Development of Electrodynamic Tethers for Propellantless Propulsion in Low-Earth Orbit

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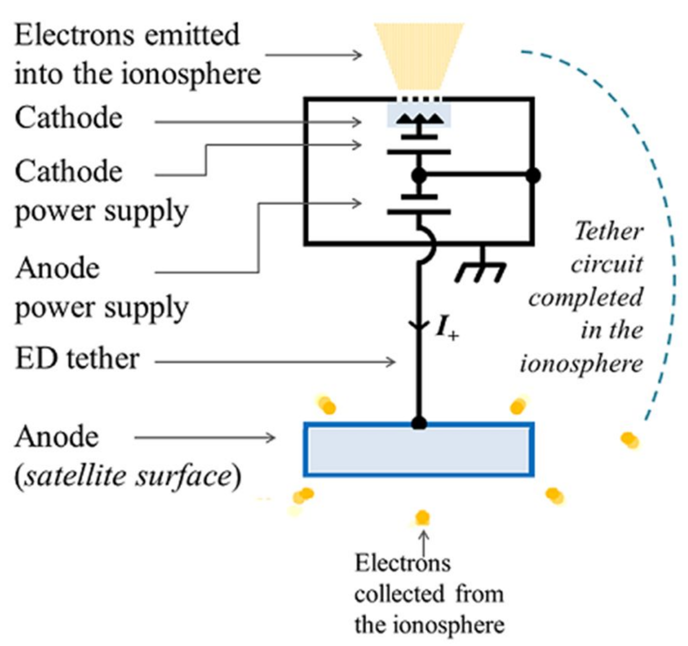
Objective

The Miniature Tether Electrodynamics Experiment (MiTEE) is a faculty research project at the University of Michigan providing a technology demonstration of using miniaturized (~10 - 30 m), low-power electrodynamic tethers (EDTs) as SmallSat propulsion modules. The first CubeSat from the team, MiTEE-1, uses a 3U CubeSat architecture to characterize the spacecraft charging dynamics of a picosat attached to the end of a rigid 1m boom. Data from this mission will guide the demonstration of technology needed to successfully enable electrodynamic tether propulsion on future CubeSat platforms.

In the past three years, MiTEE-1 has matured from its initial design phase to the fabrication of a fully functional 3U CubeSat. In the past year, specifically, the final assembly of the flight spacecraft was completed, flight software was refined, and launch vehicle integration compliance testing was completed. MiTEE-1 will launch as a NASA sponsored mission on ELaNa 20, with an anticipated launch on Virgin Orbit's LauncherOne vehicle in 2020.



Simplified overview of the MiTEE-2 EDT circuit depicting the Lorentz Force Equation F = IL x B

Electrodynamic Tethers (EDTs)

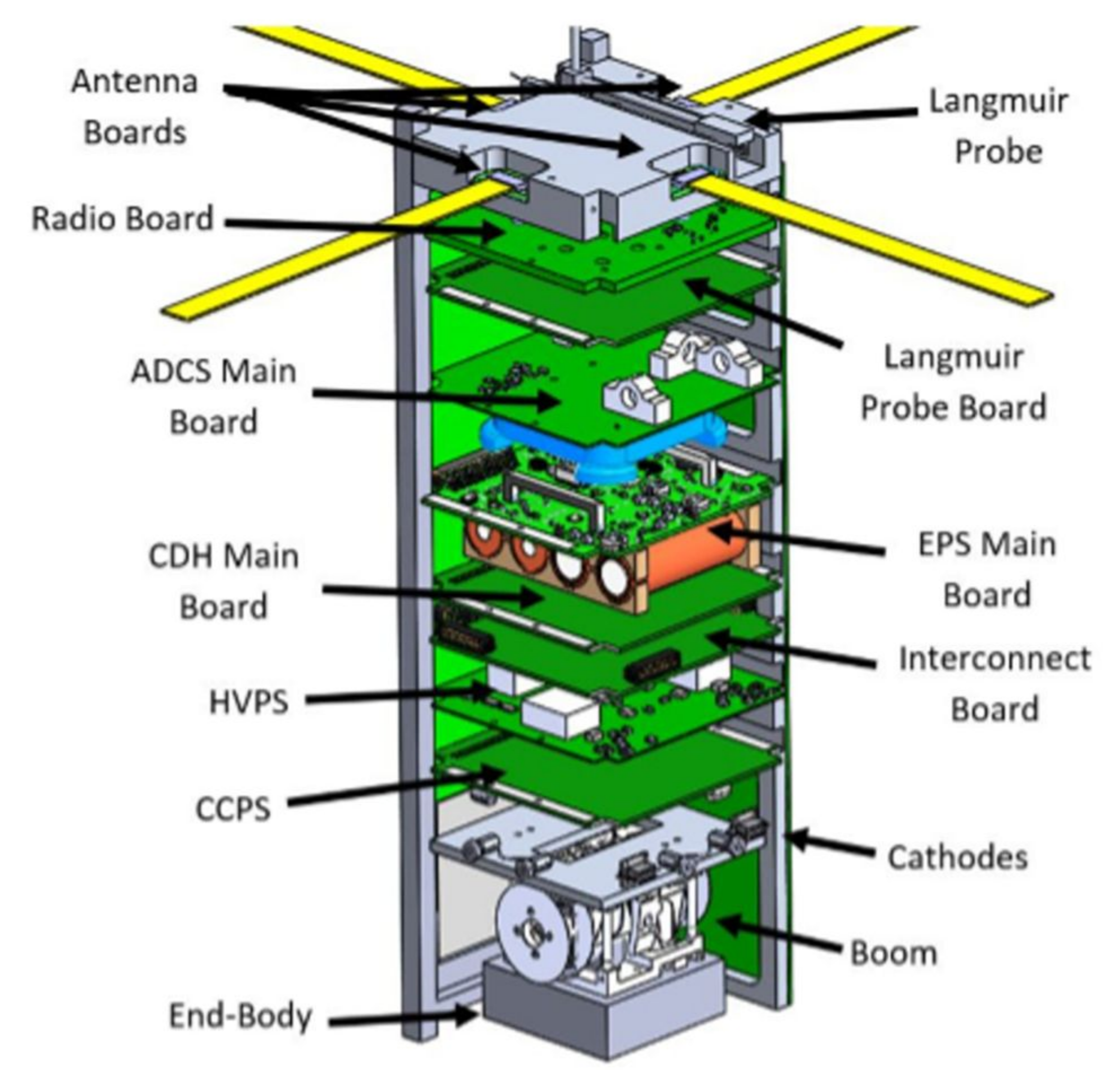
Electrodynamic tethers (EDTs) serve to create a propulsive Lorentz force on a spacecraft by interacting with Earth's magnetic field. This is accomplished through interactions with the ambient plasma environment that create a flow of current across a long, conductive tether. By biasing the voltage of a picosat at one end of the tether positively or negatively, the spacecraft can control the direction of current flow through the tether, thus changing the direction of its localized electromagnetic field and the resulting Lorentz force.

Since MiTEE-1 will investigate the charging behavior of its picosat's geometry, the team will have extensive knowledge of the expected charging behavior of future MiTEE CubeSats operating in the same LEO environment. MiTEE-2 will use the results discovered from MiTEE-1's mission to properly bias its endbody to achieve the desired current flow (and thus the desired Lorentz force) in order to perform stable and controlled maneuvers for station-keeping, orbit raising, and deorbiting events.

MiTEE-1 System Design

MiTEE-1 has been designed and assembled nearly entirely in-house by student members of the team over the past seven years. Evolving from a 1U to a 3U bus, the flight configuration of MiTEE-1 is comprised of the following six subsystems:

- Plasma Electrodynamics: Defines the mission's driving science requirements, interprets the mission data, and helps to develop the overall electrical requirements of the EDT. Main focus is on the picosat, deployable boom, cathode, and Langmuir probe.
- Orbits, Attitude Determination & Control System: Responsible for running relevant mission simulations, characterizing system dynamics, and implementing an active attitude control system for spacecraft detumbling and nominal attitude adjustments.
- Electrical Power Systems: Safely collects, stores, and distributes power across all the major subsystems of the MiTEE-1 CubeSat. Provides proper bias to the EDT and Cathode system and powers the filaments expelling electrons via thermionic emission.
- Command & Data Handling: Controls all aspects of electrical interfaces and flight software needed to control MiTEE-1 by following a modular design providing each major subsystem with its own low-power MSP430 microcontroller.
- Structures: Designed all structural aspects of the MiTEE-1 mainbody and implemented the deployable Langmuir Probe and boom/picosat systems. Driven by a backplane design onto which all boards of MiTEE-1 are slotted in for integration.
- Communications: Responsible for tracking, telemetry, and control of MiTEE-1 during flight as well as communicating with other ground stations interested in collaborating with the MiTEE team.

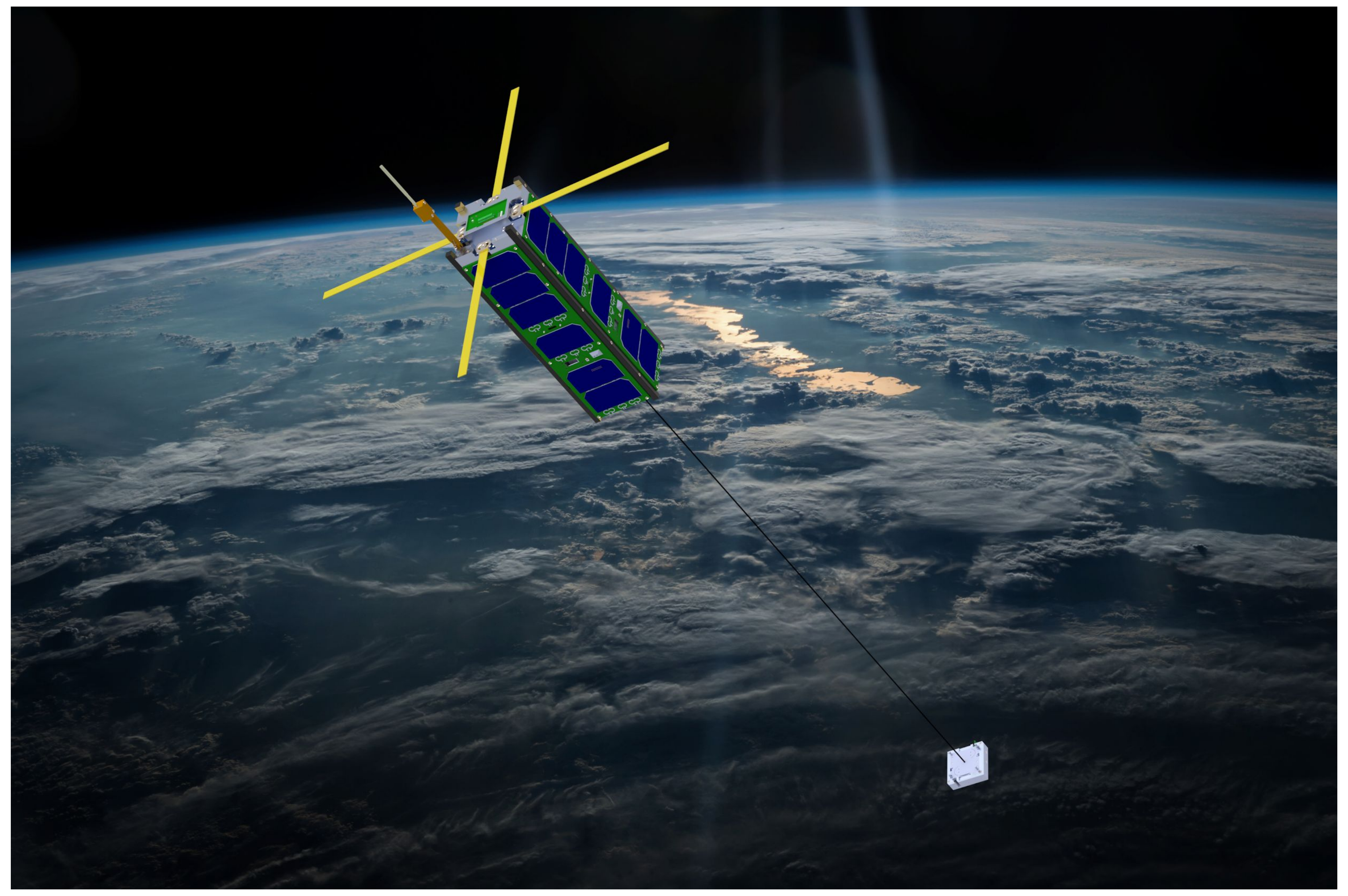


CAD image of the internal MiTEE-1 structure with labelled components.

MiTEE-2 & Beyond

MiTEE-1's successor, MiTEE-2, will implement a full EDT propulsion system using the information gathered by the MiTEE-1 mission. Despite remote work setbacks from COVID-19, MiTEE-2 is currently under development and on schedule for an anticipated launch sometime in the 2020s. It is projected to utilize a 30-meter long electrodynamic tether connecting a 3U mainbody to a smaller picosat endbody that shares the same geometry as MiTEE-1's picosat. This tether will enable MiTEE-2 to perform on-orbit maneuvers without using expendable propellants, thus providing possibilities of extending the usable mission lifetime of the spacecraft. The MiTEE team is also investigating the possibility of using the tether as a communications antenna for increased connectivity with ground support systems.

Future iterations of MiTEE spacecraft may see progressively smaller endbodies and longer tethers to maximize the propulsive impact of the EDT on the spacecraft. This aligns with the end goal of launching and controlling a constellation of coordinated EDT picosats capable of executing operations as a cohesive fleet with far more capabilities and redundancy than a single spacecraft system.



Digitally rendered image of MiTEE-2 partially deployed and operating nominally in LEO.

Acknowledgements

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