Information Sciences Institute

Department of Astronautical Engineering

SERC

SPACE ENGINEERING RESEARCH CENTER

USC Viterbi
School of Engineering

The Space Engineering Research Center (SERC) is a joint venture between two components of the University of Southern California —the Information Sciences Institute and the Department of Astronautical Engineering. The Center is dedicated to disruptive space engineering, research, and education–including hands-on build, test and flight demonstrations of spacecraft and satellites. SERC seeks to challenge traditional methods of space R&D, manufacturing, and exploration with approaches that dramatically reduce costs, enable novel capabilities, and support vital democratization of the space domain.

WHO WE ARE

USC's Information Sciences Institute (ISI) is a world leader in research and development of advanced information processing and computer and communications technologies. As one of the nation's largest, most successful university-affiliated computer research institutes, it attracts over $100 million annually in grants from federal agencies and the private sector. Research ranges from the theoretical and basic to that of applied research and development.

USC's Department of Astronautical Engineering encompasses the dynamic and cutting-edge fields of advanced space engineering and technology. Space engineers design, build, and operate rockets, space launchers, communications and direct broadcasting satellites, space navigational systems, remote sensing and reconnaissance satellites, space vehicles for human spaceflight, and planet probes. The USC ASTE Department is a fully accredited degree department for bachelor's to PhDs and beyond.

OUR RESEARCHERS

PhDs, master's, undergraduate students from all USC Viterbi departments, local community college student interns, and high school summer interns.

OUR FACILITIES

- Engineering office spaces
- USC (campus) ground station with S-Band and UHF/VHF antennas
- Class 100K cleanroom
- 3D printers for rapid prototyping
- Electrical/electronics test equipment
- CNC mill and lathe & machine shop
- PCB design, reflow and laser cutter

RESEARCH AREAS OF INTEREST

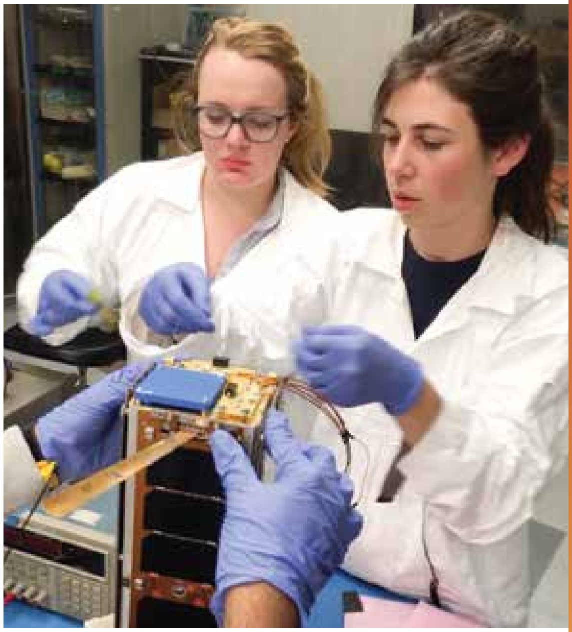
- Rendezvous and proximity operations technologies
- Satellite servicing
- Earth-based low-cost testbeds
- Satellite communications and tracking
- Cellularized spacecraft
- GNC algorithms for aggregation
- Small satellite design, build, integration and launch

Over the past several years, we have seen great accomplishment and growth. This has resulted in a gamut of new disciplines, enabling over 40 new students to be involved in a variety of exciting space application products. Some of SERC's highlights are described in the following text.

The second year of technical support to CONFERS continued—this time increasing the scope of evaluation to look at all functions/attributes that encompass on-orbit servicing (OOS). CONFERS is the premier commercial consortium looking to set the standards and guidelines for on-orbit servicing worldwide. The SERC project team also evaluated the large constellations planned for deployment in the next 5-10 years to update the orbital spatial density plots to present to the commercial consortium members, while advising them of safe or less-populated orbits for early OOS demonstration missions.

The third year of the Jet Propulsion Laboratory's (JPL) Space Swarm project was funded, with SERC continuing to support the docking interface design and supporting rendezvous and docking for a trio of three CubeSats to build an aperture "on orbit."

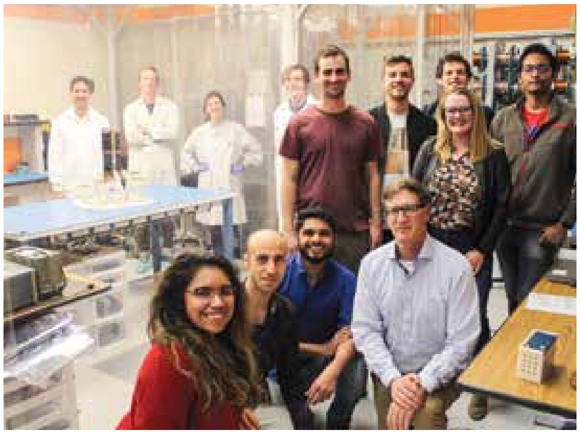
SERC received an award from a small commercial firm, Parabilis Space Technologies, under a NASA STTR effort. The SERC team began working on electronic, mechanical and control inputs for design considerations to support the integration and design input on a unique nanosatellite orbit transfer vehicle propulsion system.



SERC received two major space projects in 2018—REACCH and Dodona. The Reactive Electro Adhesive Capture ClotH (REACCH) project is creating a unique "octopus" robotic end-effector-based gripper with multiple tendrils that use the unique properties of electro-adhesion (EA) as the "contact" points. The project is in conjunction with JPL who is creating the small EA "tiles."

The third USC-based nanosatellite, named Dodona (after the second-largest oracle in Greek mythology), was awarded by an industry partner to support a payload qualification flight of their new technology. The SERC faculty and student team took a "sister satellite" from the original Aeneas CubeSat class built and launched in 2012, modified its software, and upgraded various components from a nonfunctional to a functional status.

As a part of the Dodona effort and the ongoing graduate class on campus, SERC led an upgrade to the USC Satellite Ground Communications station's UHF/VHF antennas. With these antennas, USC's ground station is fully operational for data downlinking, and implementation of uplink capabilities is ongoing in support of future USC CubeSat mission operations.



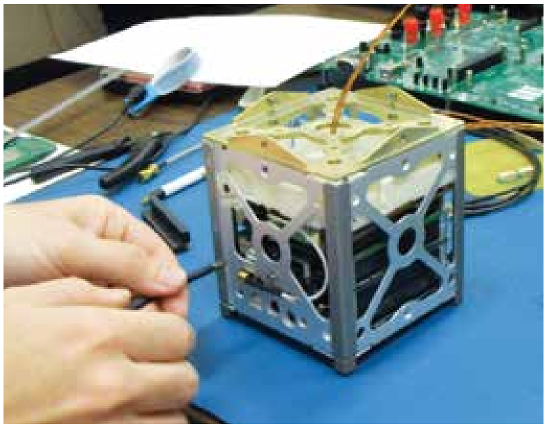
Members of SERC participated as subject matter experts in ISI's Computational Systems and Technology Division's project "SpaceAware," a unique effort that couples data fusion capabilities of the ISI-developed Karma model to the space domain. The entire team project is meant to create a unique set of standalone software that is able to pull in the latest information on every satellite identified in open depositories (like Space Track and CelesTrak) and identify their unique characteristics for heuristics and evaluation of current and future actions.

Early in 2019, SERC was awarded an internal ISI Keston Research Grant titled "Satbotics Control: How to Merge Biologically Inspired Spacecraft Together." The grant will provide support to multiple graduate students to develop a new computational architecture applied to cellular space morphology, and to demonstrate this on the SERC's internal 3-DOF air-bearing testbed, beginning in 2019.

DESCRIPTION

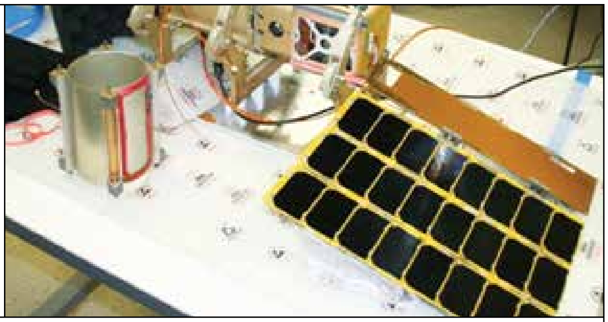
USC/ISI’s first satellite, *Caerus*, was a 1U module that supported the Northrop Grumman Mayflower 3U satellite mission. The Caerus module housed the primary telemetry and power conditioning, and used a novel quadrature spinout whip antenna to ensure a very low profile upon launch.

Mayflower was launched in 2010 and was operational for only a short duration due to an inadvertent low altitude insertion by the launch vehicle deployer.



KEY TESTING AND RESEARCH FOCUS AREAS

- First quad-based whip antenna deployer that supported UHF frequency operation with a very low volume on launch
- Power system conditioning with large arrays (provided by the bus)

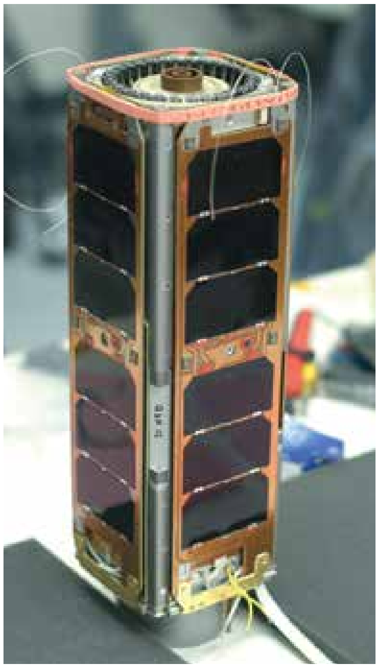


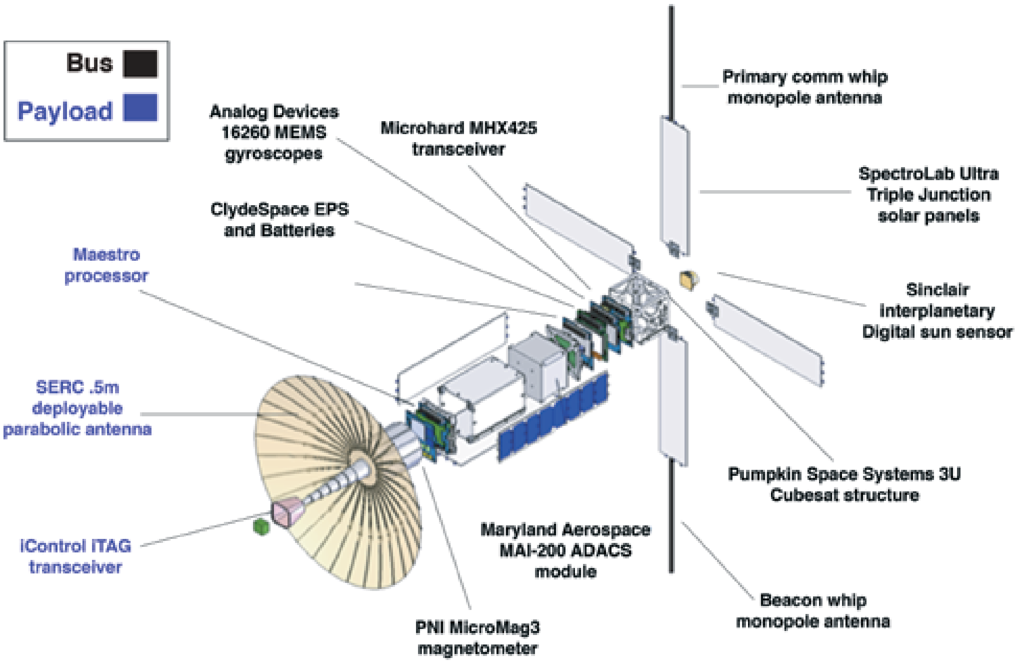
Sponsor: Northrop Grumman Corp.

DESCRIPTION

USC/ISI's second CubeSat, *Aeneas*, was a 3U CubeSat mission using the Colony-1 bus architecture built by Pumpkin Space Systems. The Aeneas payload had the first and largest-to-date deployable antenna for a CubeSat. The deployable 0.5 meter dish antenna demonstrated low power reception of ground-based RFI transmitters for a Department of Homeland Security (DHS) cargo tracking mission.

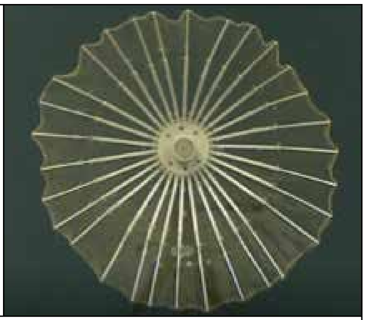
Aeneas launched in 2012, and the beacon onboard is still operating today, worldwide.





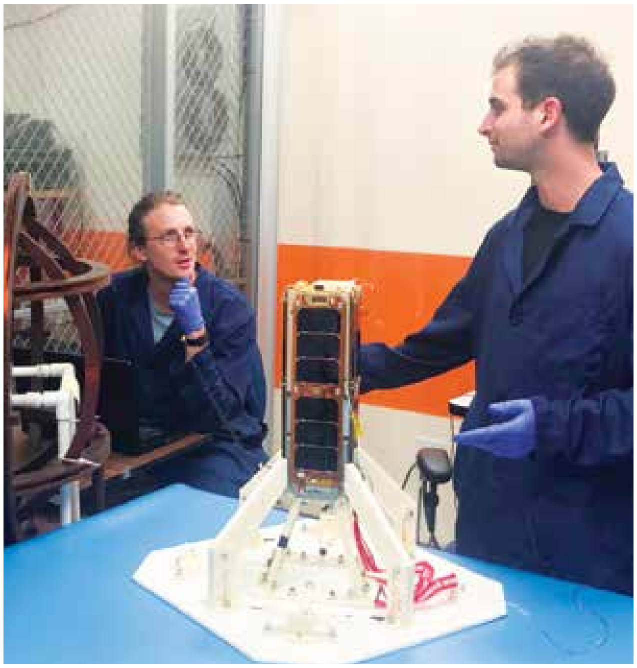
KEY TESTING AND RESEARCH FOCUS AREAS

- First deployable dish antenna from a 3U CubeSat
- Full flight software built and integrated for reaction control operation in a high drag orbit
- TT&C with primary transmitter and rotating beacons for multiple downlink opportunities
- Onboard GNC updates based on magnetic field maps in a LEO high drag environment



Sponsor: US Air Force Research Laboratory

CUBESAT MISSION "DODONA"



DESCRIPTION

USC/ISI's third CubeSat, *Dodona* (named for the second-largest oracle in Greek mythology), leverages SERC's experience with two previous successful missions to downlink telemetry. Onboard data will be used to analyze the B-Dot detumble controller for USC research. This mission supports technology risk reduction for commercial space hardware and tests novel communications systems to and from the USC campus ground station with updated guidance, navigation and control (GNC) algorithms for passive desaturation of dynamic reaction wheel operations.

After launch, SERC will support verification of the GNC algorithms, including detumbling and sun-pointing modes, analysis of mission power efficiency, and ground station tracking for the sponsor.

KEY TESTING AND RESEARCH FOCUS AREAS

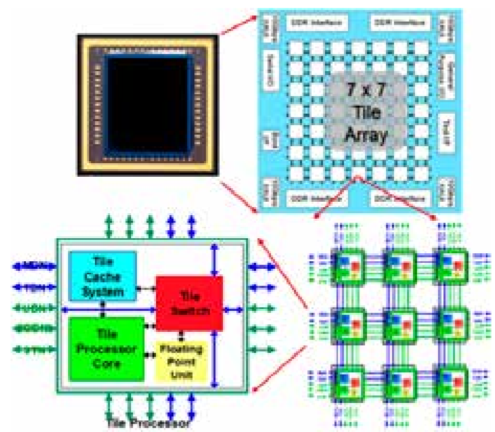
- Piecewise qualification of embedded systems
- Satellite detumbling B-Dot controller design and integration with GNC algorithms
- Space environment simulation for GNC hardware
- On-orbit power utilization simulation with verification through mission telemetry
- Software-defined radio implementation for satellite ground communication
- Satellite ground tracking with RF amplitude for validation of satellite pointing

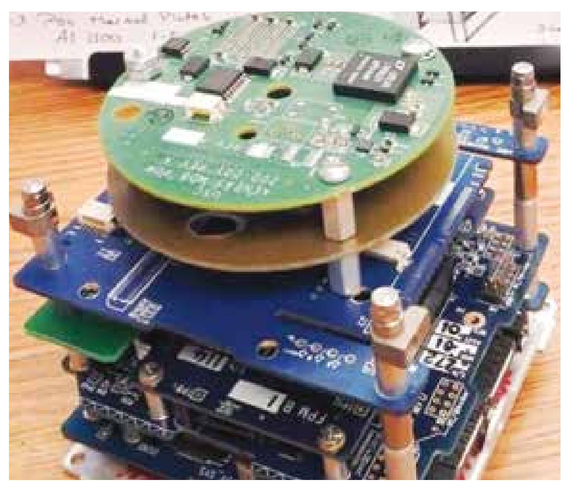
Sponsor: Vector Launch, Inc.

DESCRIPTION

The Maestro Flight Experiment (MFE) is meant to demonstrate the operation of a modern, many-core, radiation-hardened processor (the Maestro ITC) in space. USC/ISI/SERC created a 1U form factor to house the Maestro processor system and provided a mechanism integrate it with a commercial satellite. MFE executes diagnostics, performs image processing activities, addresses strategies for dealing with thermal and power constraints in orbit, and assesses the sensitivity of the processor to radiation exposure in low Earth orbit. MFE demonstrates a substantial advance in radiation hardened on-orbit computational performance, meant to handle the ever-increasing data load of modern imaging sensors and other orbital sensor systems.

The Maestro Flight Experiment launched in 2018 on a NovaWurks bus; however, the bus was unsuccessful in turning on the payloads.





Highest Performance Rad-Hard General-Purpose Processor
- 300 NHz, 44GOPS, 22 GFLOPS

Tiled Architecture
- 48-tile, 2-D processor array
- Low-latency high-bandwidth register-mapped networks
- Static switch processor

Tile Processor
- Main processor: 3-way VLIW CPU
- Floating point coprocessor (IEEE 754 single & double precision)

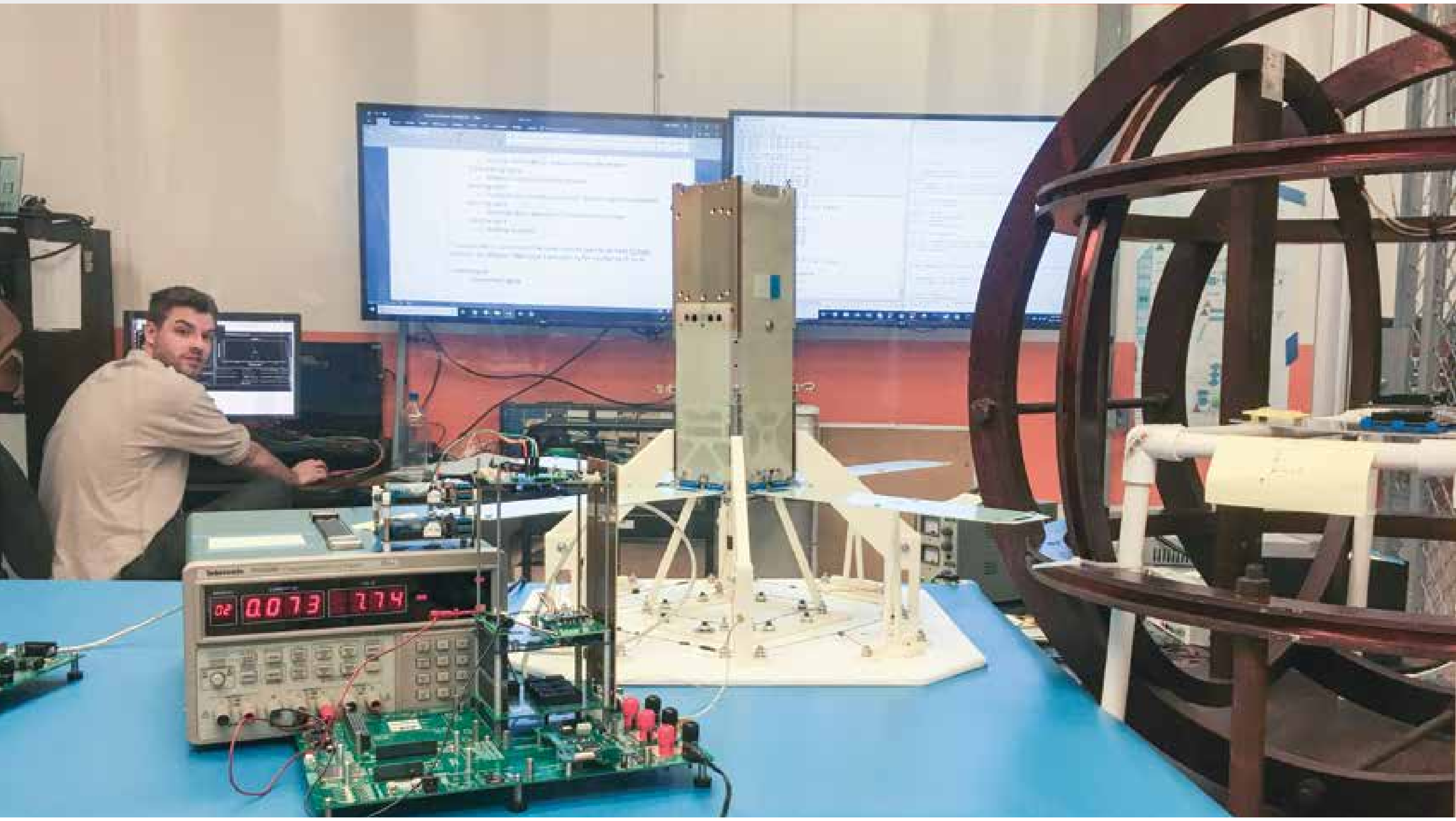
Memory
- 8k L1 instruction cache
- 8k L1 data cache
- 64k L1 instr/data cache
- Tiles can access other L2

I/O Interfaces
- Four 10 Gbps XAUI
- Four DDR2

KEY TESTING AND RESEARCH FOCUS AREAS

- Maestro processor integrated into 1U form factor and thermally tested and validated
- Hypervisor software demonstrated ability to take image and use multicore processing to resolve in the lab

Sponsor: US Defense Advanced Research Projects Agency (DARPA)



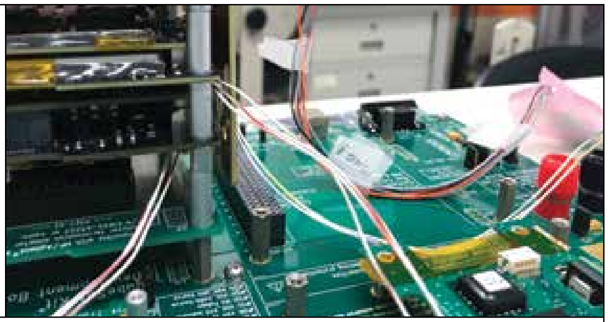
DESCRIPTION

SERC built an attitude determination and control simulator utilizing a real-time 6-DOF simulator and a 3-axis Helmholtz Coil to create a dynamic hardware-in-the-loop (HITL) testbed system. This system recreates the basic space environment, allowing preflight testing of the sensors, actuators, and controller software enabling hardware and software verification of the SERC-designed GNC systems.

A “Helmholtz” coil provides full real-time 3-axis magnetic field changes based on an Earth magnetic field model tied to orbital simulation. The coil provides a magnetometer on a prototype simulator in our clean-room excitation, simulating rotation and exercising the full GNC software and hardware. Telemetry is sent to a benchtop ground station, which is then used as feedback into the Earth magnetic field simulation to provide a realistic comparison to satellite response.

KEY TESTING AND RESEARCH FOCUS AREAS

- Full GNC operations for magnetic field, sun position simulator linked to an orbital dynamics program
- Ability to test various GNC controllers in real time with increasing sophistication, and validate the code before flight

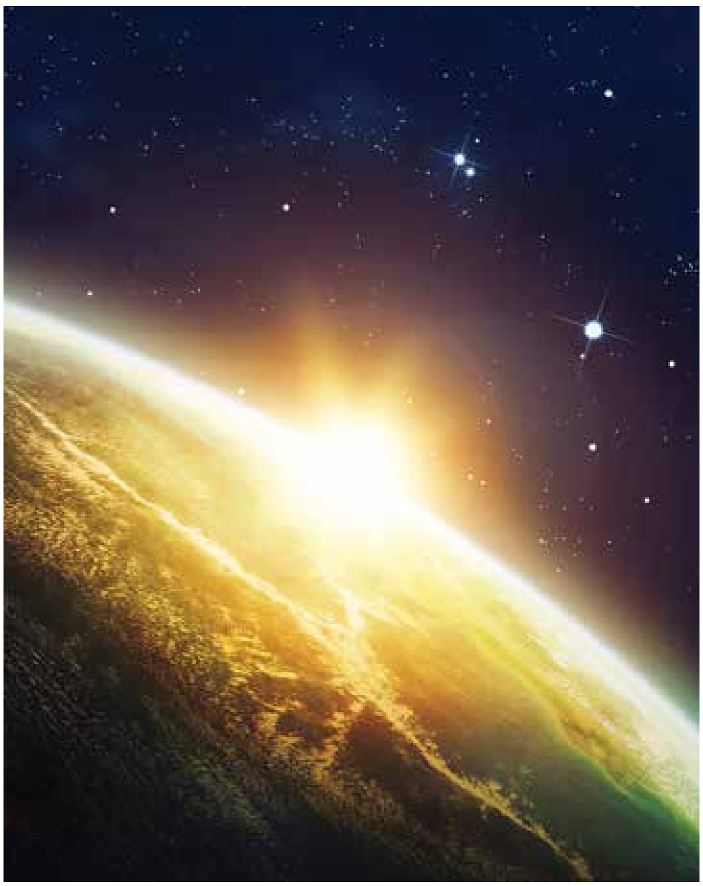


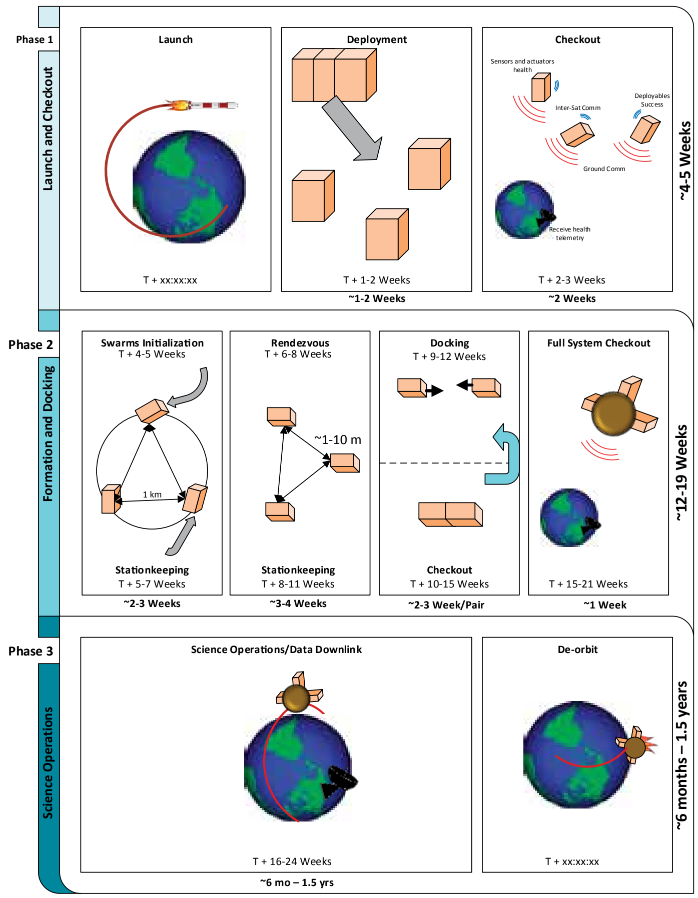
Sponsor: Space Engineering Research Center (SERC)

DESCRIPTION

Space Swarms is a three-year collaborative activity to combine technologies and capabilities in adaptive, reconfigurable, monolithic, and distributed space platforms. The motivation is to enable assembly of a reflector in orbit by combining smaller free-flying satellite elements into a swarm formation. The Space Swarms team encompasses Arizona State University, University of Southern California, Georgia Institute of Technology and University of Michigan, Ann Harbor. The team investigated techniques and architectures that allow physical aggregation/disaggregation, resolve wavelength-scale metrologies with realizable structural connections, and develop ubiquitous rendezvous methodologies that enable any type of space swarm elements to function safely.

ISI/USC's Space Engineering Research Center supported the RPO and aggregation challenges and provided a unique docking device as the interface for on-orbit connection.





KEY TESTING AND RESEARCH FOCUS AREAS

- Development of a standalone RPO sensor/docking mechanism for CubeSat (CLING)
- CONOPs for on-orbit aggregation from disparate launch sites and orbital platforms
- Systems modeling for on-orbit aggregation, RPO fuel use, and technology requirements
- Support to wavelength management in large aperture construction

Sponsor: NASA Jet Propulsion Laboratory

DESCRIPTION

The SERC's Multi-GNSS simulator aims to develop a low-cost GNSS simulator compatible with software-defined radios. Such simulators will enable us to test GNSS constellations such as Beidou, GLONASS, QZSS, GPS, and Galileo. The accuracy of positioning is essential as we progress towards IoT devices and autonomous vehicles. Combining these devices with extremely low-power GNSS devices will enable high-accuracy low-power sensors. Such simulators will help in testing smart low-power devices by providing an *easy and inexpensive test platform*.

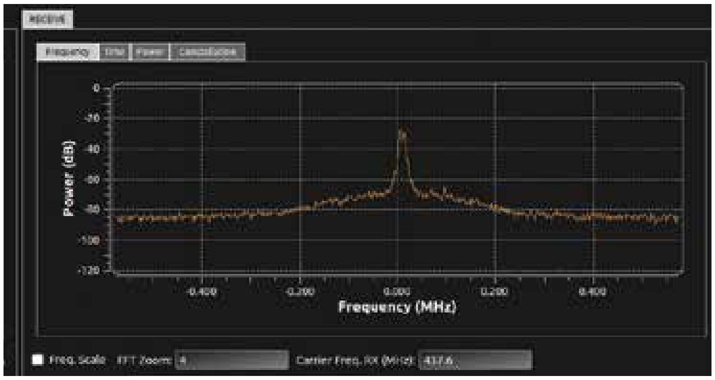
LONG-TERM APPLICATIONS

- **Network-oriented positioning:** Tracking and searching for all 26 GPS satellites on a single device requires a huge amount of computation and power. Distributing this over the entire network of interconnected IoT devices by assigning a single fixed satellite to a network node will reduce computation tremendously.
- **Cloud GNSS:** This technology will help develop GNSS receivers which perform only acquisition on a chip level, and the position, velocity and time calculations on a separate cloud server. This helps when developing extremely low-power IoT devices with positioning capabilities.
- **Development of pretrained smart GNSS receivers:** Instead of searching for all satellites, smart receivers will only search for specific satellites that are nearest to their most recently updated locations, with the least Doppler and having the least clock corrections. Developing machine learning algorithms for such deductions is under development. Such receivers will be able to identify multipath errors and discard such signals.
- **Indoor beacons:** Using multimodal augmentation such as the camera, accelerometer, gyroscopic sensor, along with well-established protocols such as BLE, Wi-Fi GNSS can be enhanced for indoor navigation.

Sponsor: Space Engineering Research Center (SERC)

KEY TESTING AND RESEARCH FOCUS AREAS

- Generation of baseband and RF-level GNSS signal
- Compatible with all SDRs
- Development of models for multipath and mitigation errors
- Augmentation with other sensors like the gyroscope, camera, LIDAR, etc., and protocols like Bluetooth beacon and Wi-Fi for centimeter-level positional accuracy



DESCRIPTION

The SERC maintains a fully operational ground station with two large S-Band and UHF/VHF antennas. Full azimuth/elevation tracking control supports LEO satellites which are actively tracked. Feeds and LNAs operate to boost the reception signal on both frequencies. Weatherproof boxes hold critical equipment at each antenna base, and a control room dedicated to the satellite communications function contains necessary tracking equipment.

SERC maintains and operates this station and antenna, while Director Barnhart teaches a hands-on course instructing students in theory, practical SDR/spectrum analysis, and “lost in space” operations on actual satellites.

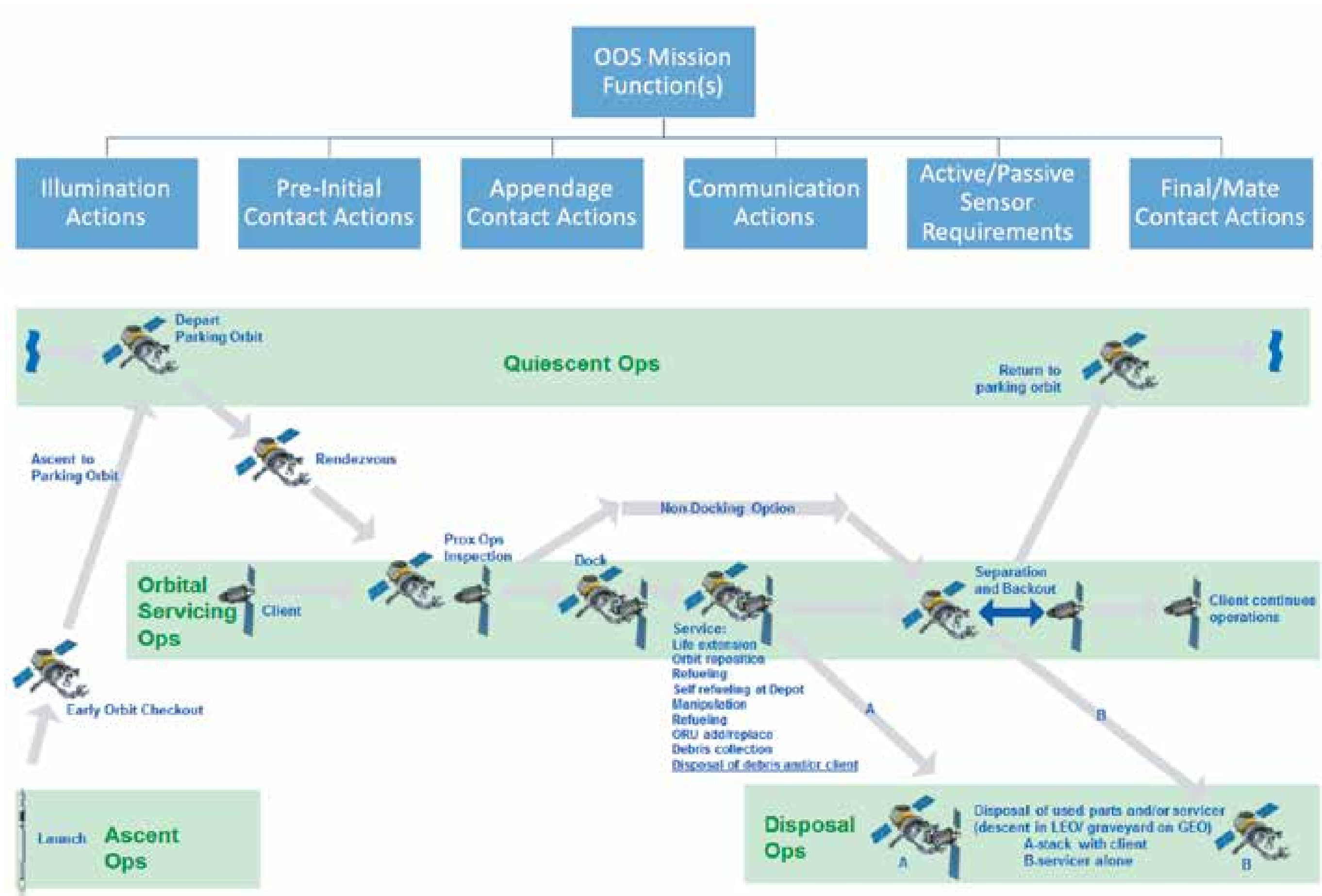
KEY TESTING AND RESEARCH FOCUS AREAS

- USC ASTE-566 graduate course lab
- LEO satellite tracking and de-commutation
- SDR programming for frequency and protocol
- TLE updating based on TOCA, and multiple pass sync
- “Lost in space” training and research

Sponsor: USC/Viterbi School of Engineering

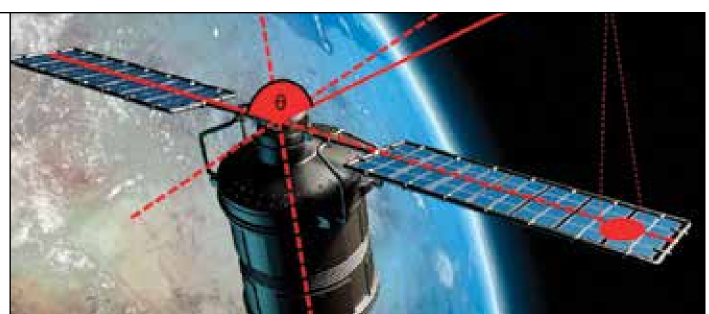
DESCRIPTION

The Consortium For Execution of Rendezvous and Servicing Operations (CONFERS) encompasses a team of scientists, researchers, and technicians from academia and industry brought together under funding from DARPA to identify standards and best practices for future satellite servicing and rendezvous proximity operations (RPO). USC/ISI has created and analyzed a database of past rendezvous operations worldwide and developed a set of safety metrics, applicable to spacecraft of any size, to mitigate risk during RPO. These metrics were presented to the entities that make up the consortium and will be applied to their individual RPO efforts. The SERC is creating functions/attributes for the entire OOS ontology and mission elements, and recommending quantitative standards for consideration in international standards organizations worldwide.



KEY TESTING AND RESEARCH FOCUS AREAS

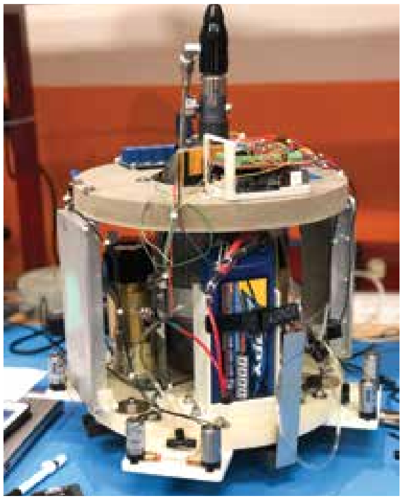
- Satellite rendezvous and servicing
- Orbital operations safety
- Standards and best practices
- Relative orbit simulation

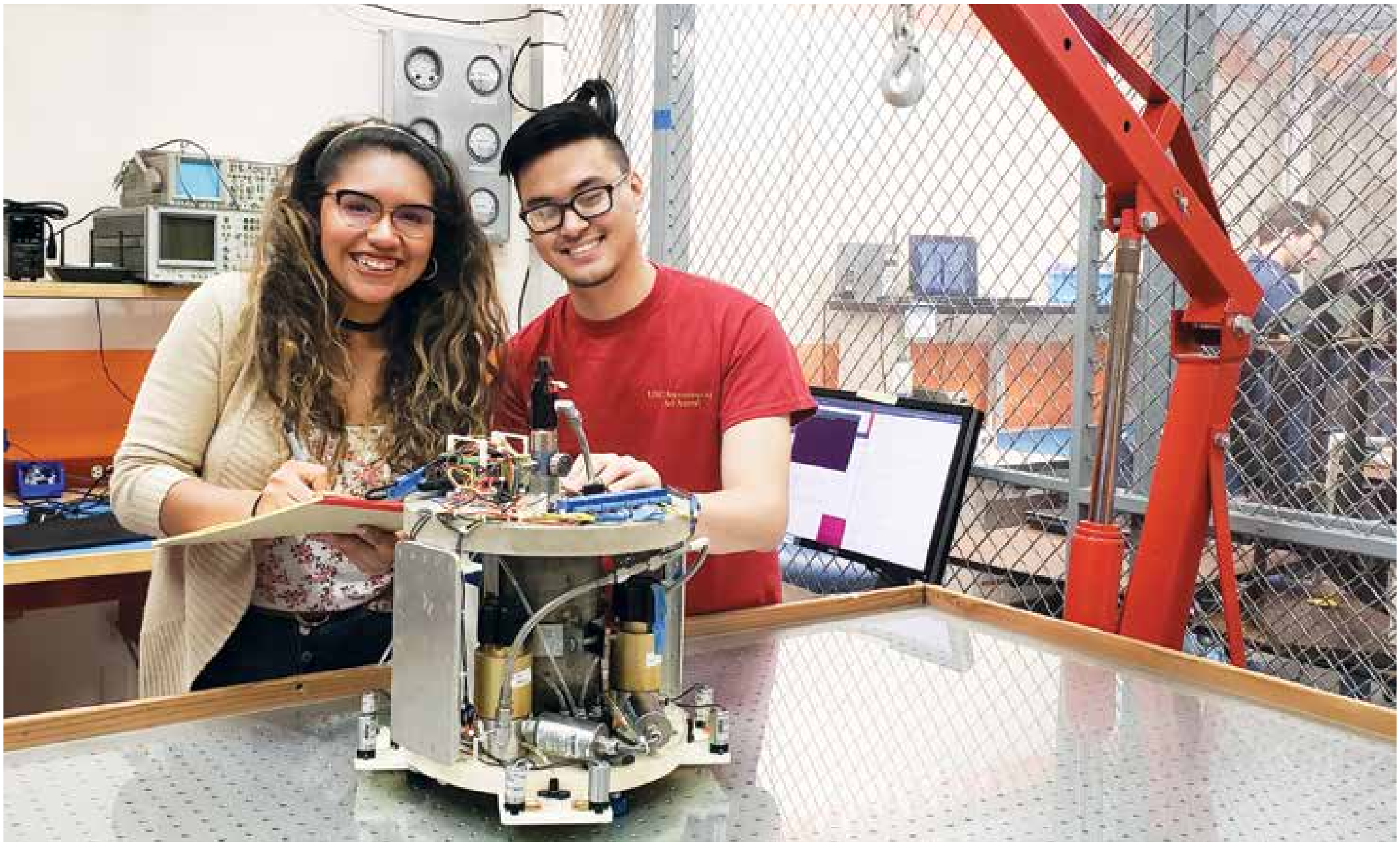


Sponsor: Advanced Technology International (ATI)

DESCRIPTION

The SERC is currently researching methods of creating new dynamics and control for cellular-based morphological satellite aggregation. An existing satellite testbed enables near-frictionless 3-DOF motion and demonstration of real-time "aggregation" of three air-bearing satellite platforms through rendezvous and proximity operations. Using these satellite modules, SERC aims to develop an unprecedented dynamic subsystem reconfiguration algorithm based on the autonomous recognition of a new multi-satellite configuration using a decentralized software architecture. These satellite modules enable the testing for an adaptive controller to continuously update the control parameters needed for the newly aggregated cellular system.

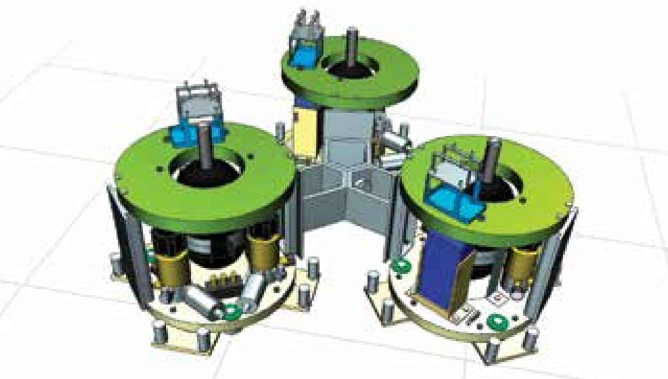




KEY TESTING AND RESEARCH FOCUS AREAS

- Computational topology for aggregation
- Real-time dynamic GNC reconfiguration algorithms for aggregating satellites
- Inertial to relative position handoff and tech demo
- Frictionless 3-DOF demonstration of satellite rendezvous and proximity operation

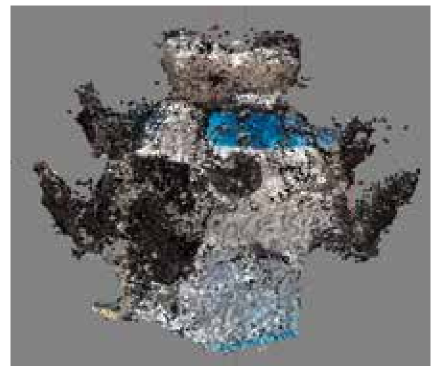
Sponsor: USC Information Sciences Institute



DESCRIPTION

The Sensor Fusion project showed multi-frequency hardware components able to merge a consistent and constant point cloud for RPO operations. Early demonstrations utilized photogrammetry, LIDAR, and low-frequency RADAR point clouds with COTS hardware in the lab.

The project recreated a scaled model of an Astrolink satellite. The goal was to show reconstruction of a model to analyze close-in RPO. The lab project performed all of the analysis at scaled distances similar to reconnaissance in GEO. Lab LIDAR and optical sensors were able to create reasonably accurate point clouds independent of one another.



KEY TESTING AND RESEARCH FOCUS AREAS

Hardware Used
- 9 Raspberry Pis
- 3 Raspberry Pi cameras
- 3 Orbecc Astra Pros
- 3 UWB RADAR boards

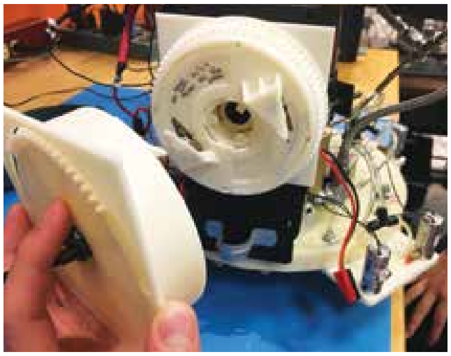
Software Used
- Agisoft PhotoScan
- Geomagic DesignX
- ReconstructMe
- CloudCompare
- Multi-frequency sensor imaging
- Fusion of point clouds from different software elements

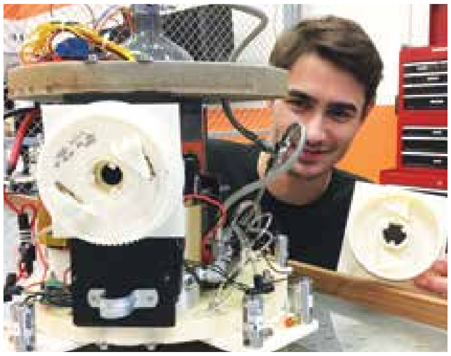
Sponsor: Palski & Associates

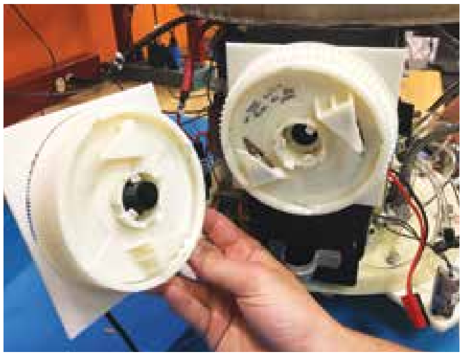
DESCRIPTION

CLING is a unique patented docking system proposed for space applications. Its features include:

- **Highly compliant:** CLING can dock under relatively high positioning errors in omni directions.
- **Low profile:** CLING is designed to minimize the docking profile volume.
- **Independent undocking:** Each CLING module can independently disengage the docking, even if the mating module malfunctions (power loss, etc.)
- **Non-protruding:** Under non-operational, passive mode, CLING does not have any protrusions from its surface.
- **Genderless:** CLING does not have a fixed male/female configuration. A pair of CLING docking modules are exactly the same.

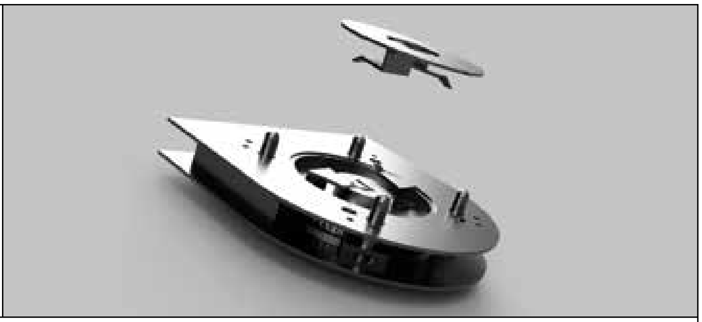




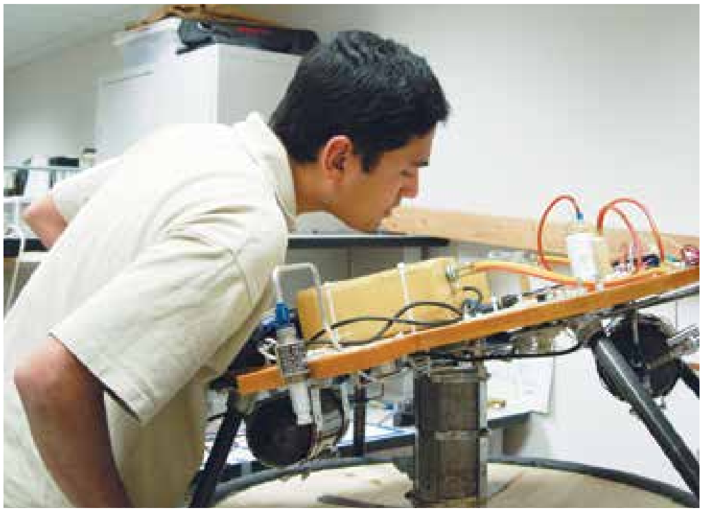


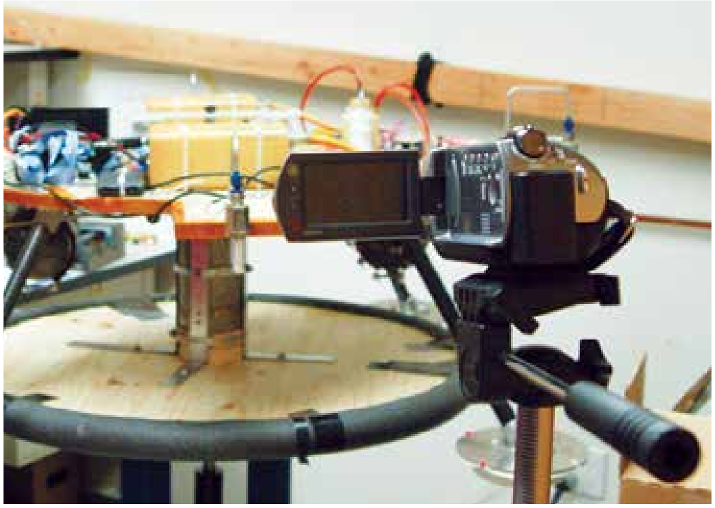
KEY TESTING AND RESEARCH FOCUS AREAS

- Ubiquitious genderless docking for small satellites
- Embedded RPO sensors
- Ability to bolt onto any satellite, after design
- Wireless power and data connectivity to satellite



Sponsor: USC Department of Astronautical Engineering and Information Sciences Institute





DESCRIPTION

Inspired by the Apollo Lunar Landing Research Vehicle, SERC's Lunar Entry and Approach Platform For Research On Ground (LEAPFORG) Generation-0 was a design-to-flight student hands-on project to build a robust, low-cost hovering platform to simulate lunar gravity. The vehicle demonstrated a prototype capable of multiple flights over the course of a single day with descent and landing sequences similar to those performed on the Moon. Generation-0 was a proof-of-concept for the design, build, integration, and flight of the platform. The vehicle demonstrated descent and landing profiles similar to those performed on the Moon. Generation-0 was the hands-on project for students who executed the full gamut of design, build, integrate and flight within a very integrated team environment.

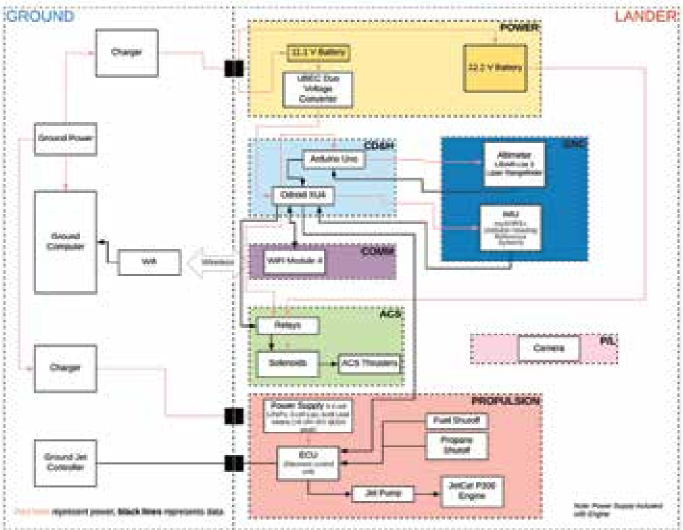
KEY TESTING AND RESEARCH FOCUS AREAS

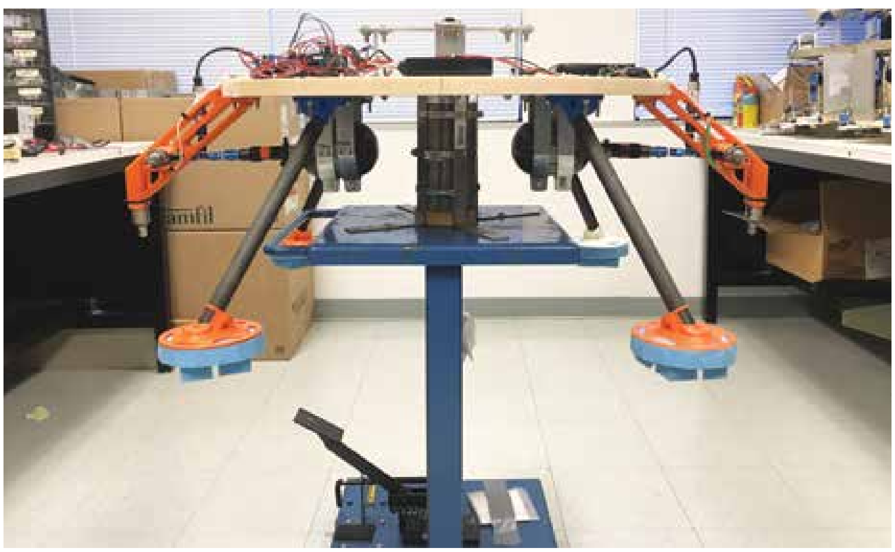
- Full system platform from design to flight
- Offset of gravity with air breathing engine
- GNC control using PWM air thrusters
- Bang-bang control validation for high accuracy stability requirements in dynamic environment
- Non-choked thrust validation of Venturi effect valves with high pressure (>1000 psi)

Sponsor: USC Department of Astronautical Engineering

DESCRIPTION

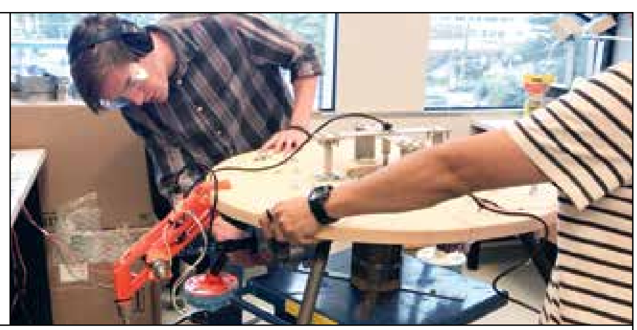
Generation-1 of LEAPFROG will use a larger thrust engine to provide a >1.25 thrust-to-weight ratio. Design optimization to reduce the mass of the structure, attitude control system, and electronics will enable a longer flight time and allow new payloads and sensors to be added. The platform will also have improved hover capability and self-correction for attitude and velocity drift.





KEY TESTING AND RESEARCH FOCUS AREAS

- Explore higher thrust-to-weight ratio (>1.25)
- New structure to support 2-5 kg of payload
- Increase flight time with more efficient GNC
- Explore inflight commands beyond safety and abort
- Develop control algorithms for various flight operations



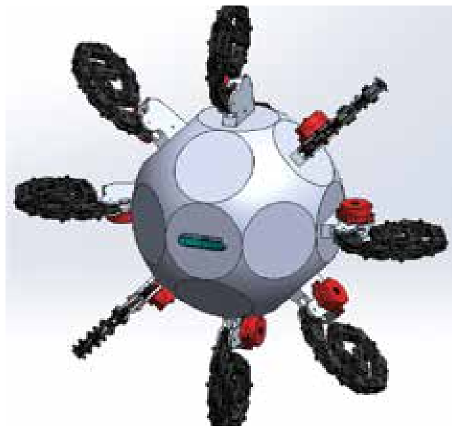
Sponsor: USC ASTE, ISI, and California Space Grant Consortium

REACTIVE ELECTRO-ADHESIVE CAPTURE CLotH (REACCH)

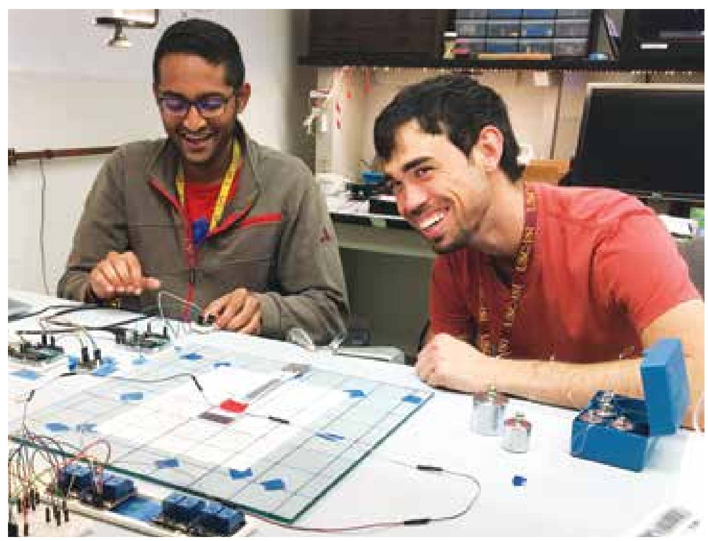
DESCRIPTION

REACCH *(Reactive Electro-Adhesive Capture ClotH)* is an applied research project for developing ubiquitous capture technology for space applications. SERC's partner is NASA's Jet Propulsion Laboratory (JPL) who is providing their experimental electro-adhesive (EA) tiles for inclusion into new elastic material patterns to create a robotic end-effector. Under funding from DARPA, the REACCH team's goal is to design and demonstrate a soft capture mechanism based on the concept of octopus tentacles that allows soft contact with on-orbit space platforms.

By mounting end-effector tiles onto sections of elastic fabric supported by an array of mechanically controlled "tentacles," the REACCH system will be able to gently but securely grip objects of any size in any orientation.

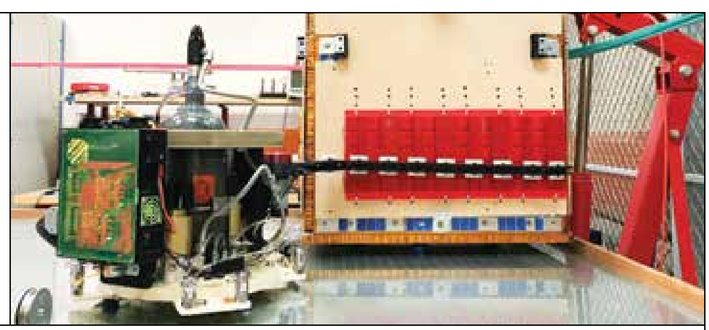


INSPIRATION FROM OCTOPUS TENTACLES



KEY TESTING AND RESEARCH FOCUS AREAS

- Electro-adhesive tile performance characterization
- Stretch sensor-based control system
- REACCH tentacle pattern simulation
- Optimal tentacle structure design
- End-effector tile geometry optimization



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