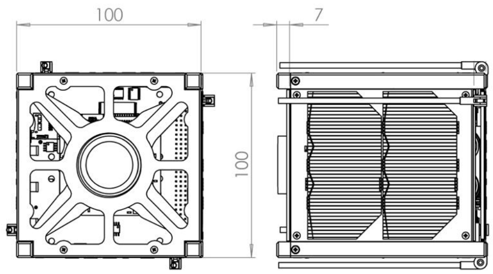


CubeSat Challenge - Multipurpose Tactical CubeSat (MTCS)
18 October 2017

The Multipurpose Tactical CubeSat (MTCS) system has been designed to satisfy Special Operations Forces mission requirements with next-generation CubeSat communications and sensor technologies. The solution we propose is relatively low cost and flexible. It can rideshare existing DOD or NRO launches as its gateway into orbit. By employing a novel, multipurpose architecture and system framework, MTCS makes it possible to rapidly field low-cost applications and tools to address complex SOF mission requirements. This will enable USSOCOM to manage dedicated space domain platforms for rapid technology prototyping, proofs of concept, real time tasking, and technology evaluation.

Recent advances in the state of CubeSat technology make possible satellite missions which were impossible to even consider ten years ago. Microcomputer systems have grown exponentially in power. Battery technology power to weight ratios have improved. MEMS sensors have improved in quality and dropped in cost. GPS technology continues to evolve. Solar panels have become more efficient and lighter. Communications systems provide smaller, lighter components capable or greater effective radiated power. Software defined radios and cognitive communications technology are poised to open up new realms satellite support for open mission concepts.

The principal focus of the MTCS is to support Special Operations Force (SOF) missions and to create a richer tactical information and situational awareness environment for special operators. Rather than attempt to determine every possible SOF mission in advance, our approach is to select key high value mission types and to modify the CubeSat software after launch. This ***open mission concept*** is a key element of the proposed MTCS solution, which will enable implementation and testing of different communications links, frequency spectrum usage, and modulation types after launch. This concept of dynamic provisioning will provide better support and return greater value for every dollar invested in the program.

Special Operations Forces Missions

The Multipurpose Tactical CubeSat (MTCS) is designed to maximize the benefits and USSOCOM's returns on investment in CubeSat technology. It will support SOF missions by providing enhanced situational awareness, advanced communications, and customized tactical support. Rather than being restricted to a narrow set of pre-defined SOF missions, the MTCS open missions concept will support pre-defined, ad hoc, and unanticipated mission concepts. The MTCS will help USSOCOM to determine the operational utility of using Multipurpose Tactical CubeSats in direct support of SOF in austere and denied areas. This Solution provides operationally relevant and technically feasible payload concepts for USSOCOM CubeSats.

The multipurpose nature of the tactical CubeSat platform is supported by redundant communications and on-board processing modules. Each of these modules is able to be customized and tasked in realtime to provide specific mission support capabilities. Software defined communications and processing will satisfy both present and future requirements. By employing an ***open missions concept,*** diverse SOF mission types will be able to be supported by the MTCS. They include Special Reconnaissance, Unconventional Warfare, Civil Affairs Operations, Counterterrorism, Counter-proliferation of Weapons of Mass Destruction, Security Force Assistance, Counterinsurgency, Hostage Rescue and Recovery, and Foreign Humanitarian Assistance.

The following three MTCS mission capabilities stand out as the highest impact open mission concepts:

1) **Improved Situational Awareness -** Use of sensors, ADS-B, ISR fusion, asset tracking, weather data collection sites, real time tasking in austere and denied areas AND in dense and urban landscapes. Dynamic communication links to ground stations, MEO, HEO, and Geosynchronous ISR Satellites. Improved Situational Awareness will benefit SOF missions by providing a more complete operational picture. By fusing sensor data collected by other satellites, real time UAV imagery, and blue force tracking, with HUMINT and SIGINT, and delivering it directly to SOF operators, MTCS will significantly improve situational awareness on the ground and improve the operational outcomes.

2) **Enhanced Tactical Communications capabilities** - Data encryption, repeater function, BLOS comms, Data exfltration, links to other satellites, advanced modulation modes, software defined radio and cognitive communications, active and plasma antenna designs, LoRa frameworks, and the concurrent use of multiple highly configurable radios will enhance communications capabilities of SOF teams. Enhanced Tactical Communications will also benefit SOF missions by filling in gaps in current mission communications support. CubeSats can bridge non-line of sight communications gaps. They can relay Command and Control and real time taskings during joint force and combined operations. Through data encryption and advanced modulation and encoding techniques CubeSats can reduce the COMINT signatures for SOF teams in dangerous or contested areas.

3) **On Board MTCS Processing -** to filter, aggregate, customize and personalize feeds for SOF teams and operators. When the MTCS is in view of other DOD satellites (or DOD ground stations) it will have standing requests for types, time frames, and geographic boundaries for ISR and sensor information which it automatically retrieves. Prior to a pass over a specific SOF team or operator the MTCS on board computer will sort, distill, and customize the fused sensor data, intelligence reports, and other near real time data of relevance to a particular SOF mission. When a link is established during a pass, the MTCS will receive data and requests from the ground, and then prioritize and transmit relevant, actionable intelligence data to the SOF team. This request driven process of updating, prioritizing, and fusing data received from a wide array of sources will provide orders of magnitude better and more timely intelligence to SOF teams and operators. The MTCS platform will be designed so it can be remotely updated as new and better versions of its control and processing software are developed, without losing any current requests or intelligence data. This software upload capability may also be used to customize a MTCS to meet special mission requirements.

Other Missions - Other missions are not proposed for MTCS: No multi-spectral, optical or image sensor applications were selected because there are already significant existing DOD investments in satellites for these missions. They already do a good job. If imagery is required by SOF on the ground, MTCS could store and forward it from existing satellites or ground stations to SOF ground operators. Likewise, sophisticated propulsion and maneuvering systems have not been proposed for MTCS, since they can be complex and costly and reliability, repeatability, and simplicity are key design goals of the system. A much simpler torque wheel ADCS will be employed.

Mission Support for CubeSat Employment - In order to achieve all of the benefits of the open mission concept a number of standard operating procedures and protocols will be required. In addition, the SOF operators will require a ground station with mission apps to facilitate use of the MTCS links and to communicate status and requirements to Command and Control:

In order to make use of the MTCS ***Enhanced Situational Awareness*** capabilities, an XML schema for a Tactical Mission Description Language (TMDL)will be required. It will document concisely all of the support elements for a particular mission, assure expedited coordination and liaison, and it will assure the best use of the satellite resources.

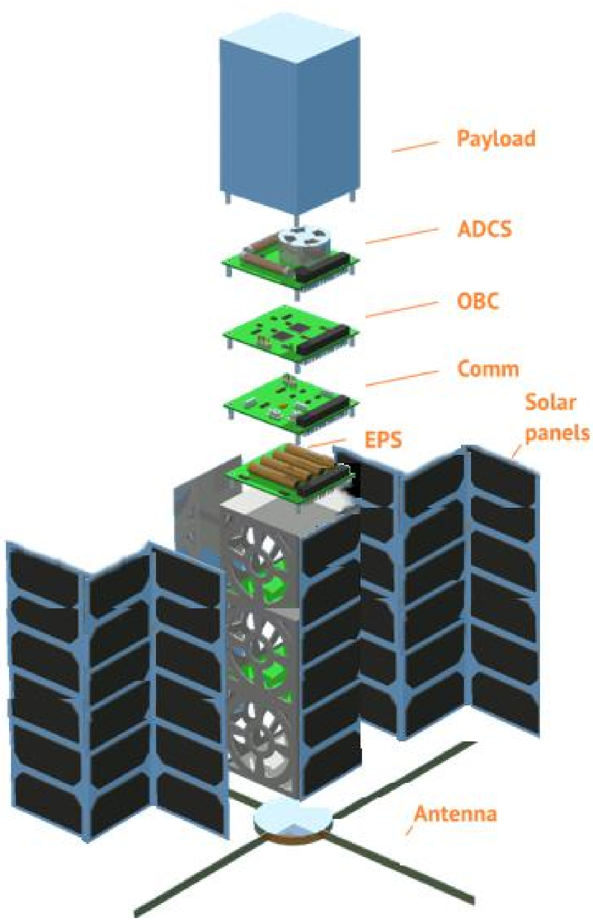
In order to get the most value from the MTCS ***Enhanced Tactical Communications*** capabilities, scheduling, link choices, and link management need to be coordinated using a Communications Link Description Language (CLDL). It will contain the digital details required to configure software defined radios and cognitive communications systems in the MTCS payload.

In order to get the most value from the MTCS ***On-Board Processing*** capabilities for customization and fusion of ISR to meet mission requirements, a Tactical Mission Requirements Language (TMRL) will be needed. It will provide Command, Control, and Mission Support functions with the detailed intelligence requirements of the mission. As intelligence is aggregated from multiple sources (satellites, RPV, SIGINT, HUMINT, etc.) the TMRL will control the on-board processing resources to assure that the most critical information is organized, prioritized, and delivered to the SOF operators on the ground.

Multipurpose Tactical CubeSat Architecture:

The Multipurpose Tactical CubeSat payload volume will be 1.5U in a standard form factor 3U CubeSat with folding solar panels. Two folding three section solar panels 30cm x 30cm in size will unfold from the 3U CubeSat structure. The payload mass will be less than 2.7kg. The payload will conform to the CubeSat Design Specification, Rev 13, Cal Poly SLO, February 20, 2014. It will be capable of surviving launch environments as described in Goddard Space Flight Center Std-7000, General Environmental Verification Standard (GEVS), April 2013.

The MTCS prototype payload solution can be built within the next 12 to 24 months. We have performed a feasibility assessment to assure that it will be possible to complete using COTS components and flight qualified CubeSat kits. With the exception of optional experimental plasma antenna technology and active directed microwave patch antennas, everything else should currently be available to meet CubeSat specifications. The following listing recaps the functional descriptions of all flight systems components and payload components.



PAYLOAD COMPONENTS (1.5U):

1 - Multiple Communications Transceivers (4) (software defined radio, low power beacon, etc.)
2 - Dual Processor Boards with Memory and SSD storage - for sensor and intelligence fusion
2 - Uplink S or L Band Patch Antennas - High Speed Inter-Satellite link
1 - S or L Band Downlink Patch Antenna - High Speed Ground Station link
1 - Deployable UHF Antenna - Low speed Tactical Ground Station link
1 - Digital Antenna Switching Unit
1 - Mission Configurable Data Logging and Sensor Platform (research)
Option - Computer and Management Controller for Synergistic MTCS Constellations

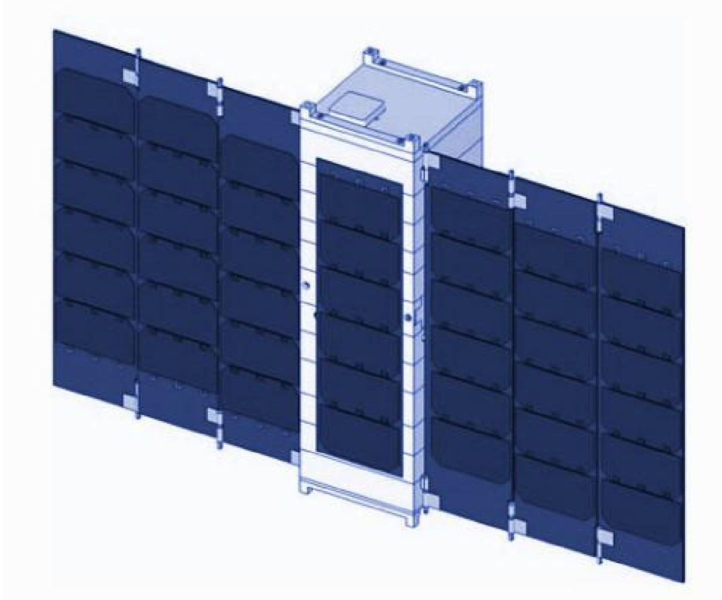
FLIGHT SYSTEM COMPONENTS (1.5U):

1 - Standard 3U CubeSat Frame
1 - Fixed 1 x 3U Attached Solar Panel
2 - Folding Self Deployed Solar Panels (30cm x 30cm)
1 - Power Systems Unit, Telemetry and Charger
1 - Lithium Polymer Battery Unit
1 - Attitude Determination and Control System (inertial)
1 - On Board Flight Computer with GPS and IMU sensors
1 - Miscellaneous Hardware and Interconnects

Power System:

The Multipurpose Tactical CubeSat (MTCS) will employ 3U x 3U solar panels that automatically unfold following deployment. In order to support a rich array of payload communications capabilities, the power system and solar panels have been sized to consistently provide 48w of On-orbit-average power at 12.6 and 5 volts using dual output DC-DC Converters. This will be accomplished through the use of one 10x30 cm solar panel and two 30cm^2 solar panels with a battery pack and a power management and charging system. Each time the CubeSat emerges from darkness the Attitude Control System will reorient the platform to optimize production of solar power. During eclipse segments of the orbit no ACS is needed for power, only for antenna alignment and polarization.

The Lithium Polymer battery has a high energy density of 200 Whrs/Kg and provides real-time monitoring and feedback of individual cell voltages, temperature, and current with full battery conditioning and cell-balancing. The deployable solar display utilizes space-proven Ultra Triple Junction (UTJ) 3-layer CIC solar cells wired in series to produce a 16VDC open circuit voltage to directly charge the 12.6vDC Lithium Polymer Battery. UJT solar cells are 28.3% efficient.



Thermal Control:

The solar panels will provide some radiation heating during solar illumination. All of the components should be capable of operation from -30C to 50C, will meet standard requirements for anticipated thermal exposure, and be flight qualified for use within the expected temperature range. The MTCS polar orbit will take it in and out of sunlight during each orbit, moderating extreme thermal control issues.

Communications Data Transfer Rate:

Data transfer rates differ for individual mission requirements. They are also affected by the amount of on-board processing which is possible, in use, or available. Although all communications channels are highly configurable, there will typically be one or more uplinks to other satellite systems and one or more downlinks to large ground stations and tactical ground stations. Typical data transfer rates for the MTCS uplinks will range from .4 to 2 Mbps. Data transfer links to large ground stations will support the highest data transfer rates of 1 to 6 Mbps. Data transfer rates over Class 1 LoRaWAN UHF downlinks to tactical ground stations will be from 9.6 to 56 Kbps. The tactical ground station link will require 1w power on the CubeSat transmitter, a simple UHF transceiver, a computer, and a directional yagi antenna on the ground. All data links will support DOD level data encryption. Up to two of the link types can operate concurrently.

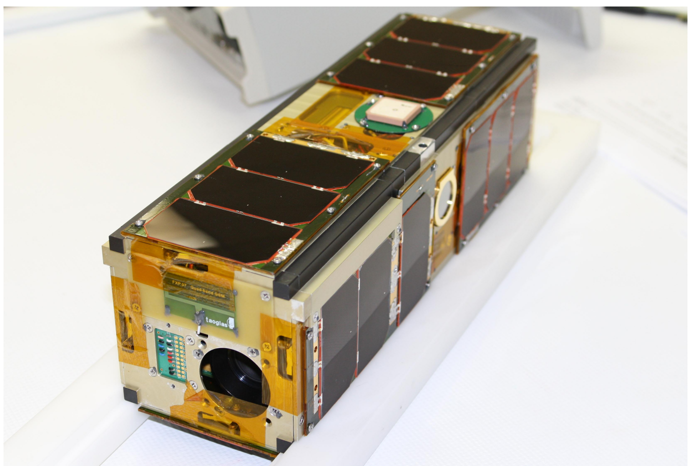
Communications Data Transfer Volume (per orbit):

Capacity of data transfer volumes, per orbit, depend on link budgets and the number of ground stations involved. This capacity will also be affected by the availability and mix of CubeSat to satellite links, high speed and tactical ground links, and individual mission requirements. Data transfer volumes can be calculated per 100 minute orbit based on one 10 minute tactical footprint, two 10 minute high speed ground station footprints, and three 5 minute satellite uplinks. Given these links and other data exfiltration, the data transfer volume per orbit could range up to as much as 1.1 GB.

Multiple MTCS systems could be launched to form a synergistic constellation of MTCSs. Such a constellation could expand ground access footprints, multiply data transfer volumes, and reduce intervals between CubeSat passes. Significant operational benefits can be gained by designing a synergistic constellation of CubeSats, launching them at the same time, and positioning them with strategic orbital placements.

Bus Stability and Attitude Control:

There are two principal requirements for attitude determination and control systems (ADCS) in the MTCS system: the reliable positioning of the solar panels to achieve maximum power generation during orbital segments when sunlight is available; and stability and anti-roll controls to maintain antenna polarization and alignment for the most robust communications with the ground and other satellites. The MTCS attitude control system incorporates 4 integral reaction wheels with a redundant 3-axis control system to enable precision pointing of the CubeSat. This simple system will be powered by the power system battery pack and controlled by the onboard computer flight control system.



Additional Requirements:

On missions with inter-satellite communications requirements, the appropriate DOD satellite network availability, frequency management, and interoperability will need to be provisioned.

Special Forces Operators using MTCS will have small tactical ground station capabilities, with portable renewable power sources, tailored to their mission requirements. Special Operations Command and Control sites will have larger ground stations with uninterruptible power sources. In addition, there may be other smaller weather, ISR data collection, sensor data, asset tracking, and geolocation stations whose telemetry will be collected and exfiltrated from austere and denied areas by MTCS.

Computer hardware, memory, and electronics are susceptible to radiation exposure in space, which can corrupt data and programs. On board processing systems will constantly monitor their own operations and whenever an anomaly is detected, the OS will reload and restart itself.

The Vreeland Institute

The Vreeland Institute is a New York State Educational Not for Profit. We are an award winning think tank which tackles, and solves, advanced technology challenges from around the world. We specialize in the cyber security, first responder, homeland security, and artificial intelligence disciplines.

We are able to call upon decades of expertise from the visionaries, innovation architects, communicators, and technologists, that we rely upon to solve international innovation challenges. In response to the requirements of each challenge, an agile matrix based team is instantiated to architect, design, and build innovative solutions. We draw upon a deep portfolio of contributors including staff, visiting scholars, alumni, interns, and other collaborators to fill our project teams.

As Director, I have personally been engaged with aerospace studies for the last 50 years. This Summer I received the 2017 national Aerospace Educator - Lifetime Achievement Award from the Civil Air Patrol, the United States Air Force Auxiliary. Over the last several decades we have been located in Boston, New York, and Washington D.C., and the Institute is now planning a permanent campus in rural upstate New York. It will be capable of fully autonomous off-grid operation and will be sustainable through the use renewable energy resources. On this campus we are building a set of “buildings that teach”, and in the words of R. Buckminster Fuller, other “artifacts of possibility”.

The Vreeland Institute is particularly well suited to take on this Challenge because of our long term involvement in, and commitment to, aerospace engineering. We have also been recognized for being highly successful on other similar challenges. In 2016 we were a prize winner in the NASA Airspace for All 2035 Challenge. In that competition we designed a comprehensive, sustainable, high performance replacement for the current National Airspace System. Our solution was capable of supporting more than 10 million daily flights in 2035, including aircraft, spacecraft, and unmanned aerial vehicles.

In 2017 we received the first prize in a USAF Special Operations Command Challenge seeking a sustainable self contained system for mobile weather data collection in austere, contested, and remote geographic locations. This system had to be capable of taking multiple daily atmospheric soundings up to 10,000’ AGL and record, process, and analyze that data.

As innovation architects, we have won two challenges conducted by DHS and DOD. In 2015, we won the DHS First Responder Indoor Tracking System challenge employing MEMS sensor fusion, dead reckoning, LIDAR odometry, differential altimetry, Bayesian filtering, crowdsourced navigation, 3D world building, heatmaps, and augmented reality. In 2014, we won the DOD Counter Terrorism Technical Support Office (CTTSO) Challenge: Pre-Event Insider Attack Recognition. In designing our solution, we considered a taxonomy of well established threat indicators, and provided innovative ways to collect behavioral data on potential attackers.

In 2017, we won a competition with our Autonomous Tunnel Location and Inspection System (ATLIS). ATLIS makes it possible to determine the precise position of a robot platform in an underground network without GPS. In 2017 we also won a Autonomous UAS Land Surveying Challenge. In that solution we employed high resolution RTK GPS for centimeter geolocation, laser ranging and LIDAR odometry, sensor fusion, and augmented reality.

In 2014, we designed a bomb sniffing robot, the CUstom Lightweight Electronic Bomb Reconnaissance Assistant, for a DHS Challenge. The snake-like robot, CULEBRA, was designed to be printed on a consumer level 3D printer, so local bomb squads could produce, assemble, repair, and maintain their own robots. CULEBRA was equipped with a wireless high resolution video camera and a capability to “cut the red……. no, the blue, wire”.