Small Satellites in the Michigan Exploration Laboratory at the University of Michigan

Michigan Exploration Laboratory (MXL) Overview

The Michigan Exploration Laboratory (MXL) works to achieve a comprehensive blend of education, research, and entrepreneurship within the University of Michigan College Of Engineering. The collaborative MXL environment has already yielded high-proven achievements in small satellite design and high-altitude ballooning, with even more innovations resulting from the analysis of flight data and completed missions. MXL is also pursuing fundamental research in the areas of satellite design and optimization, estimation and sensor calibration methods, and ground station network optimization and scheduling.

MXL aspires to foster new mission architectures, innovation in space, and to enable bold flight to extreme and remote environments. Through a variety of potential funding sources, MXL will sponsor projects that not only train future leaders, but also enhance the educational experiences of hundreds of engineering students.

Michigan Multipurpose Minisat (M-Cubed)

M-Cubed is the first spacecraft developed by the University of Michigan’s Student Space Fabrication Lab (SSFL) in collaboration with NASA’s Earth Science Technology Office (ESTO) to demonstrate an on-board processing system that is planned for the ACE Decadal Survey Mission. M-Cubed’s payload is an imaging system comprised of a 2 MP CMOS sensor and a Killinger 5-FX130T rad-hard-by-design (RHBD) Field Programmable Gate Array (FPGA) coprocessor. The camera will take an image from low earth orbit with a resolution better than 200 meters per pixel. On-board processing results and original image data will be downlinked to ground stations for verifications against ground truth.

M-Cubed launched on October 2011. The satellite is operational, but communication is difficult due to interference with another Cubesat deployed from the same POGO E1P. M-Cubed and E1P are not contacted and unexpectedly docked after launch, most likely due to interaction between their passive magnetic control systems. Because of this, communication with M-Cubed has been difficult, and the performance of the payload has not been verified.

Advancing the State-of-the-Art Through Fundamental Research

In addition to work in the design, integration, testing, and operation of small satellites, MXL is pursuing fundamental research related to increased capabilities of small satellites. Two examples are discussed below.

The Radio Aurora Explorer (RAX)

The Radio Aurora Explorer (RAX) is the front of several CubeSats sponsored by the National Science Foundation to study space weather phenomena. The satellite was developed jointly by SRI International and MXL. The RAX mission studies plasma instabilities that lead to field aligned irregularities (FAI) of electron density in the lower polar (80-300 km) ionosphere. These FAI are capable of scattering radio signals, disrupting critical space-based resources such as GPS and communication. The RAX mission provides data to study the formation of FAI with the ultimate goal of enabling short-term forecasting to predict FAI.

RAX utilizes a novel bi-static radio configuration, where the transmitter is a ground-based incoupled scatter radar station and the receiver is the RAX payload. Radar pulses illuminate the ionosphere as RAX passes overhead, and the satellite measures the radar echo from the ionosphere.

The primary RAX data product is irregularity intensity, measured by RAX, as a function of connection electric field, electron density, electron and ion temperatures (measured by the ionospheric scatter radar), altitude, and magnetic aspect angle.

There are currently two CubeSats in the RAX mission: RAX-1, launched November 2010, and RAX-2, launched November 2011. RAX-1 successfully performed measurements with ground-based radar incoupled scatter radar, but the mission ended prematurely after two months of operation due to a solar panel failure. RAX-2 was developed to correct the solar panels and is currently operating on-orbit. RAX-2 has performed experiments with incoupled scatter radar stations located at Poker Flat, Alaska, and Resolute, Canada. RAX-2 is operated by MXL, using ground stations located at the University. Scientific operations and analysis are carried out by SRI International.

On-orbit sensor calibration

We are developing new, attitude-independent, on-orbit sensor calibration techniques to increase the accuracy of attitude determination sensors. The algorithms reduce the need for careful pre-flight calibration and integration with high tolerances to ensure sensor alignments. This reduces satellite development time and cost while increasing the performance of relatively cheap, commercially-available sensors that are common on small satellite missions.

In work with magnetometers, we have mitigated the effect of the satellites induced magnetic field on the sensor. This is especially useful for small satellite missions, where volume constraints prevent physical separation and booms are often avoided due to cost and complexity.

On October 27, 2010, the University of Michigan Hosted the first ever science data from RAX. By using data from pre-launch testing to model the FAI, it is predicted the satellite will detect FAI. In addition, the satellite will enable the development of new attitude determination algorithms.

Assessment and Optimization of Constellation Missions and Federated Ground Station Networks

Motivated by the growing community of small satellites and various proposed constellation missions, such as QB50 and ArduSat, we are developing the analytical models, simulation tools, and optimization algorithms to maximize the data return of existing and planned small satellite missions. This work is crucial for both single satellites and constellations seeking to download large amounts of data to distributed ground station networks.