers are screened and cleared through ground hub
- Ensures autonomously maneuvering spacecraft are aware of each other's intentions
- Automates maneuver approval through the ground hub, rather than requiring negotiation amongst owner/operators

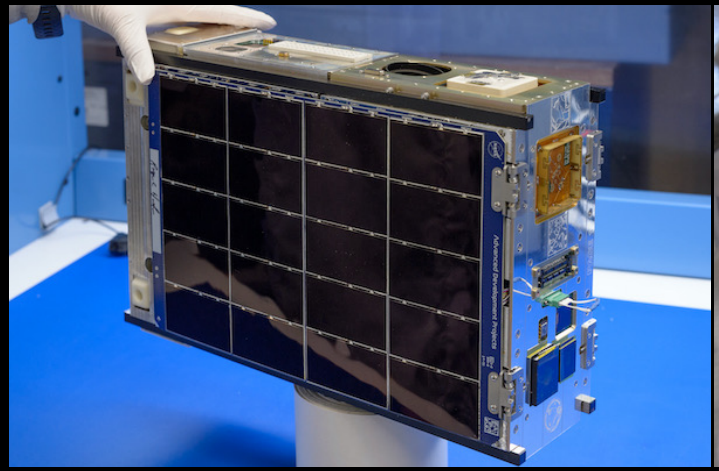


Starling 1.5 Partners

Developing a safety-of-flight system and CONOPS for multiple autonomously-controlled constellations requires a number of partners:

- NASA's Ames Research Center provides Starling 1.5 project management, systems engineering, software integration and test, and mission operations. "Freddie" air traffic management service adapted for the space traffic management demonstration.
- NASA Conjunction Assessment and Risk Analysis (CARA) program provides subject matter expertise and engineering support, as well as validation/certification of assembled system.
- SpaceX will participate in the experiment, modifying their operational system as appropriate. The formal arrangement for their participation is possible through a NASA CARA-SpaceX Space Act Agreement.
- Blue Canyon Technologies provides Starling 1.5 spacecraft command and control
- Emergent provides Starling's onboard conjunction assessment (CA) detection and collision avoidance (COLA) maneuver planning software.
- University of Texas, Austin provides astrodynamics support and calculations for the CA ground system. The formal arrangement falls under Emergent/UT STTR funded by NASA's Small Spacecraft Technology program within NASA's Space Technology Mission Directorate.
- US Department of Commerce provides funding to NASA's Ames Research Center, Code AOX, to provide the CA ground system architecture. The formal arrangement falls under a NASA/National Oceanic and Atmospheric Administration Interagency Agreement

Payload Accelerator for CubeSat Endeavors 2 – Launch Timeframe: October 2022



Mission Objective

Demonstrate upgrades to the PACE avionics system as well as a camera and image processing payload.

Partners:

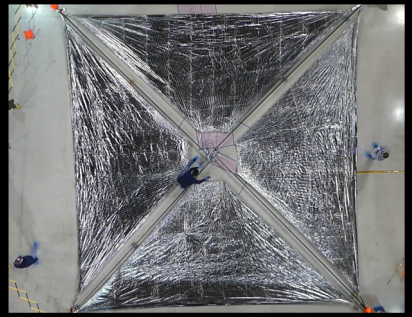
- PACE is managed by NASA's Ames Research Center in California's Silicon Valley and is funded by the Small Spacecraft Technology program within NASA's Space Technology Mission Directorate.
- Suborbital flights for PACE missions are supported by NASA's Flight Opportunities program, based at NASA's Armstrong Flight Research Center in Edwards, California and funded by STMD.
- Orbital flights for PACE missions are supported by NASA's CubeSat Launch Initiative, managed by the Launch Services Program at NASA's Kennedy Space Center in Florida, and funded by the Advanced Exploration Systems division within NASA's Human Exploration and Operations Mission Directorate.
- The ADP platform is developed by the PACE team at Ames; Dayne Kemp is the principal investigator.

Advanced Composite Solar Sail System - Launch Timeframe: October 2022

Mission Objectives

- Demonstrate successful deployment of the composite boom as well as sail packing and deployment systems in low-Earth orbit
- Evaluate the efficacy of the shape and design of the solar sail
- Characterize the thrust functionality of the sail as the spacecraft gradually changes orbit
- Collect data on the sail's performance to inform the design of larger, more complex systems

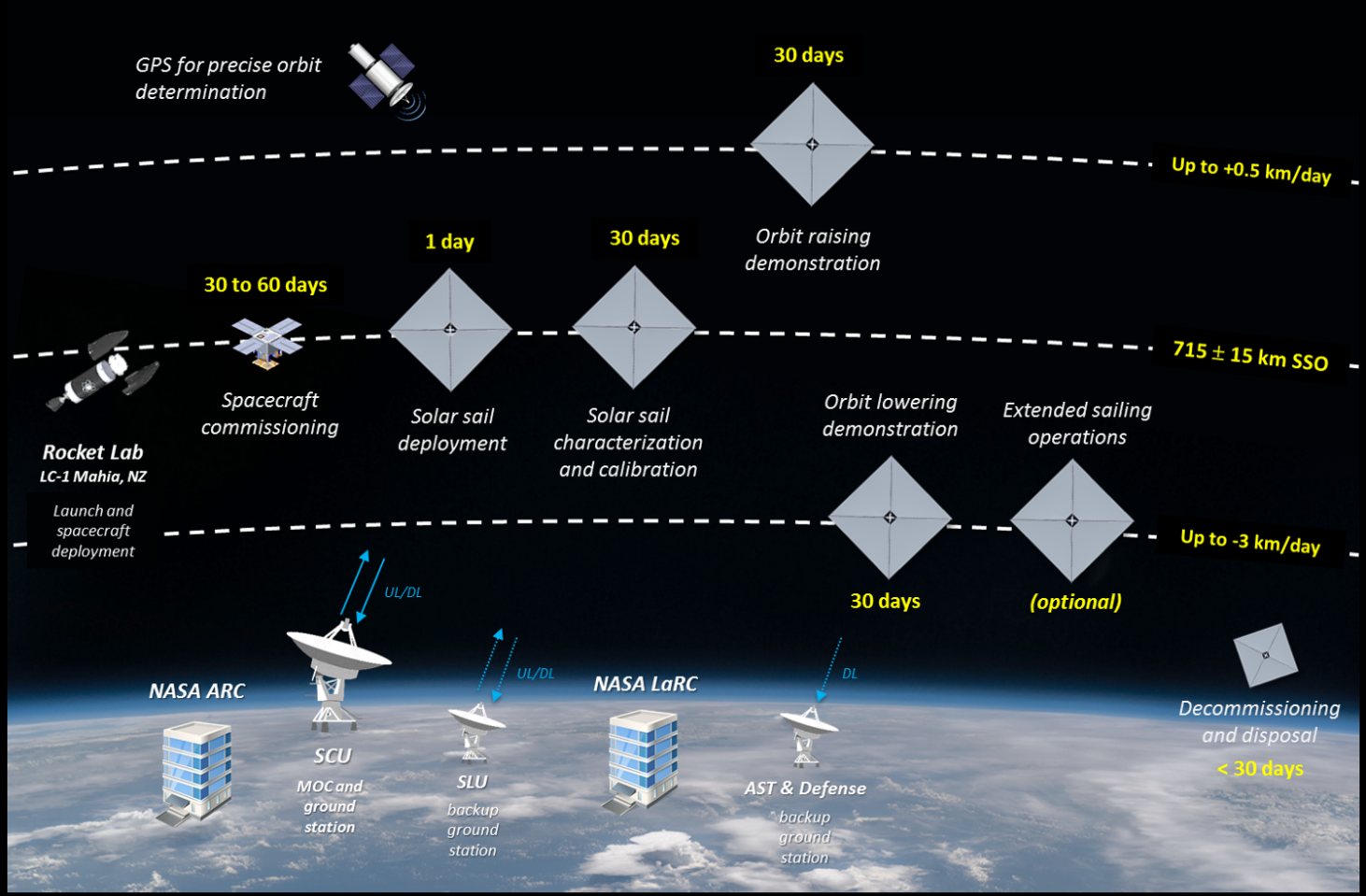
Advanced Composite Solar Sail System

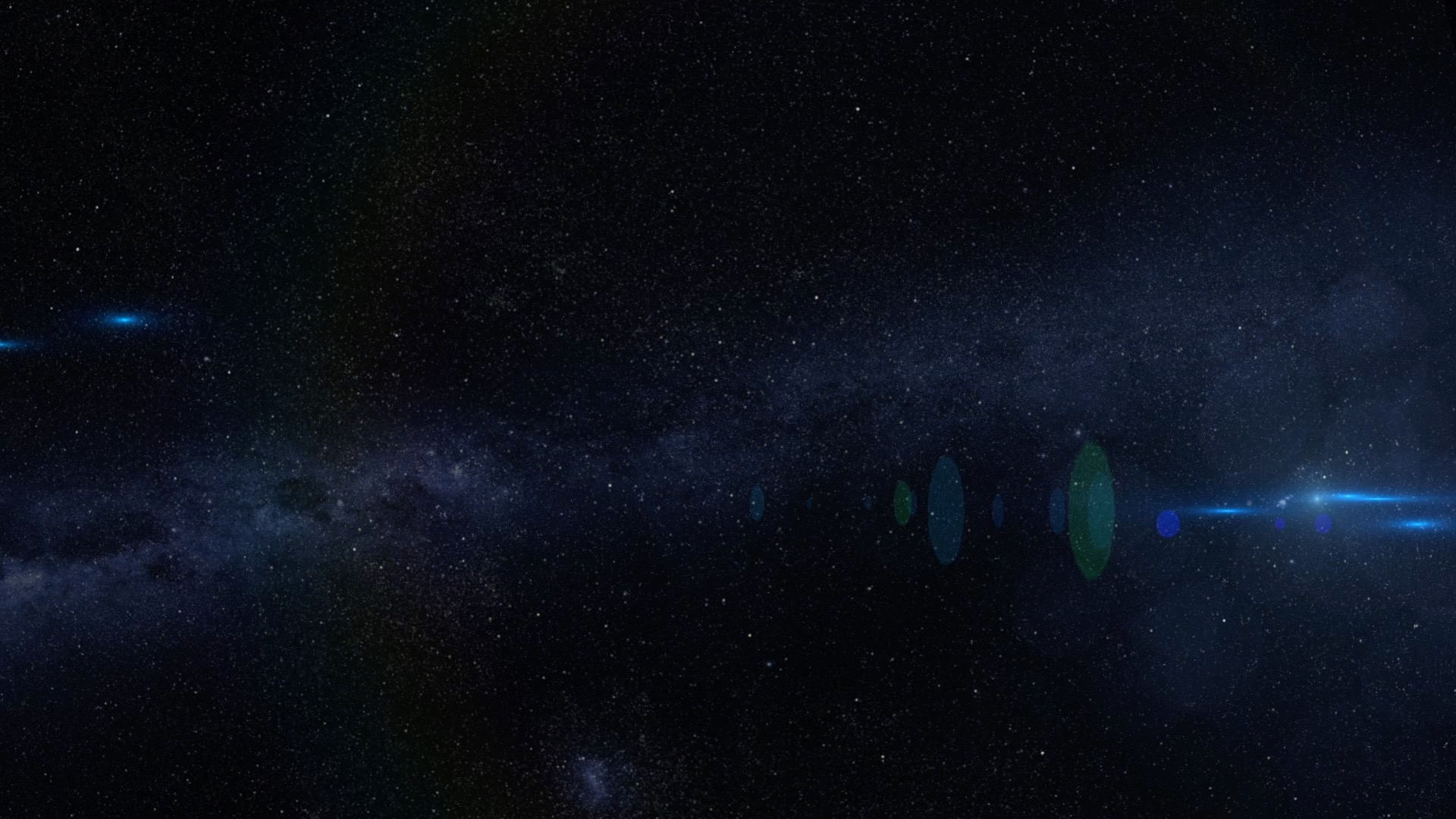


Partners:

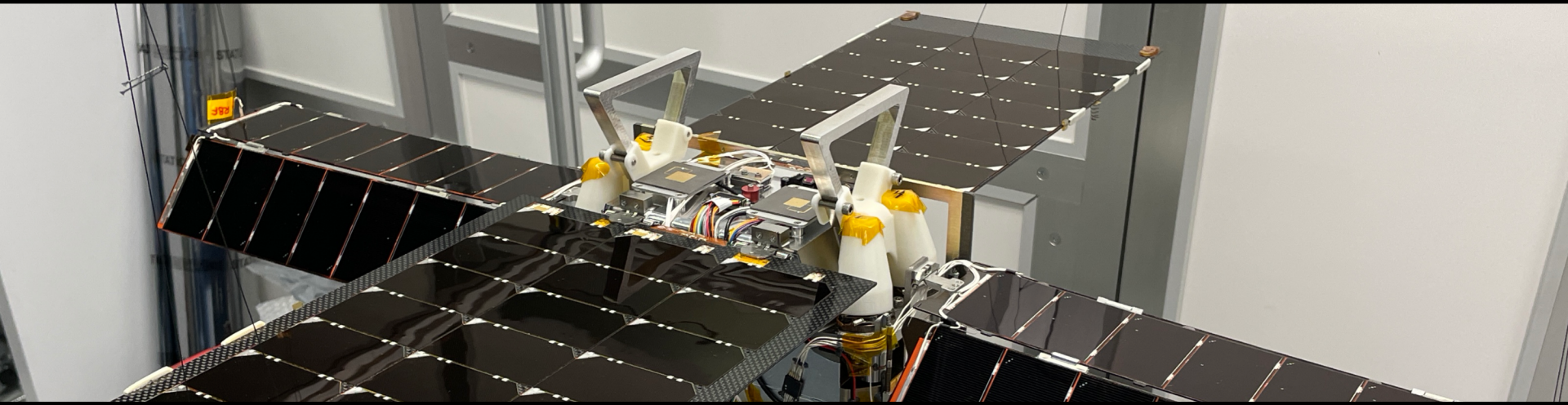
- NASA's Langley Research Center in Hampton, Virginia, designed and built the ACS3 deployable composite booms and solar sail system.
- AST&Defense LLC of College Park, Maryland, designed and built the 12U CubeSat spacecraft bus for the ACS3 technology demonstration.
- NASA's Ames Research Center in California's Silicon Valley manages the ACS3 project and designed and built the ACS3 on-board camera diagnostic system.
- Santa Clara University's Robotics Systems Lab in Santa Clara, California, is providing CubeSat operations support for the ACS3 technology demonstration.
- NASA's Small Spacecraft Technology program within the agency's Space Technology Mission Directorate is sponsoring the ACS3 project and is providing the funding for the launch.
- NASA's Game Changing Development program within the agency's Space Technology Mission Directorate developed ACS3's deployable composite boom technology.
- Rocket Lab USA, Inc of Long Beach, California is providing ACS3's launch through a Phase III Small Business Innovation Research (SBIR) contract.

Advanced Composite Solar Sail System – Concept of Operations





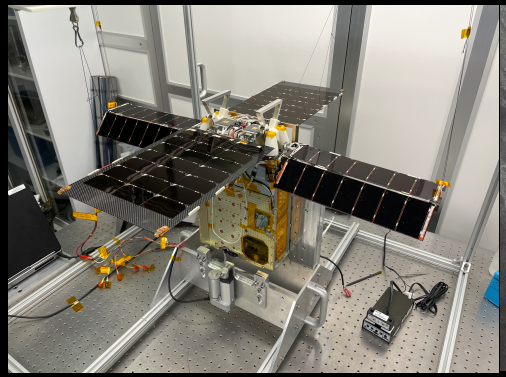
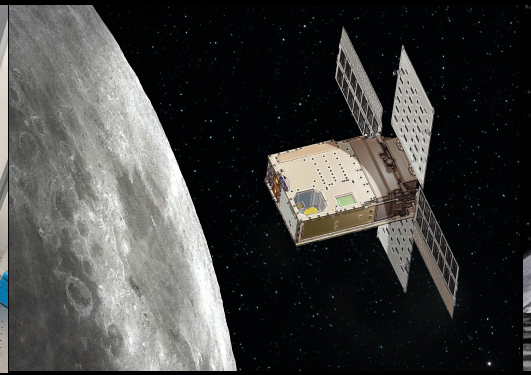
Lunar Flashlight - Launch Timeframe: Late 2022



Mission Objectives

- Demonstrate active laser spectroscopy that could differentiate between surface water ice (or frost) and dry regolith on the Moon.
- Map the locations of exposed surface water ice near the Moon's South Pole.
- Demonstrate "green" propulsion system technology for planetary missions using a low-toxicity propellant that is simpler to handle while providing higher performance than hydrazine.
- Expand the legacy of CubeSats to performing scientific study at the Moon.

Lunar Flashlight


Partners

- NASA's Jet Propulsion Laboratory is providing technological elements from predecessor systems as well as radiometer experience. JPL is the lead NASA center for the overall development of the mission.
- NASA's Goddard Space Flight Center in Greenbelt, Maryland, is the measurement lead for Lunar Flashlight.
- NASA's Small Spacecraft Technology program based at NASA's Ames Research Center in Silicon Valley and within the Space Technology Mission Directorate funds the mission.
- NASA's Marshall Space Flight Center is working with the Georgia Institute of Technology to develop the propulsion subsystem.
- Georgia Institute of Technology in Atlanta, will integrate and test and operate the spacecraft.
- The University of California, Los Angeles serves as the ground data system location and is the affiliation of a science co-investigator.
- The Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, and the University of Colorado Boulder are the affiliations of two additional science co-investigators.


QUARANTINE-
WHILE
GAME CHANGE
SIX FRIENDS
THE PROMISE
AMERICA
IKE'S BLUFF
NO EASY DAY

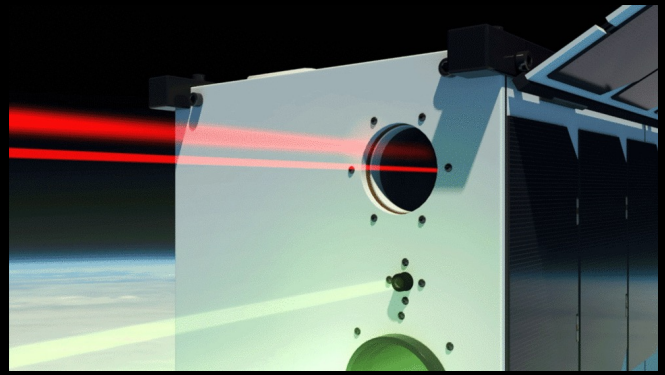
Pathfinder Technology Demonstrator-4 – Lightweight Integrated Solar Array and anTenna
Launch Timeframe: January 2023

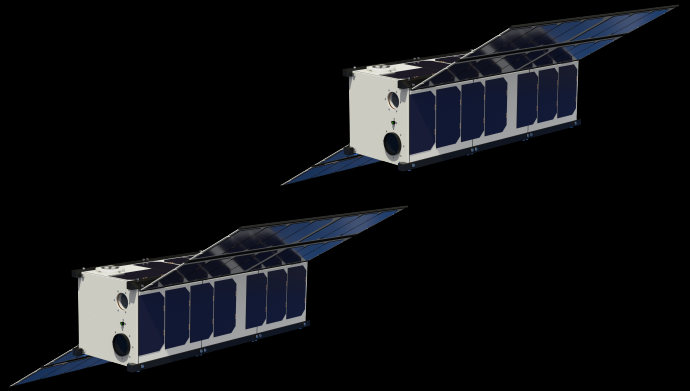
Mission Objective

- Demonstrate a very high-power, low-volume deployable solar array with an integrated antenna.
- LISA-T designs are scalable from 100 to 500 watts, with options to scale up to 1000 watts and beyond.

NASA's Marshall Space Flight Center in Huntsville, Alabama, is developing the deployable solar array and integrated antenna technology planned for launch on PTD-4.

CubeSat Laser Infrared CrosslinK B/C – Launch Timeframe: June 2023





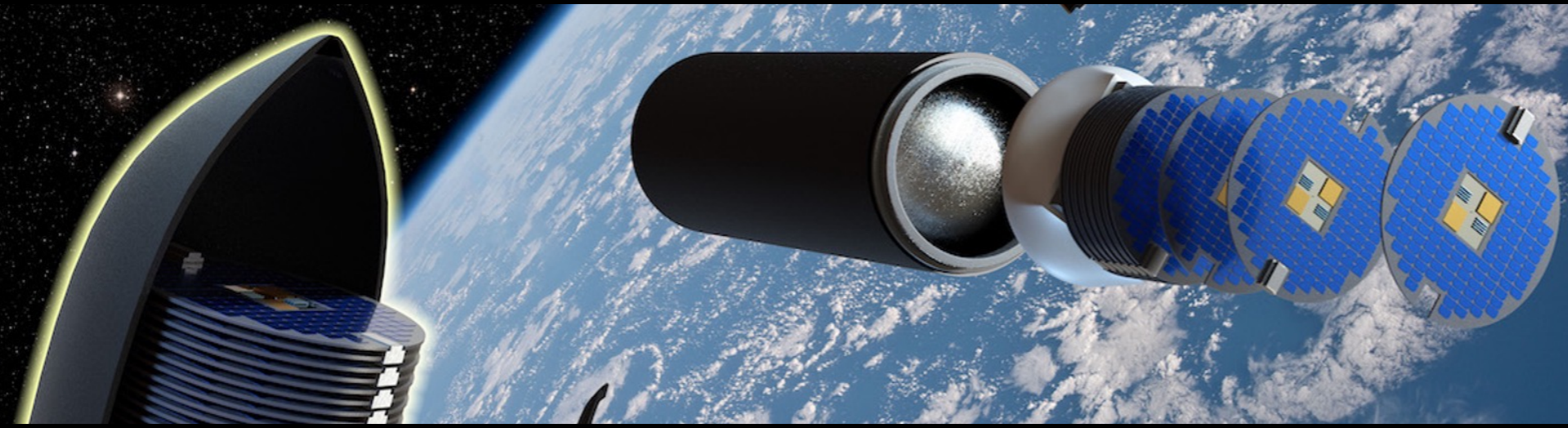
Mission Objectives

- CLICK B/C will demonstrate full-duplex optical communication crosslink between two 3U CubeSats at distances between 25 - 580 kilometers apart at data rates greater than 20 Mbps.
- CLICK B/C will also demonstrate precision ranging capability between the spacecraft that provides the ability to measure the distance and location of each with a range resolution to within approximately 0.5 meters.

Partners:

- The CLICK mission is managed and funded by the Small Spacecraft Technology program within the Space Technology Mission Directorate.
- The Massachusetts Institute of Technology, in partnership with the University of Florida, designed and build the miniature optical transceiver payloads to be integrated into the 3 small spacecraft procured by NASA Ames Research Center.

DiskSat – Launch Timeframe: 2024

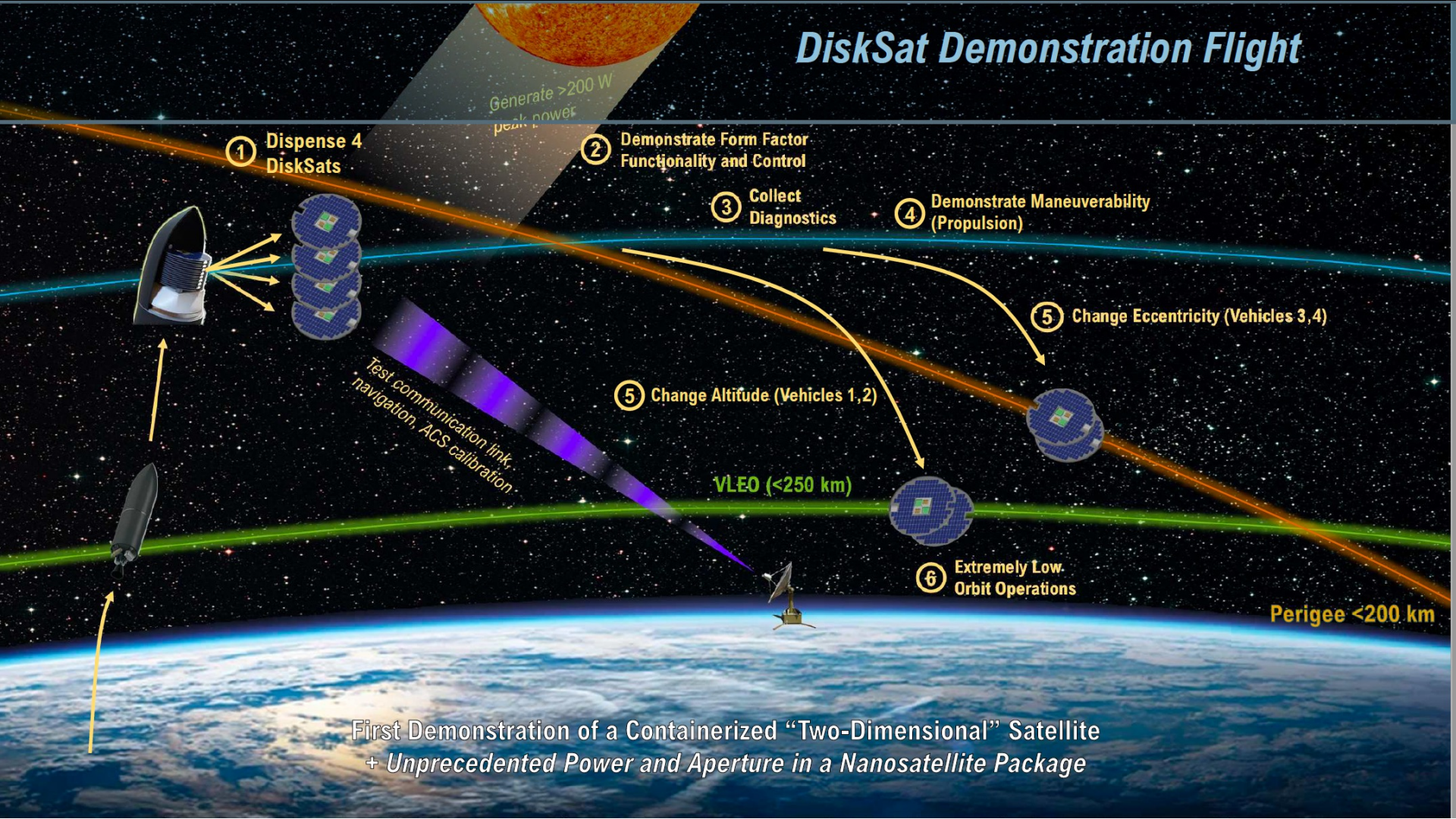


Overview

The Aerospace Corporation is developing a new paradigm for satellite form factor called DiskSat. The “Two-dimensional” bus architecture is low SWaP and has large aperture. The form factor offers unique capabilities in a 10–20 kg package:

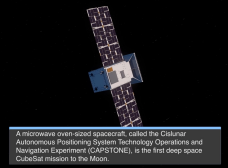
- Large surface area for high power and RF apertures
- Large ΔV via electric propulsion for maneuvering, altitude changes, or even cis-lunar missions
- Large total volume for accommodating payloads
- Very-low-altitude operations (<250 km) via low-drag edge-on flight

A DiskSat risk-reduction and proof-of-concept demonstration mission is anticipated to fly in 2024.

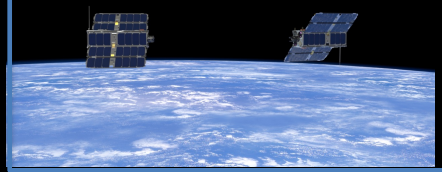

DiskSat Demonstration Flight
Generate >200 W
1 Dispense 4 DiskSats
2 Demonstrate Form Factor Functionality and Control
3 Collect Diagnostics
4 Demonstrate Maneuverability (Propulsion)
5 Change Eccentricity (Vehicles 3,4)
5 Change Altitude (Vehicles 1,2)
Test communication link, navigation, ACS calibration
VLEO (<250 km)
6 Extremely Low Orbit Operations
Perigee <200 km
First Demonstration of a Containerized "Two-Dimensional" Satellite
+ Unprecedented Power and Aperture in a Nanosatellite Package

Animations

CAPSTONE



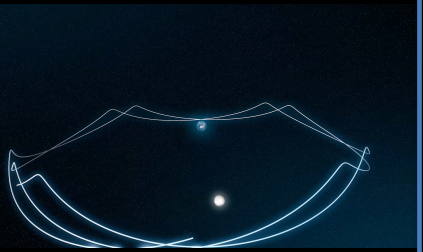
CPOD



Stephen Colbert*

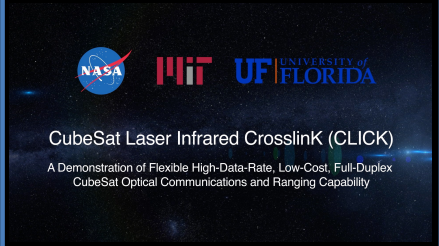
ACS3

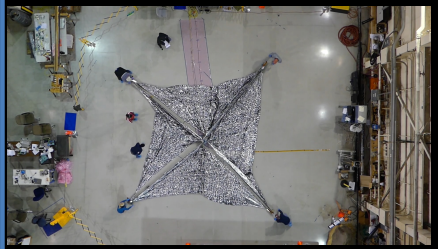
NRHO



Starling

CLICK B/C





*Retrieved from https://www.youtube.com/watch?v=P0jA0Pe-qlw&feature=youtu.be&t=217 on July 30, 2020. Credits to *The Late Show with Stephen Colbert*, producers Spartina Productions and CBS Television Studios

Image and Illustration Credits

Slide 3: Pathfinder Technology Demonstrator 3. Image Credits: Terran Orbital Corporation
Slide 4:
- Left Image: TeraByte InfraRed Delivery Payload. Image Credits: Massachusetts Institute of Technology Lincoln Laboratory
- Middle Image: Pathfinder Technology Demonstrator 3. Image Credits: Terran Orbital Corporation
- Right Image: Pathfinder Technology Demonstrator 3. Image Credits: Terran Orbital Corporation

Slide 5: CubeSat Proximity Operations Demonstration Spacecraft. Image Credits: Terran Orbital Corporation
Slide 6: CubeSat Proximity Operations Demonstration Spacecraft. Image Credits: Terran Orbital Corporation
Slide 10: Near Rectilinear Halo Orbit Animation. Credits: Advanced Space, LLC
Slide 11: CubeSat Laser Infrared CrosslinK A Spacecraft. Image Credits: Blue Canyon Technologies (both images)
Slide 20:
- Middle Image: Advanced Composite Solar Sail System's Spacecraft Bus. Image Credits: AST&Defense LLC
- Right Image: Advanced Composite Solar Sail System's Spacecraft Bus. Image Credits: AST&Defense LLC

Slide 23: Lunar Flashlight Spacecraft. Image Credit: NASA/JPL-Caltech
Slide 24:
- Left Image: Lunar Flashlight Spacecraft. Image Credit: NASA/JPL-Caltech
- Right Illustration: Lunar Flashlight Spacecraft Illustration. Credit: NASA/JPL-Caltech

Slide 25:
- The Late Show with Stephen Colbert. Video. Retrieved from https://www.youtube.com/watch?v=P0jA0Pe-qlw&feature=youtu.be&t=217 on July 30, 2020.
- Credits to *The Late Show with Stephen Colbert*, producers Spartina Productions and CBS Television Studios

Slide 29: DiskSat Illustration. Credit: The Aerospace Corporation
Slide 30: DiskSat Concept of Operations. Credit: The Aerospace Corporation

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