Components, subsystems, or innovative approaches that will enable small satellites to significantly advance performance.

Session Chair: James Newman, Naval Postgraduate School

8:00 AM
Maximum Power Point Tracking Techniques for Efficient Photovoltaic Microsatellite Power Supply System
Hadi Malek - Energy Dynamics Laboratory; Sara Dadras, YangQuan Chen - Utah State University; Robert Burt, James Cook - Space Dynamics Laboratory

ABSTRACT: Due to limited power availability and constraints imposed on satellite mass, volume, and available area for photovoltaic (PV) panels, high power conversion efficiency is an important goal in the design process of an electrical power source for microsatellites. In this research, we model, design, and build a photovoltaic based Electrical Power System (EPS) for a satellite to ensure the supply of maximum power and stable operation.

This paper presents the results of our MPPT (maximum power point tracking) research. We describe the EPS power system boundary requirements used in our research. We also describe the design constraints used in our research that are typical to the microsatellite class missions such as extremely low power requirements, limited volume, and minimal, fixed point, processing capabilities. We describe our implementation approach based on proposed algorithms such as Integer Order Extremum Seeking Control (IO-ESC), and Fractional Order Extremum Seeking Control (FO-ESC). Comparison results for the different algorithms are presented as implemented in both the model and on the actual hardware. These new MPPT techniques offer higher conversion efficiency relative to the Perturb & Observe (PO) and other techniques conventionally used in satellite power supply systems.

8:15 AM
Additively Manufactured Propulsion System
Matthew Dushku - Experimental Propulsion Lab; Paul Mueller - Experimental Sounding Rocket Association

ABSTRACT: New high-performance, carbon-fiber reinforced polymer material allows additive manufacturing to produce pressure vessels capable of high pressures (thousands of pounds per square inch). This advancement in turn allows integral hybrid propulsion which is revolutionary for both CubeSats and additively-manufactured spacecraft. Hybrid propulsion offers simplicity as compared to bipropellant liquid propulsion, significantly better safety compared to solid or monopropellant hydrazine propulsion, and much better performance than cold-gas or hydrogen peroxide monopropellant propulsion. The safety benefits are especially important for CubeSats because they are generally secondary payloads whose impact on primary payload operations must be minimized. The possibility of safe, high-performance, high-thrust propulsion opens up a huge variety of possible mission scenarios previously unavailable to CubeSat spacecraft. In addition, a “printed in” cold gas attitude control system that draws its propellant from the main thruster's oxidizer tank allows spacecraft pointing, midcourse corrections, and proximity operations with little reduction to the available spacecraft volume. With the advancement in additively manufactured propulsion, CubeSat-sized spacecraft can offer real responsive space capabilities never before possible.

8:30 AM
EDDE: A Multi-Km Modular Upper Stage for SmallSats

ABSTRACT: EDDE® (the ElectroDynamic Delivery Express) is a persistently maneuverable modular propellant-less vehicle for low earth orbit (LEO). EDDE has at least 2 major applications: payload delivery and debris removal. Vehicles as light as 20-30 kg can deliver secondary payloads to custom orbits, but 50-100 kg vehicles plus capture hardware are needed to efficiently remove orbital debris above 800 km. EDDE uses a reinforced aluminum foil tape to collect and conduct electrons, and solar arrays distributed along the length to limit peak local voltages. Hot tungsten wires emit electrons back into the ambient plasma. Air drag sets EDDE's minimum altitude of 300-400 km. There is no hard ceiling, but thrust decreases at high altitude, requiring use of longer and heavier vehicles for efficient thrusting. In general, short electrodynamic thrusters do not perform well, since thrust scales with the product of current and length. Large electron collection areas are needed. Making the collector also serve as a long conductor makes it far more effective. This paper describes EDDE’s design, components, and operations, and some options for stowing and delivering multiple secondary payloads. The most attractive thing about EDDE to the smallsat world may be the possibility of “custom orbits without dedicated launch.

8:45 AM
CubeSec and GndSec: A Lightweight Security Solution for CubeSat Communications
Obulapathi Challa, Gokul Bhat, Janise McNair - University of Florida
ABSTRACT: Communication protocols implemented for CubeSat networks have trivial overhead and almost no security features. As CubeSats are heavily constrained for resources, complex security suites and protocols can seldom be implemented. Cyclic Redundancy Check (CRC) which is currently used in CubeSats provides no protection against intentional corruption of data and moreover, CubeSats are vulnerable to eavesdropping due to the wireless channel. Message integrity also becomes questionable as an attacker can modify commands and data. This paper proposes CubeSec and GndSec, a very light-weight security solution for CubeSats communications. CubeSec and GndSec provides mutual authentication, confidentiality, data integrity between Cubesat and ground Station using preshared keys.

9:00 AM
A Novel Hemispherical Anti-Twist Tracking System (HATTS) for CubeSats
Eli Bashevkin, Joseph Kenahan, Brian Manning, Brian Mahlstedt, Andrew Kalman - Stanford University/SSDL

ABSTRACT: Satellites must often point a device continuously at an object while the satellite and/or object move through space. With these devices, connections are typically made between the articulated device and a fixed base around which the device rotates in one or more axes while tracking. Implementing these connections can be a challenge in sizeconstrained applications or when uninterrupted tracking is required. Within the small satellite realm, some new solutions (e.g., Canfield joint) have recently been developed to address this problem. Given the mass and volume constraints imposed upon CubeSats, the authors feel that none of the existing solutions solve the problem elegantly or efficiently. A new, simple two degree-of-freedom (2-DOF) joint - the Hemispherical Anti-Twist Tracking System (HATTS) - is proposed that allows continuous tracking through a hemisphere with continuous rotation while avoiding any twist in the connection(s) from the device to the base. This design is notable for its simplicity and its ability to continuously rotate. The HATTS joint has a reduced component count and fewer interfaces between moving parts than other solutions, thereby potentially increasing pointing accuracy while lowering cost, mass and complexity. In the CubeSat-specific implementation (CubeHATTS), two identical motors are rigidly affixed to the chassis of the satellite and provide the two DOFs via a jointed elevation arm and dual coaxial gears operated either synchronously or differentially. CubeHATTS is able to track continuously through a hemisphere and when stowed, the entire system fits in a volume of approximately \( \frac{1}{4} \) U (10cm x 10cm x 2.8cm).

9:15 AM
High Performance Green Propulsion (HPGP): A Flight-Proven Capability and Cost Game-Changer for Small and Secondary Satellites
Aaron Dinardi - Ecological Advanced Propulsion Systems, Inc.; Mathias Persson - ECAPS AB

ABSTRACT: In recent years, the capabilities (and as a result, the wider acceptance) of small satellites has increased tremendously. This has been primarily due to advances in payload technologies, which have allowed sensor components to better operate within the volume and
power constraints imposed by smaller platforms. However, in order for small satellites to provide a truly viable alternative to a greater number of missions and customers, the platforms themselves must begin offering increased capabilities - more on par with those of larger satellites. An important area where the capability of small satellites has continued to lag significantly behind their larger cousins is propulsion. The reasons for this are many, including: platform mass and volume limitations, personnel safety concerns, hazard limitations of existing integration facilities, costs associated with propellant transportation and launch site processing, or “blanket restrictions” imposed on secondary/rideshare satellites (due to concerns regarding possible adverse impacts to the primary satellite). But regardless of the specific reasons applicable to any individual mission, the resulting capability limitation is the same: small satellites are usually “stuck” in the orbit they are initially injected into; which adversely affects their scientific utility and can make them a non-option for many customers.

High Performance Green Propulsion (HPGP) provides a flight-proven solution to each of the many concerns which typically preclude the inclusion of a liquid propulsion system on small satellite missions. Additionally, the many benefits of HPGP provide a game-changing capability increase for small satellites; thus allowing them to further close the gap with larger platforms. This paper will: 1) provide a PRISMA mission overview and short “2 year update” of the on-orbit HPGP data, 2) delve into the details of each of the issues identified above, and 3) provide examples of the capability increases and cost savings able to be achieved through the implementation of various HPGP hardware solutions on small satellite platforms.

9:30 AM
A Constrained Attitude Control Module for Small Satellites
Henri Kjellberg, Glenn Lightsey - The University of Texas at Austin

ABSTRACT: The Satellite Design Laboratory at the University of Texas at Austin is building a general purpose guidance, navigation, and control (GN&C) module with 6 degree-of-freedom maneuver capability. The GN&C module is capable of meeting multiple pointing constraints autonomously utilizing new constrained attitude control algorithms. Attitude keep-out zones are avoided by first discretizing the unit sphere into a graph using an icosahedron-based pixelization subroutine. An admissible path is found using the A* pathfinding algorithm. The trajectory is followed by a rate and torque constrained quaternion feedback controller. The algorithm is capable of running in real-time on a low power embedded flight computer. The module has secured flight opportunities on two student-built 3U CubeSats for flight projects sponsored by the Air Force and NASA. Both sets of mission requirements are satisfied with the same 3U CubeSat attitude control system, demonstrating the algorithm’s versatility as a general purpose controller. The autonomy provided by the advanced constrained control algorithms enables more complex picosatellite missions and decreases the cost of spacecraft subsystems by shifting requirements away from the hardware and onto the control algorithm.

Alternate:
ABSTRACT: As a mission design envisions travel further from Earth, transmission power and onboard or ground-based antenna sizes must be increased to maintain a given transmission throughput. However, onboard capabilities are constrained by volume and mass limitations, thus constraining a mission's science-value. Model-based transmission reduction (MBTR), is a ‘game changing’ technology that allows greater science to be performed (and the results transmitted to Earth). Instead of conventional link requirement reduction approaches, which make marginal reductions by compression techniques, this approach intelligently reduces data transmission requirements by transmitting only the differences between a shared (between the spacecraft and ground analysis site) model and the data required to support these change assertions.

This paper discusses model development, a model definition language, and a communications framework for MBTR transmission. It discusses the onboard autonomy requirements for a MBTR mission and reviews how the link budget requirements, under this model, become a function of the accuracy of the initial model and the magnitude of validation data required by mission scientists. The benefits of MBTR for small satellite missions within the solar system and its requirement for interstellar missions are discussed.