Developing the Miniature Tether Electrodynamic Experiment

Completion of Key Milestones and Future Work

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Miniature Tether Electrodynamic Experiment (MiTEE)

MiTEE Spacecraft: CubeSat with picosat scale end-body on 10 meter miniature electrodynamic tether (EDT) designed to characterize and demonstrate miniature EDT technology.

Mission Goals:
• Provide a hands-on multidisciplinary educational experience rooted in faculty driven research

• Understand the impact of hands-on multidisciplinary participation in faculty research on STEM education for undergraduate and graduate students

• Understand the functionality of miniature electrodynamic tethered systems
Miniature Tether Electrodynamics Experiment (MiTEE)

Science and Engineering Objectives

Characterize voltage-current transfer functions for EDT system under a variety of ionospheric plasma conditions
• Measure tether current as a function of anode/CubeSat voltage for a range of cathode emission levels

Characterize miniature tethered system dynamics
• Cubesat and End-body attitude and position as a function of time and tether operational modes (thrusting/non-thrusting)

Demonstrate use of the tether as a high gain ground-pointing traveling wave antenna
• Compare primary antenna and tether-based signal strength as a function of overpass attitude and distance
Miniature Electrodynamic Tethers (EDTs)

EDTs can provide propulsion
- Drag make-up
- Change inclination, altitude, etc.
- No consumable propellant

Additional benefits of tethers:
- Provided gravity gradient stability
- Tether as antenna
- Ionospheric plasma probe
Lorentz Force (Deboost)

Motional EMF

Forward Motion

Earth’s Magnetic Field

Tether Current

Plasma

Ion

Electron
Earth's Magnetic Field
Forward Motion
Lorentz Force (Boost)

Motional EMF
Tether Current
Tether Biasing Power Supply

Plasma

Ion
Electron
Plasma Circuit

Ion Current (~1uA)

Hot Cathode Electron Current (up to 10 mA)

Tether Biasing Supply

Motional EMF

Anode/Plasma Voltage Controlled Current Source

Plasma Potential
Passive Current Mode:
- Hot cathode is off and does not contribute to electron emission
- Anode/plasma voltage is very small due to required ion/electron current balance
- Ion collection primarily due to ram current (~1uA)
Active Current Mode:
- Hot cathode begins actively emitting electrons
- Anode/plasma potential difference rises due to electron emission
- Tether current increases in response to increased anode/plasma voltage
- Ion ram current cancelled by electron ram current
Miniature Tether Electrodynamics Experiment (MiTEE)

Envisioned ED Tethered PicoSat

Each end-body equipped with tether biasing supply and active cathode for fully reversible thrust

PicoSat End-body

~10 m Tether

PicoSat End-body

MiTEE CubeSat

CubeSat platform offers mass, power, and volume necessary for technology demonstration instrumentation

Langmuir Probe Mast

CubeSat Test-bed Platform

Monopole Antenna

Tether Deployment System

~10 m Tether

PicoSat End-body

PicoSat End-body

CubeSat Test-bed Platform
Miniature Tether Electrodynamics Experiment (MiTEE)

Envisioned ED Tethered PicoSat

- Each end-body equipped with tether biasing supply and active cathode for fully reversible thrust

PicoSat End-body ~10 m Tether

- MiTEE CubeSat
  - Langmuir Probe Mast
  - Langmuir Probe Circuitry
  - EPS Circuitry
  - C&DH Boards
  - ADCS Circuitry
  - Transceiver
  - Magnetorquer
  - Hot Cathode and Power Supply
  - Camera

- CubeSat Test-bed Platform
- Additional Payload Capacity
- Tether Biasing Power Supply
- PicoSat End-body

- Camera
- Deployment System
- ~10 m Tether

Additional Payload Capacity
Electrodynamic Tether as Traveling Wave Antenna

High gain annular radiation concentric with tether axis

Peak gain occurs toward the end of the tether opposite the driving circuitry (nadir pointing)

For demonstration purposes, tether signal strength and transmission integrity will be compared to primary antenna. Attitude and distance will play key roles in this analysis.

Selected four-way synchronously driven monopole antenna array for primary communications
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- Peak Gain: 1.5 dB Gain
- Nadir Angle
- 1.2 dB Gain
- Coupling from primary antenna to tether

Polar Gain Plot (dB)

3D Gain Model (dB)
WINCS thermionic cathode
- Barium-oxide coated tungsten filament
- Designed to output more than 7 mA
- Manufactured by E-Beam Inc
- Flying aboard then UM CADRE CubeSat later this year
Motorized spool and roller design for slow controlled deployment

- Spring-loaded pinch rollers
- Small piezo-electric motor
- Structure can be 3D printed
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Moved to distributed (hub and spoke) processing architecture to simplify parallel development and operation of subsystems. Additional benefits:

• Greater redundancy
• Lower over-all power consumption
2014-2015 Major Design Decisions: Form Factor

Converted from 1U to 3U for increased mass, power, and volume capacity
• Selected for 6th round of NASA's CubeSat Launch Initiative
• Ranked 4th among selected missions
• Launch opportunities in 2016-2018
Future Development and Major Milestones

Future Development

• Improved tether dynamics modeling
  o Software modeling (ADAMS) of tether system with all relevant drag, thrust and gravity gradient forces well characterized

• Evolving designs for end-body position characterization
  o Lidar based distance determination coupled with on-board attitude determination with CubeSat link

• Tether core and insulative coatings research
  o Research into “semi-rigid” tether materials is ongoing as well as analysis of potential insulative coating materials

• Indium-Tin-Oxide solar cell coatings
  o Solar cell surfaces are required to be conductive and grounded for maximum ion ram current collection

• Antenna/Tether coupling analysis
  o Preliminary study suggests strong coupling with primary antenna array

Milestones

• Preliminary Design Review (Ongoing)
  o September 2015

• Critical Design Review
  o March 2016

• Flight Hardware Assembly, Integration and Testing
  o Flight Readiness Review
    • Q1 2017
  o Hardware Delivery
    • Q2 2017
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