COLE

Cubesats Outside Low Earth orbit

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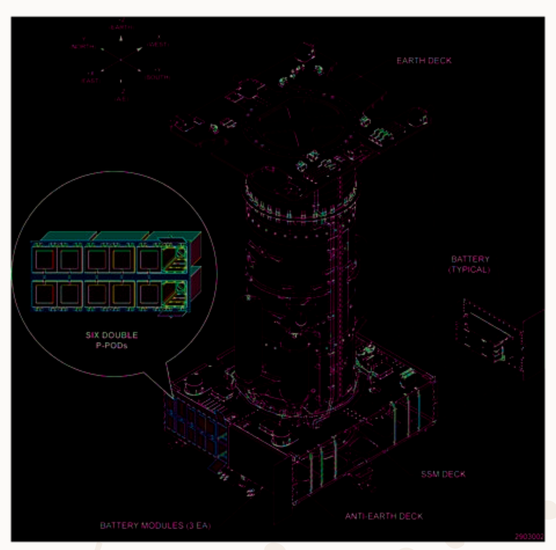
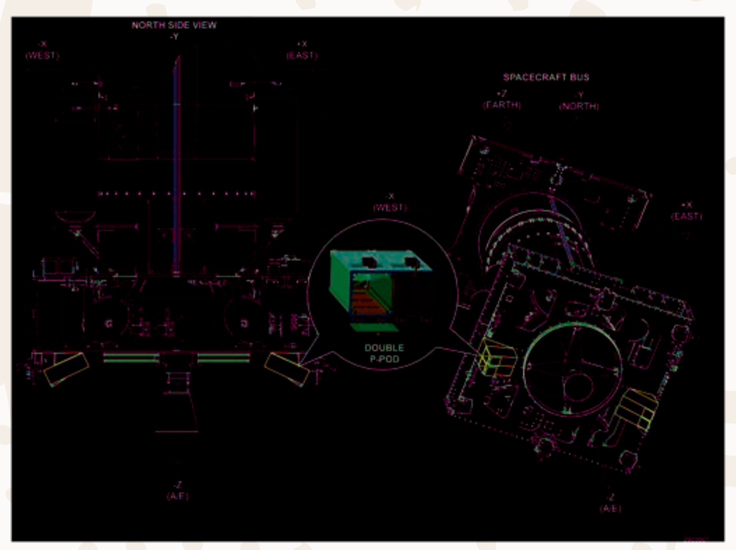
SPACE SYSTEMS/LORAL MOTIVATION

Space Systems/Loral (SS/L) is the leading provider of geostationary commercial satellites, with experience building and integrating some of the world's most powerful and complex satellites and spacecraft systems for a roster of international customers.

SS/L partnered with the University of Michigan to develop an assessment of the Cubesat market and its applicability to Geostationary Transfer Orbit (GTO). SS/L is driven by developing strategic relationships with Universities and Government to promote increased access to space for small satellites and hosted payloads. By leveraging open space on the Anti-Earth deck and battery compartments of the Loral 1300 series satellite platform, small satellites could be deployed in Geostationary Transfer Orbit (GTO) and Geostationary Earth Orbit (GEO).

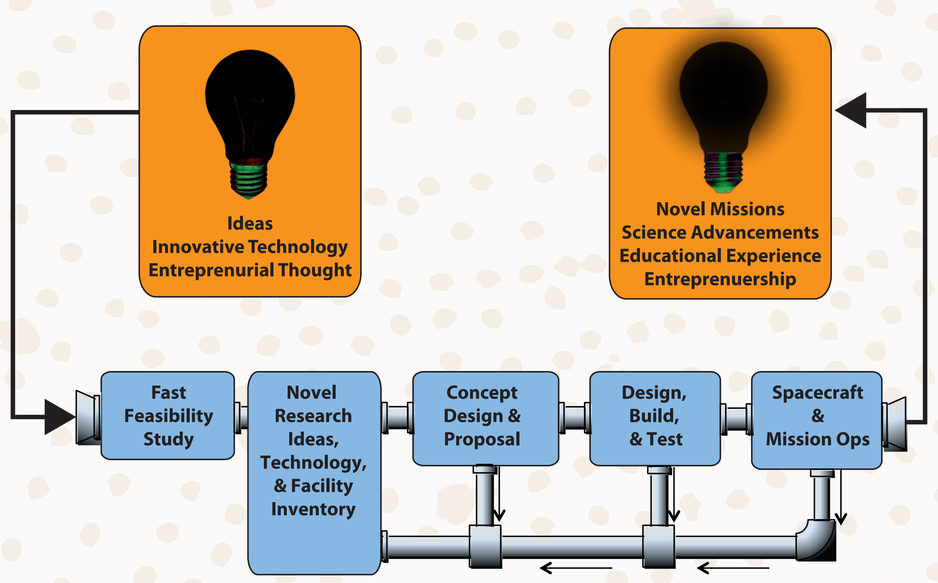
Specifically, due to the CubeSat platform's heritage and standardized design, CubeSats are an ideal candidate to investigate this concept's feasibility.





Above left: Diagram showing potential placement of P-PODs in battery module. Above right: Diagram showing P-PODs stored and deployed from anti-Earth deck.

But why the University of Michigan?



Above: Overview of the Michigan Nanosatellite Pipeline showing the flow of knowledge, capability, etc.

The Michigan Nanosatellite Pipeline (MNP) has...

CubeSat flight heritage

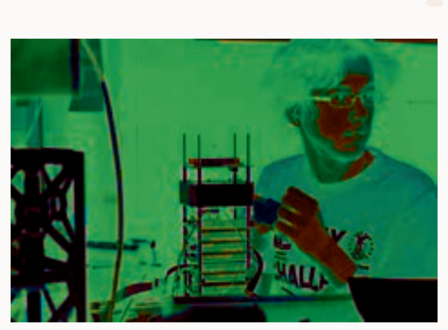
- RAX
- M-Cubed
- RAX 2

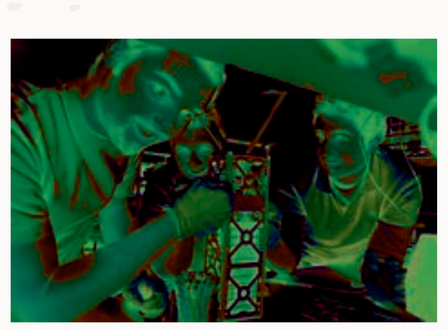
Multi-disciplinary efforts from faculty, student labs and course projects with industry support

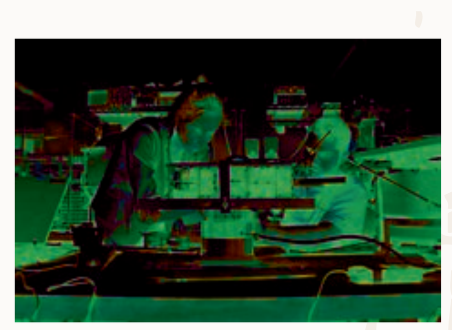
- Aerospace Engineering (AE)
- Atmospheric, Oceanic and Space Sciences (AOSS)
- Electrical Engineering and Computer Science (EECS)

University of Michigan has been working on CubeSat technology since Fall of 2007. Since that time, CubeSat development efforts have expanded from grassroots development to full-fledged industry flight projects that are doing real science and enabling technology demonstrations.

With faculty expertise in science, engineering and multi-disciplinary design, the University of Michigan has the necessary infrastructure to tackle all aspects of small satellite design, integration and operations.





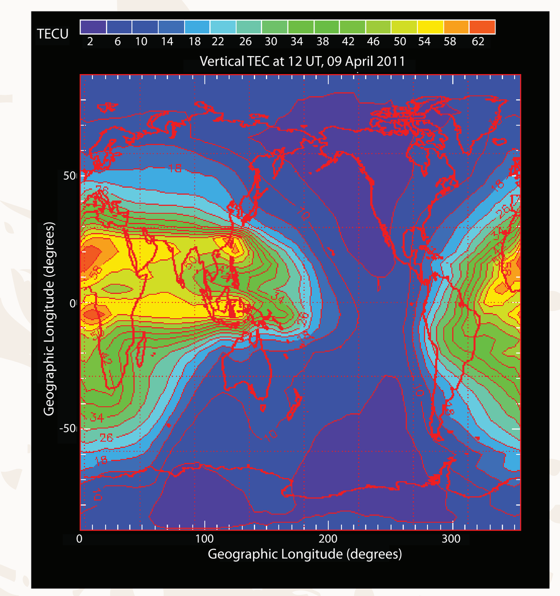


SAMPLE GTO MISSION: CUBESAT OUTSIDE LOW EARTH ORBIT (COLE)

Science

Proper characterization of the magnetosphere will require density measurements. Currently, only ground based measurements are being taken, which is limited to a vertical dilution of precision where only column density information can be taken between the ground and satellite. To achieve a higher resolution, a dual frequency GPS receiver can be used to obtain the horizontal column of density measurements. This allows for a distinction in measurements between the ionosphere and plasmasphere electrons.

Ref: Kronman, J.D., "Experience Using GPS For Orbit Determination of a Geosynchronous Satellite"



Above: Sample GPS tomography capture of magnetosphere

Radiation

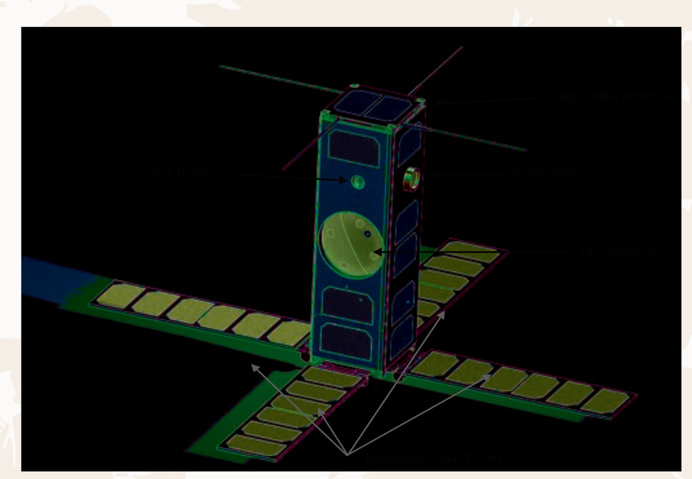
The radiation environment in GTO is very intense. A satellite in this orbit would constantly pass through the Van Allen belts. The table to the right shows the total ionizing dose (TID) that is expected for 1 year. This is on the high end of what non-radiation hardened systems can handle. According to SPENVIS simulations, COLE will require 2.5 mm of shielding.

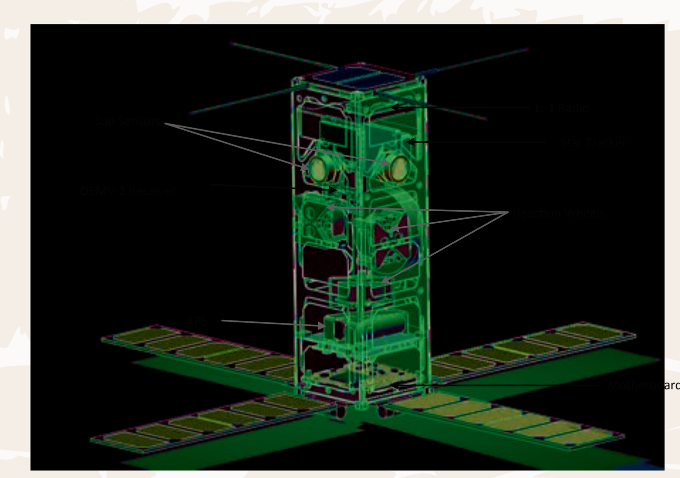
Perigee [km]	Apogee [km]	Dose for 1 year [rad] With 1 mm Al shielding
500	500	8.19×10^{-3}
300	6000	4.69×10^{5}
300	12000	2.68×10^{5}

Above: TID in one year at varying orbits

Payload

COLE's dual frequency GPS will use a receive antenna with about 4 dBiC at the L1 and L2 frequencies. This gain falls within the nominal collection region shown below. As such, the GPS receive antenna will see the GPS signals up to GEO altitudes. Placement of the GPS, along with other structural components, can be seen in the figures below.





Above left: External view of the COLE structure and component layout. Above right: Internal view of the COLE structure and component layout.

Concept of Operations

Deploy during first transfer orbit of SS/L bus

Operational modes

- Mission science: requires GPS lock for 10 seconds
- Downlink: occurs below altitudes of 19,000 km
- Standby: charge batteries
- Momentum dump: occurs near perigee

Attitude Determination and Control System

Pointing accuracy better than 5° required

Determination & Control

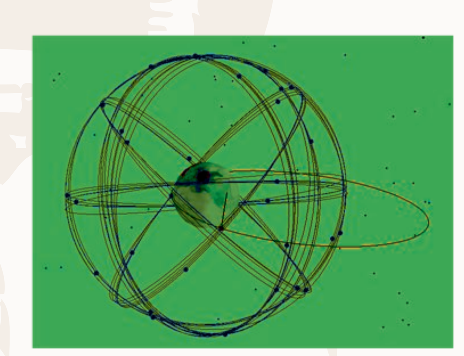
- Sun sensors
- Star tracker
- Reaction wheels
- Magnetorquers

Communications

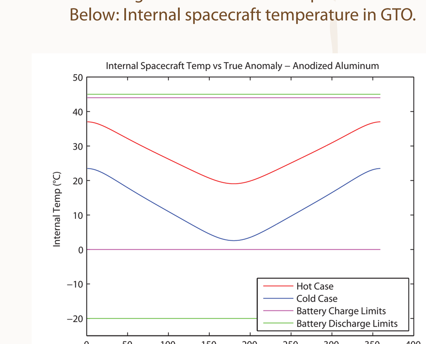
A UHF transceiver with 30 dBm transmit power is used for all communication with a 1.76 dBi deployable half wave dipole antenna. The link is maintained with a BER of 10^{-5}. Average throughput for downlink mode is 3.61 MB per orbit, which is more than sufficient to transmit GPS data, which is generated at 100 bps (327 kB per orbit).

Thermal

COLE uses anodized aluminum insulation combined with a 1 W thermofoil heater to maintain an internal temperature between 0°C and 45°C. The heater never operates when the radio is at full power. Internal temperature is shown at the right as it varies throughout the orbit for both a hot and cold case.



Above: Diagram of one of COLE's operation modes.
Below: Internal spacecraft temperature in GTO.



RIDES

ride to deploy smallsats in gto

SPACE SYSTEMS LORAL

Michigan**Engineering**

GTO BUSINESS CASE

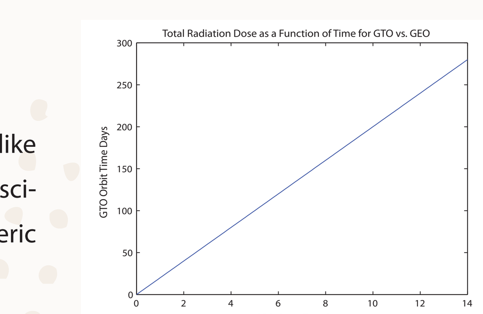
Why CubeSats in GTO?

The main hurdles facing satellite manufacturers are the extremely high costs and long production times for developing spacecraft. CubeSats are a much cheaper and faster alternative to traditional (greater than 1,000 kg) satellites. One 3U CubeSat takes 18-24 months to develop and costs between $1-3M; larger satellites have production times of about 30-40 months and cost hundreds of millions of dollars. Corporations and government organizations are increasingly using CubeSats not just for education but for real missions (e.g. Boeing CSTB, Aerospace Corporation AeroCube, and the NASA Ames GeneSat).

Potential GTO Customers

Universities

Universities are primarily interested in conducting scientific research missions, like the University of Michigan's Radio Aurora eXplorer (RAX). GTO opens up new scientific measurement opportunities not available in LEO, such as magnetospheric GPS tomography.



Above: Equivalent radiation dosages in GTO vs. GEO

Commercial Companies

Raising the TRL of innovative, enabling technologies is of distinct interest to the private sector. CubeSats in GTO provide a very cheap method for on-orbit testing of important metrics like radiation tolerance. GTO presents a harsh radiation environment to perform radiation tolerance testing. As seen in the figure above, 5 month radiation dosage in GTO is equivalent to 7 years of dosage in GEO.

Government Agencies

The military is primarily interested in Space Situational Awareness (SSA) of orbital debris and anti-satellite weapons. CubeSat constellations in GTO can catalogue all objects from LEO to GEO altitudes. Additionally, the government is interested in doing fundamental science on the CubeSat platform much like universities. NASA and the NRO are prime examples of agencies already involved in CubeSat missions.

Market Size

Currently, 20 GEO spacecraft are launched per year, providing CubeSat developers with abundant launch opportunities. With 1,220 satellites expected to launch over the next decade as compared to 770 over the previous decade, even more GEO launch opportunities will be able. To date, over 50 CubeSats have been launched since 2001 with 20+ CubeSats scheduled to launch in 2011 alone. In addition, large constellations like QB50 (50), Armada (48), and Boeing/NRO weather colony (20+) are being developed. With all factors considered, SS/L can hope to launch about 4-5 CubeSats per year in the next s years.

GTO MISSION NON-RECURRING ENGINEERING (NRE)

NRE for commercial CubeSats is treated as worst-case. A GTO CubeSat mission would require a team of ~12.5 engineers and scientists. Assuming they dedicate 50% of their time on the development, it would take 1.6 years from conceptual design to deliver at Cal Poly. Compensation costs are $250 K/year including 50% overhead. In total, labor costs including overhead are $2.5 M, with most of the effort coming from power, software and ADCS.

Mission	NSF Funding
RAX	$1 M
FIREBIRD	$ 1.2 M
Firefly	$ 1.1 M

Although obtaining such levels of funding at a University level can be difficult, NSF currently sponsors three programs of relative magnitude as shown by the table above.