

*The Department
of Astronautical
Engineering (ASTE)*

10TH ANNIVERSARY



USC Viterbi
School of Engineering



The cover features photos of:

(Top) The high-vacuum, high-volume Collaborative High Altitude Flow Facility (CHAFF) chamber at the ASTE Laboratory for Astronautical Plasma Dynamics.

(Left) The SpaceX Falcon 9 Rocket launch in December 2010, which took Caerus, a nanosatellite developed by the Department, into Earth orbit.

(Right) The ASTE Department Faculty with the USC President Max Nikias and Viterbi School Dean Yannis Yortsos. From left are: Nikias, Mike Gruntman, Joe Wang, Joe Kunc, Dell Cuason, Dan Erwin, and Yortsos.

2004

Messages from the President & the Dean of Engineering

The entire USC community stands proudly with our Department of Astronautical Engineering, as we mark its 10th anniversary. Professors Joseph Kunc, Mike Gruntman, and Dan Erwin laid the program's foundation a decade ago, with staff member Dell Cuason at their side – each inspired by the central role of the space enterprise in our nation's security, economy, and growth. Together, they built a vibrant program that provides a solid education in astronautics, as well as outstanding laboratory experience for our students. Today, the department's stellar faculty and staff advance space science and engineering, creating the world's most cutting-edge space assets, while charting new terrain in space's vast landscape. The program's innovative contributions to the American space enterprise draw well-deserved praise from industry and research centers, benefit our society in profound ways, and generate tremendous pride here at USC.

C. L. MAX NIKIAS, PRESIDENT
University of Southern California

From the ancient days of astronomy, when mapping the heavens was limited by what is visible to the naked eye, space exploration has been a vital part of the quest for the origins of the cosmos and the exaltation of the human spirit. Since the 1970s, space has had a strong presence in the USC Viterbi School of Engineering. This year marks the 10th anniversary of the creation of the Astronautics Department at USC Viterbi – the only university in America that offers degrees at all levels (bachelor's, master's, and doctoral) in astronautical engineering. Space has always inspired young minds to push the boundaries of the possible. At USC, this is what fuels the Department of Astronautical Engineering, ably led by a cadre of key faculty who are shaping today's programmatic efforts in the field and supervising impressive extra-curricular projects in rocket propulsion, flight dynamics, and microsatellites. These remarkable programs reassure us that the future of space is indeed in very talented hands.

YANNIS C. YORTSOS, DEAN
USC Viterbi School of Engineering

2014

ASTE Department History

IN 1986, a small group of faculty members in the University of Southern California, Viterbi School of Engineering's Department of Aerospace Engineering noted a growing interest from individuals in the space industry and students in modern academic programs in space technology and high-energy flows. They responded to this interest by launching a research group called "Hypersonics and High-Energy Flows Program."

Also known as the "Non-Equilibrium Phenomena Group" or the "Gas Physics Group," the group was founded by H.K. Cheng, member of the National Academy of Engineering; Dan Erwin, current chair of the Department of Astronautical Engineering; Joe Kunc, fellow of the American Physical Society; and E. Phillip Muntz, member of the National Academy of Engineering. In 1993, Mike Gruntman, corresponding member of the International Academy of Astronautics (IAA), joined the team.

IN 2004, then-Dean of Engineering Max Nikias expanded the group's activities into an independent academic unit, and the Viterbi Department of Astronautical Engineering (ASTE) was born. The new department consisted of one staff person – Administrator Dell Cuason – and three full-time faculty: professors Erwin, Gruntman, and Kunc.



THE BEGINNING

Founders of the Department of Astronautical Engineering (ASTE) (from left in group photo): Dan Erwin, Joe Kunc, Mike Gruntman, (and in single photo): Dell Cuason.



Moonwalker Dr. Buzz Aldrin (third from right) visits the Department of Astronautical Engineering.

This four-person team has retained primary responsibility for operating and developing the Department over the last decade, with Gruntman serving as Chair from 2004 to 2007 and Erwin serving as Chair from 2007 until today. In 2005, USC approved joint appointments in ASTE of F. Stan Settles, member of the National Academy of Engineering, and Darrell Judge, fellow of the American Physical Society. During the last few years, Cuason has been supported by Student Services Advisor Marrietta Penoliar and Budget Technician Ana Olivares.

IN 2009, the program welcomed Joseph Wang and, in 2014, Azad Madni, a fellow of the Institute of Electrical and Electronics Engineers (IEEE). The same year, two members of the National

Academy of Engineering, Barry Boehm and E. Phillip Muntz, along with Behrokh Khoshnevis, fellow of the National Academy of Inventors, joined the Department through joint appointments. ASTE has a number of departmental adjunct professors and lecturers who are employees of major space organizations, such as the Aerospace Corporation; Boeing; Lockheed Martin Corporation; Microcosm, Inc.; National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory; Raytheon; and Space Environmental Technologies. Each of these instructors has participated in research and/or development of various space missions for NASA and other organizations.



Academic Programs



Welcome ASTE students.

During the first six years of the Astronautical Engineering program's existence, the three founding faculty members developed all four Astronautical Engineering degree programs that serve students today: B.S. in Astronautical Engineering, M.S. in Astronautical Engineering, Ph.D. in Astronautical Engineering, and Graduate Certificate in Astronautical Engineering.

The Bachelor of Science (B.S.)

The B.S. in Astronautical Engineering at USC Viterbi is among the very few space-focused undergraduate degree programs in the United States. The program received its first accreditation from the Accreditation Board of Engineering and Technology (ABET) in 2010. The program supplements USC Viterbi School of Engineering's general engineering courses with specialized courses in space science and technology.

Our B.S. alumni accomplishments are impressive. Graduates have gone on to Ph.D. programs at USC and other institutions including California Institute of Technology (Caltech), Massachusetts Institute of Technology (MIT), Purdue University, Stanford University, and the University of Michigan. Alumni have also accepted positions at leading companies and national labs, including The Aerospace Corporation; Boeing; Fermi National Accelerator Laboratory (Fermilab); Microcosm, Inc.; Northrop Grumman Corporation; Pratt & Whitney; Raytheon; Space Exploration Technologies Corporation (SpaceX); Air Force Rocket Propulsion Laboratory (RPL); National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory; NASA Lyndon B. Johnson Space Center; Intel Corporation; and Millennium Space Systems, Inc. Others have founded their own startup companies.

The Bachelor of Science – Minor (B.S. Minor)

For students who hope to work in the space industry but who are pursuing other engineering degrees at USC Viterbi, the Astronautical Engineering B.S. minor offers a secondary education focused on space technology, supplementing students' major coursework and preparing them for a career in the space industry.

The Master of Science (M.S.)

The M.S. program focuses on meeting the engineering workforce development needs of the space industry and government space research and development organizations. The program is directed by Dr. Mike Gruntman, professor of Astronautics, Aerospace Engineering, and System Architecting and Engineering.

More than 1,000 graduate students have enrolled in the program's flagship course on spacecraft design over the past decade.

The M.S. program offers two dozen space-related courses and is open to students with B.S. degrees in engineering, mathematics, or natural sciences from accredited universities. In addition to full-time, on-campus students, the program reaches many students through the distance education platform of DEN@Viterbi. Many of the latter are working full-time while earning their degrees. This flexibility and the wide selection of advanced astronautics courses make ASTE's M.S. program one of the largest space engineering degree programs in the United States.

At Times, it Takes a Rocket Scientist.

Astronautics students can study through our Distance Education Network (DEN) from all across the United States and around the globe. The program has awarded master's degrees to a large number of students, including students from 16 foreign countries.

Although all students admitted to the M.S. program have bachelor's degrees in engineering or science, some already have earned their master's or even doctorates in other areas of engineering and have successful careers in the space industry. Some of these students are seeking to improve their chances of being selected for astronaut training or to advance to leadership positions in major space programs. In addition, occasionally, a medical doctor enrolls in the program.

Adjunct faculty and lecturers are a great strength of the program. They work at various space companies and government research and development centers. These experts teach highly specialized courses in the rapidly changing areas of space technology. They also bring real-world experience, a vital component of any high-quality engineering education program.



National Aeronautics and Space Administration (NASA) Administrator Dr. Charles Bolden (left) visits the School of Engineering recruiting booth.

Doctor of Philosophy (Ph.D.)

The Ph.D. program boasts 59 students who have graduated or are on the path to graduation, as well as dissertation subjects ranging from “Development of the Two-Stage Micro Pulsed Plasma Thruster” to “Extravehicular Activity (EVA) Emergency Aid for Planetary Surface Missions,” “Large Set Data Transmission Using Algorithmically Corrected Techniques for Bandwidth Efficiency,” and “Three-Dimensional Exospheric Hydrogen Atom Distributions Obtained from Observations of the Geocorona in Lyman-alpha.” In 2012, ASTE student Darren Garber was honored with the Best Thesis Award from the USC Viterbi School of Engineering for his Ph.D. thesis, “Application of the Fundamental Equation to Celestial Mechanics and Astrodynamics.”

Dr. Joe Kunc, professor of Astronautics, Aerospace Engineering, Physics and Astronomy, and System Architecting and Engineering, has been the Ph.D. program director since its inception in 2004.

In addition to overseeing these dissertation projects, ASTE faculty members have been chairs and members of numerous Ph.D. dissertation committees in other academic units, including Aerospace Engineering, Architecture, Chemistry, Electrical Engineering, and Physics and Astronomy.

The Engineer Degree and Graduate Certificate

The ASTE Department offers two additional programs that provide opportunities for engineers interested in professional growth. Professor Mike Gruntman directs both programs. The Engineer in Astronautical Engineering degree allows students to continue their studies after achieving their master’s degree with specialized coursework in space technology. Engineers who are interested in enhancing their knowledge but who cannot commit themselves to pursuing a Ph.D. degree find this option particularly attractive.

The Graduate Certificate in Astronautical Engineering is tailored to professionals with a bachelor’s degree who, after working in the industry for a number of years, would like to go back to graduate school but may not feel confident returning to studies after a long absence from the academic environment.

The Graduate Certificate allows them to select graduate courses in their own areas of strength. Courses taken while earning the certificate can also be credited towards the M.S. program, should students choose to continue their postgraduate education.

By complementing the master’s degree with the Engineer degree and Graduate Certificate in Astronautical Engineering, ASTE strives to reach working professionals with a full range of opportunities for educational growth.

Hands-On Undergraduate Programs

The ASTE Department also offers three hands-on undergraduate laboratory programs: Lunar Lander Lab, Microsatellite Lab, and Rocket Propulsion Lab. These programs allow students from several USC Departments to design, build, test, and launch various spacecraft hardware and software. Participants learn about and apply various high-tech tools and methods used in the space industry and at national space laboratories.

Lab program training requires students to not only learn and practice engineering, but also to understand the science needed to solve related interdisciplinary issues. Students are divided into small groups, each working on different hardware and software tasks. Participants rotate between groups to get first-hand experience with all subsystems of the final hardware and software made during the projects.

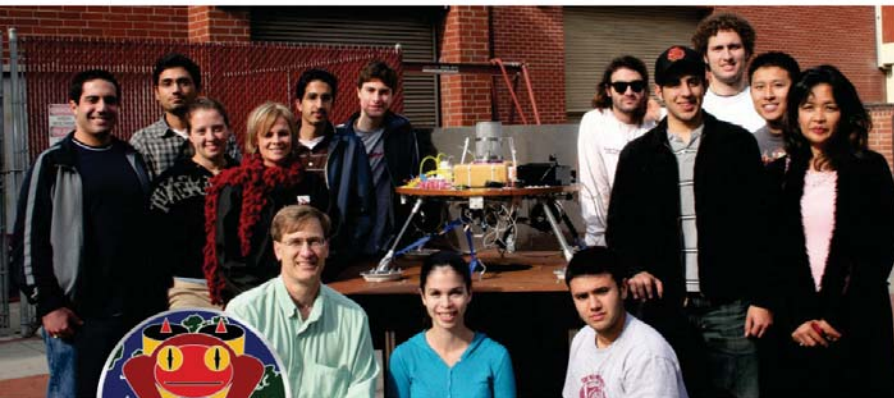
The ASTE labs are, by their nature, highly multidisciplinary, dealing with spacecraft design, avionics, propulsion, heat and radiation transfer, thermal and material stress, wireless communication, electrical and control systems, and guidance algorithms.

Participating undergraduates come from Departments of Astronautical Engineering, Aerospace and Mechanical Engineering, Computer Science, Electrical Engineering, and Physics and Astronomy. The students take what they learn in the hands-on programs back to their own departments and apply it to other projects and/or research programs there. The activities of the programs have also broadened the Department of Astronautical Engineering curriculum, forming a base for the introduction of new courses.

Hundreds of undergraduate students, including dozens of Merit Research students, have participated in research and development of spacecraft hardware and software in these hands-on labs. Lessons and outcomes from the labs are also shared with the science, technology, and educational communities on a broader scale through various state and national organizations, including the California Space Grant Consortium (CaSGC), California Space Authority (CSA), and Universities Space Research Association (USRA).

The research results obtained in the labs have been published and presented at domestic and international conferences, as well as featured in stories in several major news outlets and a major television channel.

The undergraduate activities of the Lunar Lander Laboratory and the Microsatellite Laboratory are part of the Space Engineering Research Center (SERC), directed by Professor Joe Kunc with Associate Director David Barnhart (2006-2010) and Associate Director Tim Barrett (2010-2014). The Rocket Propulsion Lab is directed by Professor Dan Erwin.



Lunar Lander Laboratory

The Lunar Lander Laboratory offers students a chance to design, build, and test an autonomous lunar lander vehicle and its software. The vehicle was initially conceived as a low-cost solution (using commercial off-the-shelf components) and designed to operate as a highly customizable test bed for in-flight operations testing for interplanetary missions. Every year, a team comprising mostly undergraduate students is divided into several groups, each working on some aspect of the lunar lander vehicle and its software (e.g., structure, thrusters, avionics, guidance, navigation, control). Rotating through these project groups, students gain diverse knowledge of what is involved in creating this type of vehicle. Professor Joe Kunc has been academic advisor of the Lab for the last eight years.



The first LEAPFROG student team poses with the first prototype out of the Lunar Lander Laboratory.

A close-up of the LEAPFROG autonomous lunar lander.



The first prototype of the vehicle was called LEAPFROG (Lunar Entry and Approach Platform For Research On Ground). The LEAPFROG lander has active onboard guidance, navigation, and attitude control (12 thrusters). Hover propulsion is supplied by a jet turbine engine. The vehicle software is integrated on a Rabbit 3400 microprocessor module interfaced to a small inertial navigation system, which provides GPS, 3-axis accelerometer inputs, and Wi-Fi communication access. MATLAB and Simulink flight simulation software accounts for external disturbances and controls the input commands.



Pictured above is the LEAPFROG student team with Joe Kunc (first row, first from left), David Barnhart (first row, second from left), and Jeff Sachs (second row, second from left).



Pictured above is the Lunar Lander Gen-X student team.

The LEAPFROG project has attracted much positive attention from the space community. In 2008, the Universities Space Research Association (USRA) identified LEAPFROG as the only viable academic effort of its kind to compete with industrial teams in the X-Prize Competition. USRA invited the LEAPFROG team to compete against industrial competitors at a professional level of skill and experience in this international space competition. No other universities were invited to compete.

In October 2012, another version of the vehicle prototype, the Lunar Lander Gen-X, won first prize at the Great Minds in STEM Conference (formerly the HENAAC Conference) over teams from Cornell University, Massachusetts Institute of Technology (MIT), and Rice University, among others.

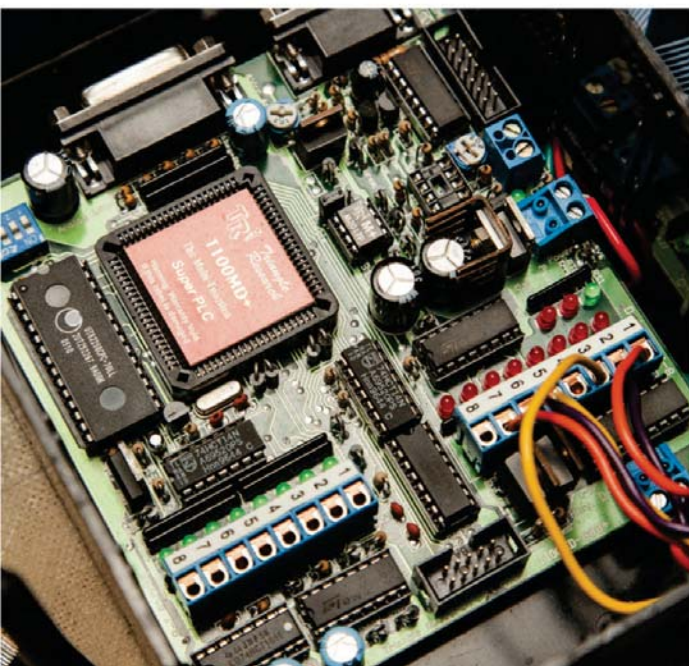
Microsatellite Laboratory

Microsatellites reduce cost and can undertake missions that larger satellites cannot. For instance, they can be used to create satellite constellations for low data rate communications configured to fly in formation to gather data from multiple points or used for in-orbit inspection of larger satellites. What once required a \$6 million spacecraft and a \$20 million launch can now be accomplished at a fraction of the price. As advanced technology shrinks sizes of spacecraft, the industry has developed a new nomenclature for small satellites. Space vehicles with a mass between 10 and 100 kilograms (22 to 220 pounds) are usually called “microsatellites” or “microsats,” while satellites with mass between 1 and 10 kilograms (2.2 to 22 pounds) are called “nanosatellites” or “nanosats.”

Students from the Microsatellite Lab have participated in research and development of CubeSat class nanosatellites. These undergraduate activities are part of the ASTE Space Engineering Research Center (SERC) described below. Professor Joe Kunc has been academic advisor of the Lab for the last eight years.



National Medal of Science recipient and namesake of the Viterbi School of Engineering, Andrew Viterbi, discusses space platform communications with David Barnhart (left) and Joe Kunc (right).



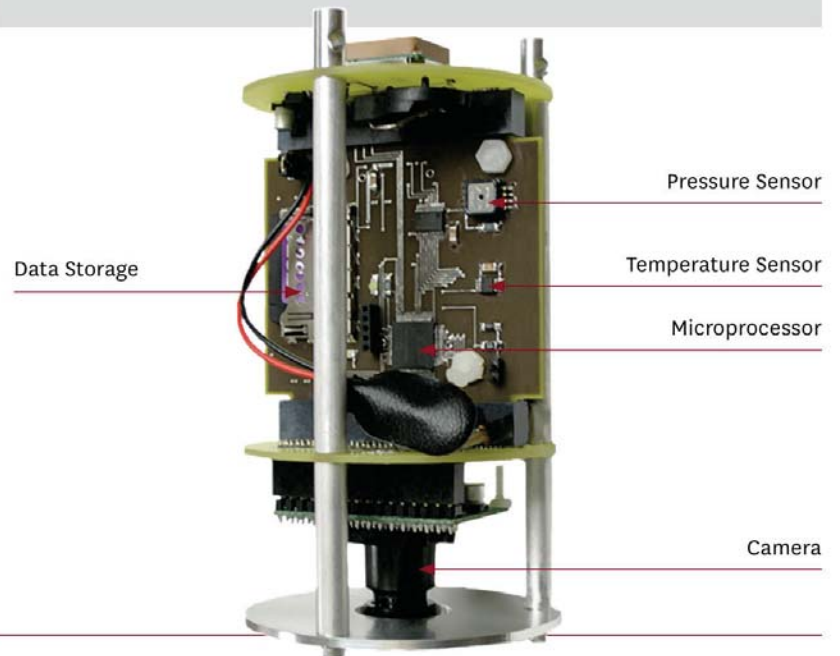
The Micro-Electro-Mechanical Systems (MEMS) Technology Demonstrator Test Flight, called Traveler Lite, was another early space project of undergraduate students. Participants launched this space hardware in cooperation with California State University Long Beach. Traveler Lite had five MEMS-based payloads designed by the students: a Knudsen compressor (vacuum pump/compressor), free molecule micro-resistojet (FMMR), electric propulsion thruster (EPT), accelerometer, and magnetometer.

Undergraduate students developed the Traveler Lite space hardware, which included these MEMS-based payloads.



Other ASTE undergraduate student adventures with microsatellites began several years ago when students designed and built a CanSat class (soda-can-sized) microsatellite that was launched by a sounding rocket in the Mohave Desert in California. The microsatellite ejected at an apogee of about 20 miles, floated under parachute while transmitting data to a ground station, was recovered, and then reused. It incorporated the functional components of a large satellite (i.e., power system, structure, sensors, thermal control, data acquisition, telemetry). The CanSat hardware included GPS, temperature and pressure sensors, a wireless transceiver, and removable on-board data storage.

Students show the soda-can-sized microsatellite they created with all the functional components of a large satellite.



Rocket Propulsion Lab (RPL)

Founded in 2005, the ASTE Department's Rocket Propulsion Lab (RPL) is managed by USC Viterbi School of Engineering undergraduates operating with a great deal of autonomy. Armed with the determination to accomplish their goal of building a rocket from scratch and launching it into space, RPL students design, build, and test experimental rocketry and propulsion hardware.

This lab draws passionate students from various departments of Viterbi. For the past decade, RPL students from these diverse backgrounds have worked to surmount a unique set of obstacles under the direction of Dr. Dan Erwin, professor of Astronautics and Aerospace Engineering.

Three RPL students, William L. Murray III, Sarah W. Hester, and Steven A. Leverette, won the Best Paper Award at the American Institute of Aeronautics and Astronautics (AIAA) Region VI Student Conference in Seattle on March 31, 2012. The paper was based on their senior design project and demonstrated that the thrust of a solid rocket motor could be increased after ignition by injecting inert gas into the combustion chamber.



ASTE Rocket Propulsion Lab students.

Some samples of rockets designed, built, and tested by RPL students:



Del Carbon (above)

The first student-built rocket, known as Del Carbon, was a strong, high-tech, reliable, and unbelievably light rocket that allowed students to hone their composite techniques for future rockets. It was designed as a test platform for RPL's avionics and carbon fiber construction techniques. First launched on May 20, 2006, it flew three flights, the highest to 21,500 feet at Mach 1.4. Del Carbon is now a hangar queen.

Double Double (left)

RPL student's first two-stage rocket was the Double Double, launched on October 30, 2007. Double Double's booster stage was powered by RPL's 10,000 pound-per-second P6110 motor, propelling the vehicle to 8,000 feet. During the flight, the stages separated successfully and the sustainer reached Mach 2.5 and 45,000 feet.



Turbo Encabulator

The Turbo Encabulator was a 6-inch diameter vehicle designed to flight-characterize RPL's 10,000 pound-per-second P6110 booster motor. The rocket was constructed of fiberglass, with a composite fin consisting of laminate, foam, and carbon fiber cloth. It took to the skies on October 1, 2008, in the Black Rock Desert.



Texas Two Step (left)

Texas Two Step was RPL's second two-stage rocket, launched on April 27, 2013. It featured an 8-inch diameter, single-grain booster and 6-inch diameter, three-grain sustainer. The rocket tested the launch tower that would later be used for the Traveler rocket and performed RPL's first successful 8-inch motor case flight. During the second stage of the flight, the shock cord of the sustainer broke at an apogee of 14,000 feet.

Kiwi (below)

RPL's first-ever filament-wound motor case, Kiwi, can fire about 6 pounds of propellant at a time (one 4-inch diameter grain). Its first firing in June 2012 primarily tested the case technology, while four more firings in January and February 2013 enabled the characterization of propellant additives. Kiwi and its thrust stand were designed for simplicity and ease of integration, allowing it to accomplish a record three firings in one day.





Traveler

Traveler is RPL's most powerful rocket to date, with a design speed of Mach 5.5 and maximum altitude of 400,000 feet.

Its motor, contained in a carbon fiber motor case, used 211 pounds of AP/Al propellant, generating over 4,000 pounds of thrust. Traveler was launched on September 21, 2013, but did not reach the maximum altitude because of motor failure, a result of the propellant grains burning on their back sides.

Space Engineering Research Center (SERC)

SINCE 2006, the Space Engineering Research Center (SERC) has been a valuable place for ASTE departmental research and development. ASTE Professors Joe Kunc (SERC's director since its inception), Dan Erwin, and Mike Gruntman started the Center based on discussions with local space industry and national lab experts. Herb Schorr, director of the Information Sciences Institute (ISI), provided lab space, and a few researchers from ISI joined the Center, including two who would become the center's associate directors: David Barnhart (2006-2010) and Tim Barrett (2010-2014).

From its founding, the Center has offered more than 100 undergraduate and graduate students, including dozens of Merit Research students, the opportunity to be directly involved in the research and development of space hardware and software. In addition, the laboratory work conducted in SERC has helped the Department of Astronautical Engineering broaden its curriculum.



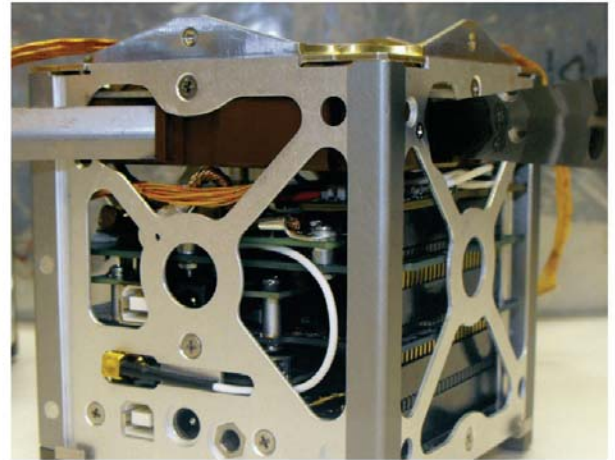
SERC student leaders are joined by USC Trustee Mark Stevens (left), SERC director Joe Kunc (fourth from right), USC President Max Nikias (second from right), and National Aeronautics and Space Administration (NASA) Administrator Charles Bolden (right).

Both graduate and undergraduate participants obtain first-rate, hands-on experience with spacecraft technology by participating in designing, building, testing, and launching satellite hardware. The Center helps prepare these students for the complex and multidisciplinary arena of space technology.

USC undergraduates from the Microsatellite Lab have participated in the research and development of two nanosatellites (CubeSat class units Caerus and Aeneas) that were launched in the last few years as SERC projects.

1. The CubeSat unit Caerus was launched into earth orbit from the National Aeronautics and Space Administration (NASA) Cape Canaveral Center in December 2010 as part of the Falcon 9/Dragon mission by SpaceX. Caerus was deployed to evaluate a SERC-modified satellite communication and control system as a part of the Northrop Grumman Mayflower mission. This was the very first commercial flight of a recoverable capsule and demonstrated the ability to carry astronauts to the International Space Station (ISS) – a major breakthrough for the private space industry in the United States.

Caerus orbited the earth approximately every 90 minutes at an altitude of more than 300 kilometers. A beacon radio sent out a brief message every 10 seconds and assisted in satellite identification and location after deployment from the launch vehicle. The space mission tested the main flight processors, attitude gyroscopes, and flight software in addition to the ground system software for capturing data and uplinking commands. A deployable quad monopole whip antenna was developed for Caerus' communications.



The CubeSat Caerus ready to fly.



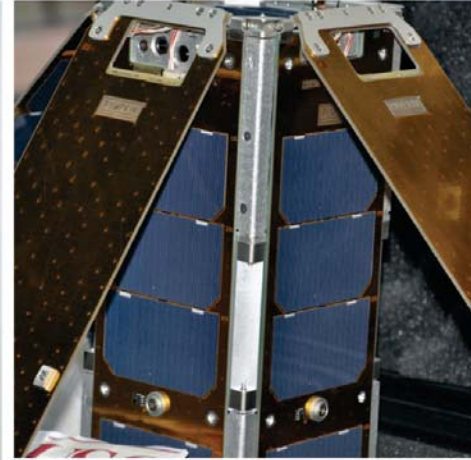
The NASA Cape Canaveral Space Center, December 2010: The SpaceX Falcon 9 Rocket takes Caerus, developed by ASTE's Microsatellite Lab, to earth orbit.



Photo Credit: United Launch Alliance

The Vandenberg Air Force Base, September 2012:
Atlas V Rocket takes Aeneas to Earth orbit.

2. The CubeSat unit Aeneas was launched into earth orbit in September 2012 on an Atlas V Rocket from the Vandenberg Air Force Base. Aeneas orbited at an altitude of between 440 and 880 kilometers, circling the earth approximately every 90 minutes. The SERC team developed an antenna for Aeneas, the largest antenna deployed on a CubeSat-class satellite, and procedures to stow and deploy the half-meter dish antenna. While satellites are usually pointed toward a fixed location, such as the earth, the sun, or a star, Aeneas employed three-axis stabilization control to track moving objects, demonstrating that global asset tracking can be performed by nanosatellites.



The CubeSat Aeneas
ready to fly.



Joe Kunc, Jeff Sachs, and Tim Barrett with
a recent Microsatellite Lab student team.

SERC has its own Satellite Flight Control Center where researchers and students operate RF satellite detection of, communication with, and control of spacecraft using resource monitoring, vehicle commands, and data storage.

Over the past eight years, SERC researchers and students have developed several other successful programs, including:

1. SERC researchers working with Professor Didkovsky's group from the USC Department of Physics and Astronomy designed OzMOSIS, a CubeSat-based atmospheric ozone measurement experiment. OzMOSIS is an advanced on-orbit, hyper-spectral imager analysis experiment using a small satellite and a cluster of three nanosatellites.
2. Designing and fabricating six frictionless spacecraft simulator vehicles on a precision flat floor to conduct a number of rendezvous and docking experiments. The flat epoxy floor offers precision greater than half of a thousandth of an inch over a 50- by 100-foot area. It has been used to simulate both life-sized and scaled vehicles, as well as extreme distance operations. Cold gas thrusters are used to move real-world-scale test vehicles in this frictionless, two-dimensional spaceflight simulation environment.
3. Developing SERC's own clean room for final fabrication and integration of flight units with a dedicated machine shop, electronic assembly area, three-dimensional stereo lithography printing area, and optical bench.

SERC work has been supported by the Congressional STEM Program; the National Reconnaissance Office (NRO); the U.S. Office of Operationally Responsive Space (ORS); California Space Grant Consortium (CaSGC); Boeing, Lockheed Martin, and Northrop Grumman corporations; Air Force Research Laboratory (AFRL); NASA Jet Propulsion Laboratory (JPL); Information Sciences Institute (ISI); Universities Space Research Association (USRA); International Foundation for Telemetry; Lord and Rose Hills Foundations; and other organizations and institutions.

Laboratory for Astronautical Plasma Dynamics (LAPD)

The Laboratory for Astronautical Plasma Dynamics (LAPD) carries out computational, experimental, and theoretical investigations in both astronautic engineering and space science. The engineering aspect has focused on electric propulsion, spacecraft-environmental interactions, and spacecraft reliability. The science aspect has focused on the fundamental plasma physics relevant to spacecraft and space environments.

A recurring theme in many of the lab's projects is the effect of microscopic physics on macroscopic systems, from thrusters to spacecraft, to the Sun-heliosphere-Earth system. Current major research projects are investigating plasma interactions and the charging of the lunar surface, short wavelength plasma turbulence in the solar wind, and CubeSat-based architecture and missions for planetary exploration.

The lunar environment simulator facility allows researchers to investigate the near surface lunar plasma environment and plasma-surface interactions. It consists of a vacuum chamber with cryogenic pumps maintaining a 10^{-7} torr base pressure and a plasma source that generates a mesothermal plasma flow ($\sim 1\text{keV}$ beam ions and $\sim 1\text{eV}$ thermal electrons) to simulate the typical solar wind plasma environment. A suite of plasma diagnostics is mounted on an automated three-dimensional (3-D) traversing system to scan the 3-D plasma flow fields and surface potential.



The Laboratory for Astronautical Plasma Dynamics (LAPD) developed the lunar environment simulator facility.

The facility allows researchers to conduct experiments on surface charging and dust charging at the lunar terminator.

LAPD has become a leader in developing and applying large-scale plasma particle simulation models on state-of-the-art supercomputers. For instance, an ongoing study seeks to carry out the first comprehensive kinetic simulations of short wavelength plasma turbulence in the solar wind. This research involves 3-D particle-in-cell (PIC) simulations using 1.1 trillion superparticles and a total computer memory of about 66 terabytes. The research, conducted on the Yellowstone parallel supercomputer at the National Center of Atmospheric Research (NCAR) using 32,768 cores with a hyper-threading domain decomposition of 65,536 subdomains, represents one of the largest PIC simulations of plasma turbulence ever conducted.

Laboratory research projects are supported by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Air Force Research Lab. The director of LAPD is Dr. Joseph Wang, professor of Astronautics and Aerospace Engineering.

Collaborative High Altitude Flow Facility (CHAFF)

The Collaborative High Altitude Flow Facility (CHAFF), developed by Professor Phil Muntz, is now a part of LAPD. At 3 meters in diameter by 6 meters in length, the CHAFF vacuum chamber is one of the largest vacuum chambers housed in an academic institution. LAPD recently finished upgrading the chamber, including installing a cryogenically cooled inside chamber wall. The chamber can now be used as a cryogenic pump with a designed pumping speed of 10^7 liters per second and a base pressure of 10^{-9} torr.

The LAPD is also home to the high-vacuum, high-volume CHAFF chamber.



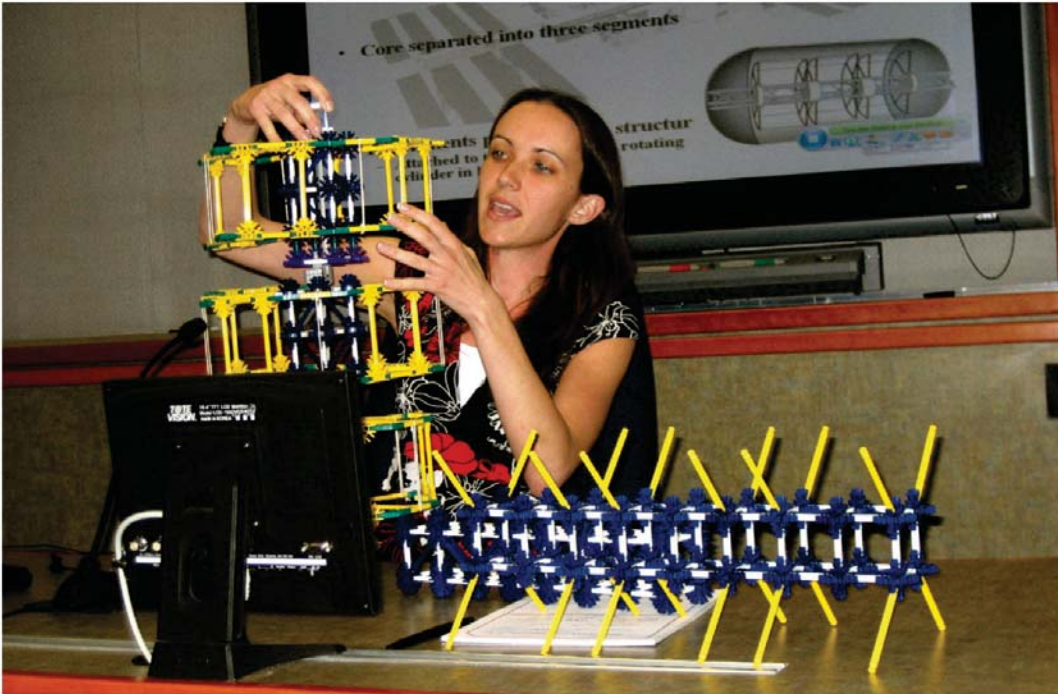
Space Architecting Studio

The Space Architecting Studio is led by lecturer Madhu Thangavelu, architect and engineer. The Studio incorporates the graduate course “Space Exploration Architectures Concept Synthesis Studio” and a variety of lectures and seminars given by the USC faculty and by visiting experts from the space industry and national laboratories. The Studio seeks to inspire students to create new products by allowing them to engage with instructors who are themselves successful innovators. The instruction model parallels those used by architecture school studios and professionals to create innovative concepts. Studio students develop and refine their ideas through rigorous debate and discussion.

The Space Architecting Studio presents both interdisciplinary scientific concepts and the engineering theory behind space system architectures. Beyond that, students learn about the concept generation theory and methods, form-finding processes, visualization, and presentation techniques through a hands-on studio approach that allows participants to design their own concept architectures. Students present these concepts to an expert panel of faculty and government and industry professionals for feedback and discussion. They can then develop their concepts into papers and presentations, many of which are published or presented at peer-reviewed meetings and conferences.



Finals reviewers join students in the Space Architecting Studio: Front row, from left: Bob Brodsky, ret. director of Advanced Projects at TRW; Robert Walquist, ret. director of Research at TRW; and Paul Griffin, propulsion systems manager at Alliant Techsystems Inc. (ATK). Middle, row, seated right: Gene Rogers, chief technologist of Boeing. Back row, from right: Peter Will, Information Sciences Institute; Harvey Wichman, ret. director of the Aerospace Psychology Laboratory at Claremont McKenna College; and National Aeronautics and Space Administration (NASA) Apollo Lunar Rover designer and Silver Snoopy winner Ron Creel.



A graduate student explains the concept for the centrifugal space agricultural farm module she developed in the Studio and presented at the AIAA Space Conference in 2010.

Participants work on both an individual mini project and a larger team project. The individual projects offer students a chance to explore new ideas in their own area of interest. Past mini projects have included the evolution of space transportation systems, on-orbit assembly of large stations/vehicles, orbital debris mitigation systems, communication satellite architectures, human and robotic facilities in space, and human expeditions to the moon and Mars.

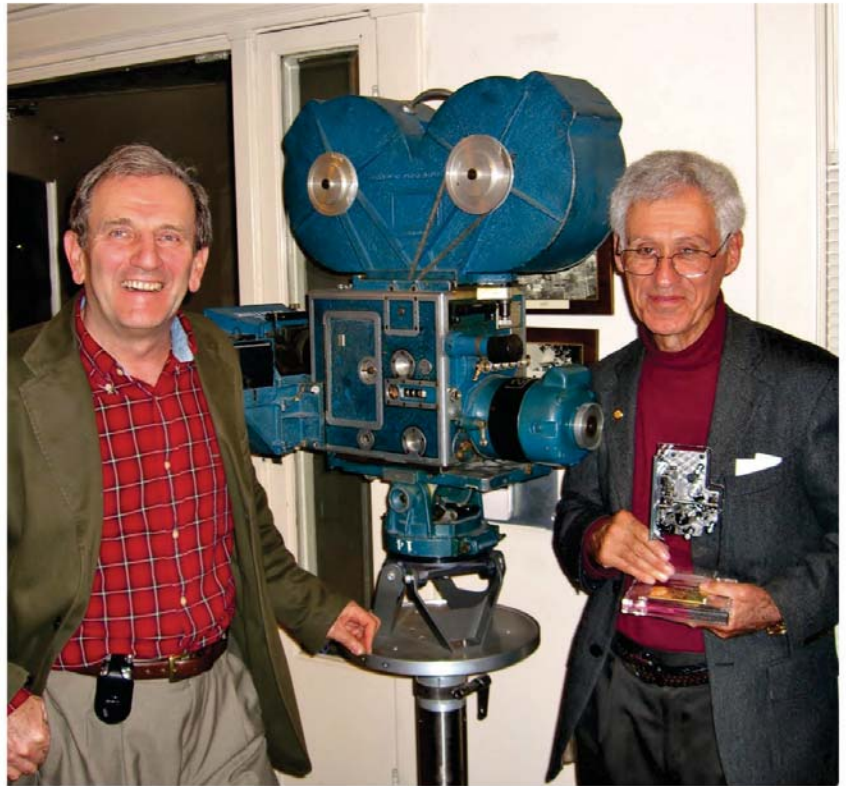
The team projects rely on National Aeronautics and Space Administration (NASA) studies of space missions to focus on such timely topics as human and robotic exploration, commercial space activities, and planetary defense. Past team projects have included lunar missions, Mars exploration, solar power satellites, the International Space Station (ISS), and planetary defense architectures.

Some of the concepts discussed and developed in the Studio have been reviewed and commended by NASA, the National Research Council, and the National Space Council and have been presented before the National Academy of Sciences.

Other Research and Development Programs

The research programs in ASTE have incorporated a broad range of fundamental and applied subjects, including hypersonic and supersonic flows, advanced spacecraft propulsion, space exploration, heliospheric and magnetospheric physics, space instrumentation, orbital debris, atomic and molecular interactions, statistical physics, kinetic theory of gases and plasmas, physics of light sources, plasma and material processing, and environmental studies.

*American Society of Cinematographers President Woody Omens (on right) talks with Professor Joe Kunc about spectrum-controlled light sources for the movie industry in front of the breakthrough camera that was used to film *Gone with the Wind*.*





The Interdisciplinary Atmospheric Research Group is pictured (from left, seated): Lowell Stott, Leonid Didkovsky, John Christy, Joe Kunc, and Seth Wieman; (from left, standing): David Barnhart and Dan Erwin. Donald Rapp (single photo) is also part of the group.



Stan Settles and his wife (center) are pictured with the technical team and the Trojan Thunder, ready to race on the Bonneville Salt Flats. Maximum speed over a measured mile was 263 miles per hour. The car is powered by a 565-cubic-inch unblown V8 gasoline engine, which generates more than 1,000 horsepower.

ASTE's Professor Mike Gruntman participated as co-investigator in the National Aeronautics and Space Administration (NASA) space missions Interstellar Boundary Explorer (IBEX) and Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS). *Science* magazine highlighted the discoveries of IBEX on its 2009 cover when the mission mapped the interstellar boundary of the solar system for the first time. Gruntman's pioneering work contributed to establishing new experimental approaches and developing instrumentation for imaging heliospheric and magnetospheric space plasmas in fluxes of energetic neutral atoms.

Supporters of the ASTE Department research programs include: Air Force Research Laboratory (AFRL); Air Force Office of Scientific Research (AFOSR); Army Research Office (ARO); Defense Advanced Research Projects Agency (DARPA); Department of Energy (DOE); National Center for Atmospheric Research (NCAR); NASA; National Science Foundation (NSF); Microcosm, Inc.; James H. Zumberge Research and Innovation Fund; VSoE Research Innovation Fund; USC Provost Innovative Research Fund; USC Provost Undergraduate Fund; USC Undergraduate Research Associates Fund; and others.

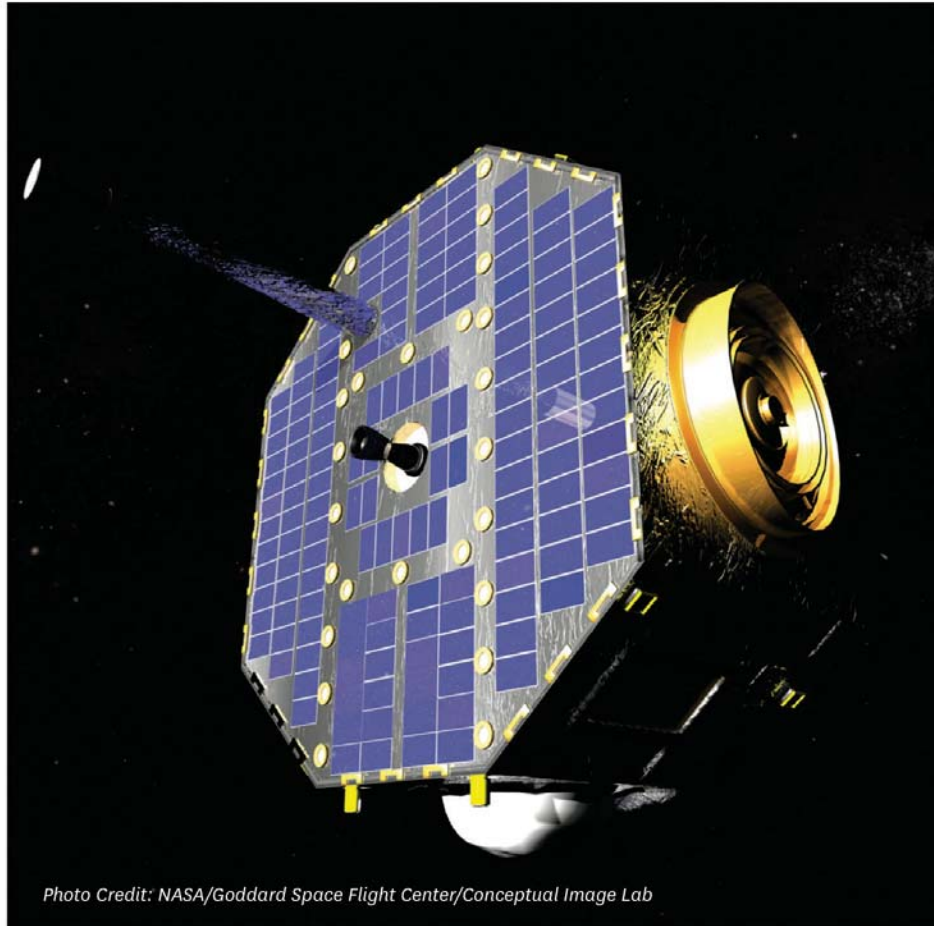


Photo Credit: NASA/Goddard Space Flight Center/Conceptual Image Lab

The Interstellar Boundary Explorer (IBEX).

Astronautical engineering faculty research has been presented at numerous domestic and international conferences and congresses and published in various leading journals:

- *The Astrophysical Journal*
- *IEEE Transactions on Plasma Science*
- *Journal of Applied Physics*
- *Journal of Geophysical Research*
- *Journal of Physics*
- *The Journal of Chemical Physics*
- *Journal of Propulsion and Power*
- *Physical Review*
- *Science*
- *Space Science Reviews*

ASTE faculty and lecturers have a number of published books to their credit. James Wertz co-edited *Space Mission Analysis and Design (SMAD)*, the world bestseller in the field. The latest edition of *SMAD* includes chapters by three ASTE faculty members. Mike Gruntman's *Blazing the Trail: The Early History of Spacecraft and Rocketry* received an award from the International Academy of Astronautics. Madhu Thangavelu is the co-author of *The Moon* – a major monograph on lunar-based architecture – and Mohamed Abid authored the book, *Spacecraft Sensors*. Recently, Gerald Hintz published the textbook, *Orbital Mechanics and Astrodynamics*.



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