National Aeronautics and Space Administration

Michigan’s Miniature Tether Electrodynamics Experiment II CubeSat Mission

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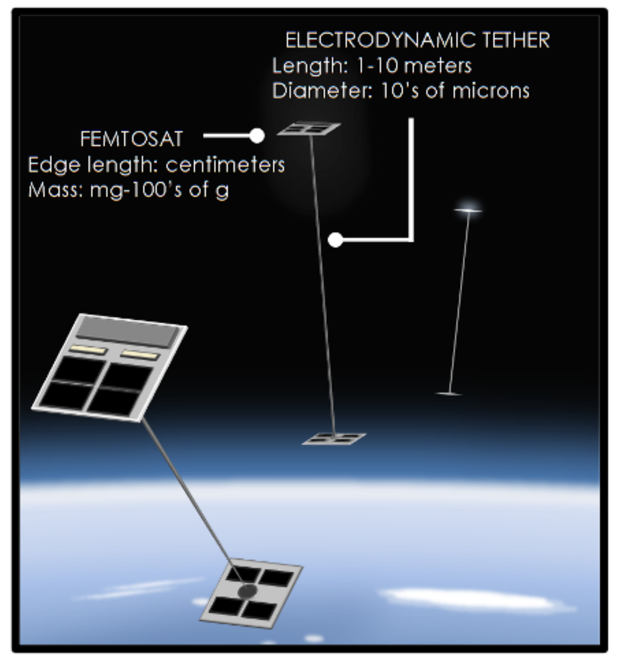
Program: FY21 SURP **Strategic Focus Area: Non-chemical propulsion**

Objectives

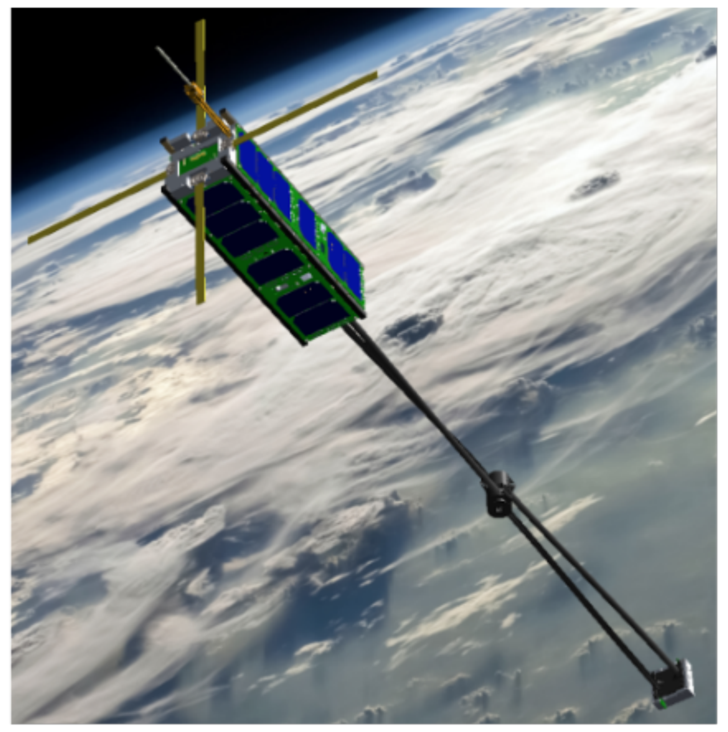
The Miniature Tether Electrodynamics Experiment (MiTEE) is a faculty research driven student educational technology demonstration mission using the CubeSat architecture to investigate the use of miniaturized (10-30 m), low-power, electrodynamic tethers (EDT) to provide propellant-less propulsion for drag make-up and maneuvering, as well as enhanced communication capabilities for “smartphone”–sized picosatellites (1 kg - 100 g) and femtosatellites (<100 g) [1,2,6]. If validated through the MiTEE missions, this technology could help enable a new paradigm for sophisticated, ultra-small, positionable constellations of pico/femtosats. A short EDT is fundamentally not constrained in terms of delta-V, can provide its own gravity gradient attitude control, can serve as a possible high gain (traveling-wave) antenna (communications and science), and/or as a plasma probe. The objective of this project is to advance the TRL of propellant-less electrodynamic tether propulsion for pico/femtosat spacecraft sensors, leading to a complete technology demonstration mission. Year 3 funding is being used to accomplish this goal by supporting MiTEE-1 mission operations following successful deployment aboard NASA’s ELaNa XX CubeSat launch (Virgin Orbit, Launcher 1) on January 17, 2021 and advancing MiTEE-2 milestones through mission concept review while progressing towards a future preliminary design review.

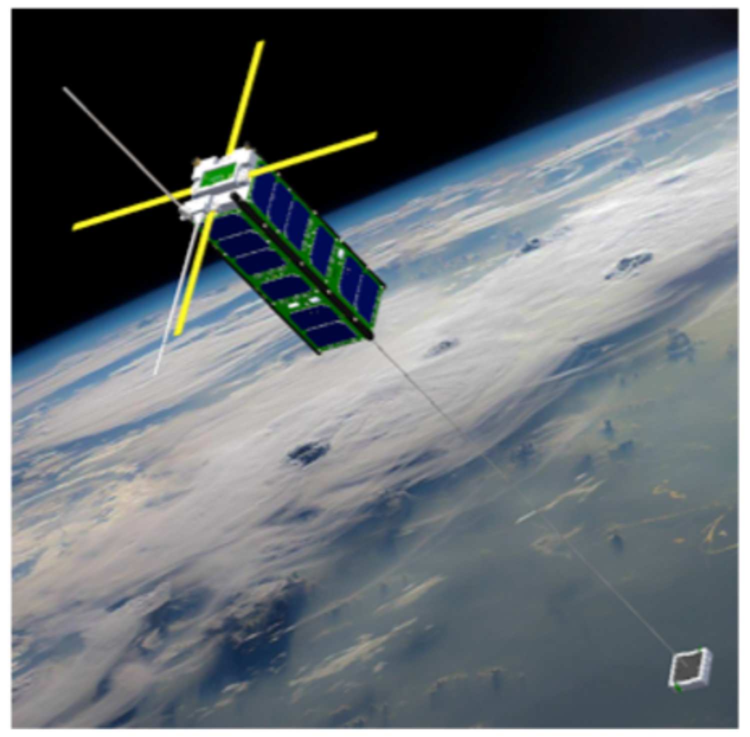


Concept of ED tethers with pairs of femtosats as a maneuverable constellation.

Background

Tethers have historically been proposed as a form of propellant-less electric propulsion, but never at the “smartphone”-sized satellite scale that the MiTEE program ultimately targets. With this new form of propulsion available, innovative designs involving constellations of maneuverable, sophisticated pico/femtosats may enable greater numbers of multipoint, simultaneous measurements or more frequent measurements around planetary systems with a global magnetic field and ionosphere. This form of propulsion also allows individual satellites to extend their mission life by providing atmospheric drag make-up. In addition to propulsion, the dual satellite tether system may serve multiple purposes; namely as a plasma (double) probe and as a VHF/microwave traveling wave antenna for communications.





Left: Concept of MiTEE-1 concept with fully deployed boom and picosat form-factor end-body. Right: MiTEE-2 concept with tethered picosat partially deployed and dual Langmuir Probe masts.

Approach and Results

Communications System:

- Simulations and trade studies have identified promising Picosat-Mainbody antenna design and has moved into physical prototyping and testing.
- Performing trade study for physical design of EDT as an antenna. Includes near and far-field characterization of tether transmission characteristics.

Plasma System :

- Completed core and insultation materials trade studies for 10-30 meter long tether based on research, simple calculations done using ideal beam theory, and tether dynamics requirements as determined by the OADCS and Structures subsystems for best stability, deployment, and control
- Re-analyzing and starting work to improve aspects of the thermionic cathode housing, Langmuir probe deployment mechanism, and CCPS board designs for ease of integration, testing, and manufacturing
- Simplifying Langmuir Probe code to allow younger members who will join the team and develop MiTEE-2 a chance to also understand and partake in testing using the code

Structures:

- Trade studies and prototypes on tether material and new deployer design in progress.
- Thermal simulation conducted for MiTEE-1 based on telemetry to diagnose health status during flight of MiTEE-1.

Orbits and Attitude Determination and Control System:

- Completing trade studies for mainbody attitude control system based on pointing requirements during tether deployment. Coalescing on a combination of reaction wheels and magnetic torque rod actuators. Additionally, selecting a passive attitude control system for picosat
- Establishing requirements/constraints for tether deployment mechanism

Mission Ops:

- Extensive revision and update of all mission documentation.
- Established pre and post-flight checklists for the launch of MiTEE-1
- Integrated MiTEE-1 ground station into the SatNOGS network.
- ConOps of MiTEE-2 being finalized with input from lessons learnt from MiTEE-1.

JPL DARTS/DSHELL Training and TEMPEST Simulations

- Four MiTEE students completed virtual training of JPL’s DARTS/DSHELL multibody dynamics simulation framework
- Updating TEMPEST EDT simulation software with modern geophysical measurements for modeling tethered picosats constellation electrodynamics with future goal to integrate within the DARTS/DSHELL framework

Electrical Power System:

- Completed trade study for endbody power source and started design for MiTEE-2 EPS board.
- Completed trade studies with cathode CCPS (constant current power supply) board for replacement with a COTS IC to reduce complexity and save internal volume

Command and Data Handling:

- Documented points of failure/improvement from MiTEE-1 and have generated roadpath to target key shortfalls during development for MiTEE-2
- Developing new watchdog and communications protocols for MiTEE-2 based on lessons learnt during MiTEE-1 ops

Lessons Learned from MiTEE-1

- Several changes have been implemented in MiTEE team structure after lessons learnt from MiTEE-1. Key restructure of management, including new chief scientist position allowing for more systems level oversight of science mission.
- Several lessons learnt in CDH for future implementation including better implementation of watchdogs, improved comms protocols and data management.
- Testing plans from MiTEE-1 have been revised and updated ready for MiTEE-2 development with key milestones and tests that we learnt to take extra care with.
- Documentation has been overhauled by mission ops to support team handover and knowledge transfer as members graduate and rotate.

Significance/Benefits to JPL and NASA

As exemplified by the Decadal Survey recommendation, GDC (Geospace Dynamics Constellation) is a NASA LWS mission with primary objective to “characterize and understand how the ionosphere-thermosphere behaves as a system, responding to, and regulating, solar wind/magnetosphere energy input” which will require measurements on various spatial & temporal scales. The results of MiTEE-1/2 will help position JPL-UM to respond to more advanced technology demonstration mission studies and flight opportunities.

MiTEE-1 at Virgin Orbit during integration before launch.

Publications

George, Li, “Lessons Learned from the Development and Flight of the First Miniature Tethered Electrodynamics Experiment (MiTEE-1) ” AIAA/Small Satellite Conference, 2021, Online. https://digitalcommons.usu.edu/smallsat/2021/all2021/249, Last Accessed, 9/20/2021.

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[3] NRC report: Achieving Science with Cubesats: Thinking Inside the Box, http://www.nap.edu/23503

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[8] G. Li et al., “Lessons Learned from the Development and Flight of the First Miniature Tethered Electrodynamics Experiment (MiTEE-1),” AIAA/Small Satellite Conference 2021, Last accessed, 9/20/2021.

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