

# Advanced degrees in astronautical engineering for the space industry



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## ABSTRACT

Ten years ago in the summer of 2004, the University of Southern California established a new unique academic unit focused on space engineering. Initially known as the Astronautics and Space Technology Division, the unit operated from day one as an independent academic department, successfully introduced the full set of degrees in Astronautical Engineering, and was formally renamed the Department of Astronautical Engineering in 2010. The largest component of Department's educational programs has been and continues to be its flagship Master of Science program, specifically focused on meeting engineering workforce development needs of the space industry and government space research and development centers. The program successfully grew from a specialization in astronautics developed in mid-1990s and expanded into a large nationally-visible program. In addition to on-campus full-time students, it reaches many working students on-line through distance education. This article reviews the origins of the Master's degree program and its current status and accomplishments; outlines the program structure, academic focus, student composition, and enrollment dynamics; and discusses lessons learned and future challenges.

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## 1. Introduction

Ten years ago in June 2004, the University of Southern California (USC) announced establishment of a new unique academic unit focused on space engineering [1]. Initially known as the Astronautics and Space Technology Division (ASTD), the unit operated from day one as an independent academic department and successfully introduced the full set of degrees (Bachelor, Bachelor Minor, Master, Engineer, Ph.D., and Graduate Certificate) in Astronautical Engineering. (This article author had the privilege to serve the founding chairman of ASTD from 2004–2007.) The Division was formally renamed the Department of Astronautical

Engineering in the USC's Viterbi School of Engineering (VSOE) in 2010.

In the United States, space engineering education was traditionally part of a significantly broader aerospace curriculum, historically anchored in aeronautics and dominated by fluids-focused engineering and sciences. Aerospace degrees are usually offered by departments of aerospace engineering or by departments combining aerospace with other engineering disciplines, particularly with mechanical engineering.

In contrast, USC established a unique separate pure-space-focused academic department to address specific challenges in space engineering education. The largest component of the Department of Astronautical Engineering has been and continues to be its flagship Master of Science in Astronautical Engineering (M.S. ASTE) program, specifically focused on meeting needs of the American space industry and government space research and development

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centers. This program successfully grew from a specialization in astronautics developed in mid-1990s and expanded into a large nationally-visible program [1].

The tenth anniversary of the establishment of the independent Department is a propitious time to review the program status; to summarize its accomplishments, impact, and challenges; and to look into the future. We specifically focus here on the Department's industry-oriented M.S. ASTE program, with other degree programs being outside the scope of this article. First, the rational for creating independent astronautical engineering departments is discussed followed by specifics of program development at USC. Then, we describe the M.S. ASTE structure, coursework, program students, and the role of distance education. The article concludes by putting the program into a broader perspective of trends in the global space enterprise.

## 2. Rational for independent astronautics departments

Gruntman [1] discussed in detail the rational for establishing an independent department in astronautical engineering. Briefly, following the beginning of the space age in late 1950s, space engineering education found a home in existing aeronautical engineering departments [2], which changed their names to "Aerospace" or some variant of "Aeronautics and Astronautics." However, the curriculum remained concentrated in fluid sciences and engineering and aeronautical applications, with some coursework added in space-related topics, primarily in orbital mechanics and rocket propulsion [3–5]. At the same time, the American space effort greatly expanded in space exploration and national security.

In 1970s and early 1980s, advocates of space education had been arguing for establishing of a curriculum in "pure" astronautics leading to a Bachelor of Science (B.S.) and higher degrees in astronautical engineering [3,4]. They hoped that such development would give "astronautics" equal status with "aeronautics" in aerospace engineering departments and thus advance space education.

Many important changes have occurred in the ensuing years. The Accreditation Board for Engineering and Technology (ABET) recognizes astronautical engineering as a separate from aerospace degree. (ABET awards accreditation to qualified Bachelor of Science engineering degrees. Master of Science degrees do not require accreditation with the exception, for historical reasons, of those offered by two military institutions [1,6].) Many aerospace departments and aerospace programs in combined (such as aerospace and mechanical engineering) departments in American universities offer space-related courses to undergraduate and graduate students.

One could argue that astronautical engineering has thus been accepted. A more precise characterization of the situation would rather be that aerospace departments "tolerate" space engineering to varying degrees [1]. Fluid sciences with aeronautical applications and astronautics are certainly not of equal status in many present-day aerospace programs. Reflecting this reality, the American Society for Engineering Education (ASEE) does not list astronautical engineering as a separate discipline category [7] and includes the degree into

generic "aerospace engineering" which combines aeronautical, astronautical, and aerospace degrees. A quick look at job advertising in academe in *Aerospace America*, a monthly journal published by the American Institute of Astronautics and Aeronautics (AIAA), does not suggest forthcoming changes in emphasis or transformation of aerospace programs.

At major American research universities, the faculty members largely determine the fields of their concentration and change in the areas of faculty interests does not come easily. It takes decades for dead branches of the evolutionary tree to fall off and for new directions to replace them in the existing academic structures. Outside the universities, the space technology world is highly dynamic, does not enjoy the luxury of undergoing slow evolution, and continues to expand. Teller once noted [8] "that the substance with the greatest inertia known to man is the human brain, and that the only substance more inert is the collection of human brains found in a large organization such as military service or the faculty of a university."

The realities of academe force faculty to vigorously defend their turf and to favor hiring new faculty in the areas of their own research interests. A change in department directions requires determined effort by visionary and powerful administrators. Many aerospace programs actually broadened their scope during the last 10–15 years by hiring new faculty in emerging and cross-disciplinary areas, such as, for example, mechatronics and nanotechnology, rather than in traditional space fields as spacecraft attitude dynamics or satellite thermal control and power systems. The vision of equal status of "astronautics" and "aeronautics" in aerospace departments has not materialized. The space curriculum in many universities is limited, and the old question "Is there any space in aerospace?" [9] remains.

Consequently, the establishment – in some universities – of separate academic space departments offering degrees in astronautical engineering to better meet the needs of the space industry and government centers was called for in [1]. It was argued that such a step would logically advance the earlier efforts of 1970s and 1980s to recognize astronautical engineering as a separate degree. Importantly, separate astronautical engineering departments could shift the existing competition (which is rarely fair) from among groups of faculty within aerospace departments to a (much more even-leveled) competition among aerospace, astronautical, and aeronautical departments of various universities.

It was specifically emphasized [1] that creation of astronautical engineering departments was a *practical* approach to achieve desired flexibility within *constraints of realities* of the glacially-changing academe. The resulting competition among the departments and universities would force a balanced mix of the offered programs, determined by national educational needs and better respond to the engineering workforce development challenges of the space enterprise.

## 3. Astronautical engineering at USC

Aerospace engineering at USC was rather typical for the country. Most of the aerospace engineering faculty have been traditionally focused on fluid dynamics research

since the founding of the Aerospace Engineering Department in 1964. (Aerospace engineering option in mechanical engineering dated back to late 1950s.) The first chairman of the department had been former chief of the fluid physics section at the Jet Propulsion Laboratory prior to joining the USC [10]. Only a few courses in space technology were offered in 1980s to graduate students by adjunct faculty [1,9,11]. A general observation about aerospace faculty in the country that "... most [faculty] are well established in research and devoted to aeronautics and thus have little incentive to take an interest in space technology" [3] did apply to USC.

On a historical note, the first man on the moon, Neil Armstrong, was among most renowned USC aerospace graduates of those times. He had studied part time while being stationed at the Edwards Air Force Base in California as a test pilot [10]. Armstrong had completed all required coursework, except the seminar, towards Master's degree when he joined NASA in early 1960s and transferred to Houston in Texas. In January 1970, Armstrong gave a one-hour seminar on the technical aspects of landing Apollo's lunar module *Eagle* on the surface of the Moon in 1969 and received – immediately after the seminar – his Master of Science degree in Aerospace Engineering from USC.

The faculty composition of the Aerospace Engineering Department had somewhat changed by early 1990s, however, when several tenure-track faculty had been added in modern areas of research such as hypersonic flight, physical kinetics, space science, and space instrumentation. This group formed the nucleus of the Astronautics Program within the Department. (The Aerospace Engineering Department merged with the Mechanical Engineering Department in 1998–1999, forming the Department of Aerospace and Mechanical Engineering [12].)

The attitude of many USC aerospace faculty toward space technology was not much different from other engineering schools in the country. The history of the department [12] published in 2004 by its former chairman highlighted the challenges faced by astronautics programs within a broader aerospace area at universities. The history only once casually mentioned the existence of the astronautics specialization in the department at the time when courses offered by this pure-space-focused program accounted for 80% of graduate students enrolled in aerospace courses, with non-space aerospace courses drawing the remaining 20% of the students. In addition, the recently established astronautics undergraduate specialization was also approaching one half of the total enrollment in the aerospace program [1,11].

The USC aerospace engineering program was also rather typical for American universities [13] in other respects: after rapid growth and large enrollments, the undergraduate and graduate student populations had dropped by late-1990s, following the end of the Cold War, by factors of five and two, respectively, from their peaks [10,12].

The response of the astronautics-oriented faculty to the prevailing doom-and-gloom atmosphere of mid-1990s was to found the Astronautics and Space Technology Program (Astronautics Program) taking advantages of some obvious opportunities [1,11]. First, we specifically

focused on providing engineering degrees in the area of spacecraft technology for the space industry and government research and development centers. The University is strategically located in Los Angeles in the heart of the American space industry in Southern California. In early 2000s, California accounted for roughly one half of the revenues of the U.S. space enterprise and dominated (~80%) the satellite segment of the market [14]. California remains the home of a major space effort to this day.

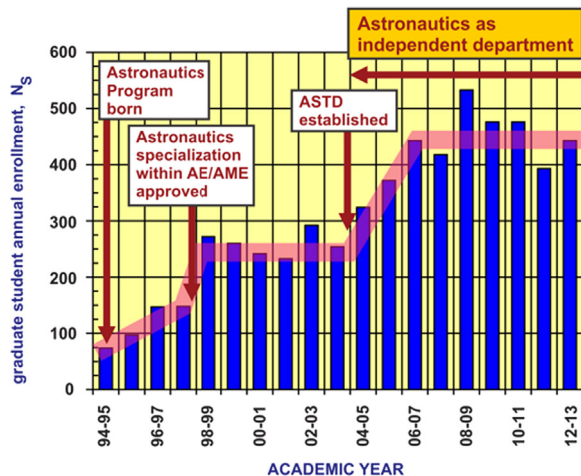
Second, we initially concentrated on the Master of Science program. Three-four decades ago engineers with Bachelor's degrees could have rewarding and fulfilling technical careers. Today, changes in industry have made Master's degrees desirable (sometimes called "the terminal degree") for a successful technical career in the United States. Consequently, many leading industrial companies and government centers now hire young graduating engineers with Bachelor's degrees and support their pursuit of M.S. degrees part-time while working full-time. In fact, tuition coverage for such studies has become part of standard compensation packages in defense and aerospace industries.

Third, we leveraged the existing VSOE distance education capabilities (discussed below) to reach students across the country. Distance education plays an increasingly important role in pursuits of Master's degrees in engineering.

Last but not the least, the traditional diversity of arrangements in U.S. higher education made it easier and possible to experiment with new approaches. The University of Southern California, the oldest and largest private university on the West Coast, has a long tradition of working with the aerospace and defense industries. Consequently, the USC Viterbi School of Engineering was a natural home for an initiative in space technology.

So, in the mid-1990s, the astronautics faculty of the Aerospace Engineering Department began expanding coursework of interest to the space industry and government research and development centers in Southern California [1,11]. Starting with only a few space-related courses taught by regular and adjunct faculty, the curriculum steadily grew. The M.S. degree program with emphasis in astronautics was first recognized as a specialization in 1997. The University formally approved it in 1998 and assigned a separate independent postcode. The approval of the Graduate Certificate and the Bachelor of Science degree specializations followed [1].

Student interest in a certain program can be characterized by an annual enrollment in program classes,  $N_s$ , during an academic year. Fig. 1 shows the annual student enrollment in classes offered by the Master's astronautics program since its inception in 1990s. At USC, the academic year begins with the fall semester and includes the spring and summer semesters of the next calendar year. (For example, the academic year 08–09 includes semesters in the fall 2008 and spring and summer of 2009.) VSOE offers few classes during summers when most students take a break from studies. The number  $N_s$  directly reflects tuition revenues brought by the program. USC is a private university without generous subsidies enjoyed by many competing state institutions of higher learning which



**Fig. 1.** Annual (academic year) student enrollment in classes,  $N_s$ , offered by the USC Master's astronautics program since its inception. AE/AME – Aerospace Engineering and Aerospace and Mechanical Engineering Departments; ASTD – Astronautics and Space Technology Division.

makes financial soundness of our programs particularly important.

Fig. 1 also reveals the importance of program clear self-identification for its growth. A separate program usually appeals to motivated students seeking education in a certain area of engineering. The approval of the independent Astronautics specialization in 1997–1998 increased student enrollment in program classes by 60% in one year. The separation from the Department of Aerospace and Mechanical Engineering (AME) in 2004 and establishment of an independent academic unit, the Astronautics and Space Technology Division, with distinct degrees in astronautical engineering led to another surge in student interest. Here, graduate student enrollment in classes increased by 80% within 3 years. This increase has proved the timeliness and benefits of the establishment of an independent space engineering department.

Some smaller year-to-year changes in the number of students enrolled in program classes are caused by various factors such as sabbatical leaves of faculty; changes in tuition reimbursement policies in major space companies; state of the national economy and industry; and even loss or award of a particular major government contract by a certain company. Despite such variations, Fig. 1 clearly shows the trends.

Following the creation of the new Department of Astronautical Engineering in 2004, it took one year to establish the full set of degrees in astronautical engineering and more than two years to achieve smooth operations of the academic unit. Parenthetically, building a new academic department is a prodigious task. Since it does not happen often in universities, many arrangements have to be re-invented. The sheer number of administrative loose ends that need to be tied up is staggering.

In addition to M.S. ASTE, the Department offers other degrees, but their discussion is outside the scope of this article. We note here that the new Ph.D. program in astronautical engineering took off to a good start, with 11 Ph.D. degrees awarded during the last two academic

years alone. Concentrations of studies of Ph.D. students are aligned with expertise and research interests of the faculty. The B.S. program in astronautical engineering enrolls 10–20 new students each year, with the size of the freshman class capped by the VSOE. The new B.S. program received the ABET accreditation in 2011–2012. (ABET requires assessment of a couple cohorts of graduating students who enrolled into a new program as freshmen and accreditation thus takes 6–8 years.) The Department actively creates opportunities for student team projects such as designing and building sounding rockets as well as space-related systems; the latter in collaboration with the VSOE's Information Sciences Institute (ISI) [15,16].

In 2003, then Dean of the Viterbi School Prof. Max Nikias (who became President of USC in 2010), Dr. Simon “Pete” Worden (then at the Space and Missiles Systems Center, and now director of NASA's Ames Research Center), and then President of the Aerospace Corporation Dr. William F. Ballhaus, Jr. challenged the USC astronautics faculty and ISI scientists to advance science and engineering (creating a “Bell Labs of Space”) of cost-effective microsatellites systems. ISI's Drs. Joe Sullivan and Peter Will and the author of this article led this major initiative, with Stan Dubyn (co-founder of Spectrum Astro, Inc. and founder of Millennium Space Systems), and Dave Barnhart (then Vice President of Millennium Space Systems) also playing particularly important roles.

This initial effort from 2003 to 2007 had developed programs that expanded into other areas of specialized technology and engineering workforce development and laid the foundation for the subsequent creation of the VSOE's Space Engineering Research Center (SERC) in 2007–2008. After 2007, activities of SERC and ISI significantly changed the focus of the initiative away from the initial objectives and toward student-centric projects [16]. Astronautics students have been involved in development of microsatellites at SERC, with two cubesats in orbit.

#### 4. Master of Science in Astronautical Engineering

The Master of Science in Astronautical Engineering is among many advanced degrees offered by the Viterbi School of Engineering. For many years, VSOE's Distance Education Network (DEN) has been playing an important role in offering Master's programs, cementing traditionally strong ties to the industry. In addition to full-time on-campus students, working full-time engineers enroll in the distance education program as part-time students. In 2011–2012 academic year, the Viterbi School awarded 1661 M.S. degrees in engineering (1224 degrees excluding computer science), more than any other engineering school in the United States [7]. Distance education students earned 301, or 18%, of these degrees.

Three practical considerations focused our initial effort on development of the space engineering specialization on the Master's level. (This article author has been directing the Master's degree program since its inception to this day.) First, there was clear interest by working full-time students in the space industry, particularly in Southern



California. Here, School's DEN provided a powerful tool to conveniently reach such students in California and beyond.

The second contributing factor was seemingly unending and especially strong resistance in academe to separate undergraduate programs in astronautics. Even today, there are only three B.S. degree programs in astronautical engineering in existence nationally [1].

The last consideration was a possibility to rely on adjunct faculty and part-time lecturers for teaching highly-specialized graduate classes, in contrast to undergraduate courses usually taught by full-time faculty. External lecturers provided flexibility for the initial program build-up without the complications of hiring new tenure-track faculty.

#### 4.1. Program structure and coursework

The M.S. ASTE degree program is open to qualified students with B.S. degrees in engineering, mathematics, or hard science from regionally accredited universities. In contrast to many other aerospace programs, we do not require a Bachelor's degree in astronautical or aerospace engineering, and also admit students with educational background in other areas of engineering and science. Typical undergraduate courses in physics, chemistry, and mathematics taken by engineering students provide the basis for successful studies in the program.

The M.S. ASTE coursework consists of nine courses (27 units), with typical semester-long graduate classes being 3 units each. The program usually offers 8–10 graduate astronautics classes each semester. Practically all our graduate classes are available not only to on-campus students but also to remote on-line students through DEN. Writing a Master's thesis is an option but not a requirement. The thesis earns credit of 4 units, usually complemented by 2 units of directed research. Most students prefer coursework; a few however choose writing theses, which requires a major effort.

A typical full-time student studies on campus, taking three courses per semester, and completes the entire program in three semesters or one year and a half. A full-time working student studies part-time and usually takes one course each semester or sometimes two. (Workload at the main job, which varies widely and depends on individual circumstances, determines the number of courses for part-time students.) Therefore, it takes on average 4 years for a working student to achieve the degree.

To earn the M.S. ASTE degree, students must take four *required courses* (12 units); two *core elective courses* (6 units) chosen from a list of core elective courses; two *technical elective courses* (6 units); and one course (3 units) in engineering mathematics chosen from a list of four different courses. The required courses include three broad overview courses in (i) spacecraft system design, (ii) spacecraft propulsion, and (iii) space environment and spacecraft interactions. The fourth required course is in orbital mechanics.

A typical 3-unit course consists of 12–13 weekly three-hour lectures and two exams (mid-term exam and final exam) complemented by weekly homework assignments

and sometimes term papers and projects. The program's flagship spacecraft system design course (taught by the author of this article) provides a broad overview of fundamental science and engineering topics essential for understanding satellites and their launch systems as well as operations and applications. It introduces main concepts and nomenclature, emphasizes interplay among various satellite subsystems and design decisions, and puts into perspective various areas of space technology. After introductory lectures on space environment and orbital mechanics students analyze various subsystems of spacecraft, with roughly one week or slightly more devoted to a particular subsystem. Many follow-on elective courses explore these particular subsystems in depth and detail.

The required spacecraft system design course also serves as an entrance gateway both for students with non-astronautical and non-aerospace engineering undergraduate degrees and for those who have been some years out of school. Some students in the latter category have been promoted to positions of engineering management of technical projects and this course helps them to return to technical studies. The course is also popular among students pursuing degrees in other areas of engineering and planning careers in the space industry. More than 1100 graduate students have enrolled in this spacecraft system design course during the last ten years.

Core elective courses cover satellite subsystems, specialized propulsion, advanced orbital mechanics, attitude dynamics, and subjects of space mission and system design. The Astronautics program objective is to offer overview courses on space systems, orbital mechanics, and space environment and supplement them by coursework focused on satellite subsystems, key applications, and emerging technologies. While we cover many satellite subsystems at this time, there are a few areas where we would like to bring new courses. Introduction of new coursework is limited by two main factors, attracting qualified instructors actively working in areas of interest and constraints of the allocated budgets and distance education infrastructure. Even maintaining the current offering of more than twenty courses presents an administrative challenge since occasionally our external instructors have scheduling conflicts or relocate to other parts of the country.

There are several areas in which we plan to bring new coursework. In 2014–2015 academic year, for example, three new courses are being introduced, in human spaceflight, launch vehicle design, and plasma dynamics. Among our development priorities are courses on space systems (reliability of space systems; space debris), subsystems and new technologies (ground control segment; space software; entry, descent, and landing; space cryogenic technology, including superconductivity; small satellites, including cubesats), and applications (global navigational systems; communications satellites; space solar power systems).

Most course lectures involve little interaction with students because many take courses through DEN (as discussed below in [Section 4.3](#)). The exception in our program is the Space Studio Architecting course. Each year this studio addresses a specific topic, such as, for example,

design of a lunar base, exploration facilities on Mars, future human spaceflight, or planetary defense. A student in the studio chooses a component that fits into the topic and focuses on its design. Student presentations during the semester and especially during the mid-term and final exams involve major interactions and discussions. We limit the course enrollment to ten students, one half on campus and one half through DEN. At this time, the studio usually uses WebEx for presentations and discussions. As technology evolves, we may be able to improve the format.

The Astronautics Program never limits the choice of technical electives to coursework offered by the home department but rather emphasizes importance of choosing courses which best contribute to achieving students' educational objectives. Most graduate non-astronautics science and engineering courses are approved as technical electives. (We only limit coursework in topics outside classical engineering and science such as, for example, management of engineering programs.) Many students find the space-focused core elective courses so attractive that they choose all their technical electives from this list.

Table 1 shows astronautics courses presently offered for graduate credit. We continuously work on addition of new courses, subject to availability of qualified instructors, distance education studio slots, and programmatic needs.

The M.S. ASTE program usually offers 8–10 courses each semester, out of two dozen Astronautics courses. All required courses are offered at least once each year and some twice a year. Students can take many popular core elective courses (for example, Advanced Spacecraft Propulsion, Spacecraft Power Systems, and Orbital Mechanics II) also every year, while other highly specialized courses are available every other year. The latter scheduling allows us to use the same number of precious distance-education studio slots to make a larger number of different courses

available to students. Since it takes four years for many full-time working students to complete their studies, careful planning of their coursework usually allows them to take all the desired courses.

Although many students prefer to begin their studies with the overview spacecraft system design and space environment courses, the program does not require a specific sequence of courses. There are a few exceptions, however. For example a course in space navigation requires introductory orbital mechanics as prerequisite and courses in liquid and advanced propulsion require prior coursework in spacecraft propulsion. Some students, particularly with aerospace degrees, have been exposed to subjects covered by some required courses, such as propulsion and orbital mechanics, during their undergraduate studies. In these cases, the required course is waived, with a student taking one additional technical elective instead.

The M.S. ASTE program provides an important educational foundation for getting into systems engineering of major space systems. A traditional path for these highly-sought positions in the space industry required first excelling in a particular engineering area. Consequently, we see interest in our program among accomplished engineers with non-astronautical background. Some already have Master's degrees in mechanical, electrical, computer, and other areas of engineering and successfully work in their specializations. They enroll in the M.S. ASTE to gain better understanding of other aspects of space systems. A degree in astronautical engineering is a natural path for them to achieve technical and managerial leadership positions in space programs.

It is important to note the difference of the M.S. ASTE program from two other areas of studies.

First, the focus of the program is not in systems engineering while we recognize its particular importance for development and operations of space systems. The M.S. ASTE program concentrates on traditional areas of science and engineering as they applied to space systems. Students may take a technical elective course or two in systems engineering or architecting offered by other engineering departments. A student with strong interest in such studies is usually advised to switch to dedicated systems engineering or systems architecting programs.

The other field of studies distinctly different from the M.S. ASTE program is often called "space studies" in contrast to "space engineering." Space studies usually combine some science and engineering classes with coursework dealing with space policy; legal, management, communications, and entrepreneurial aspects; and program development. The University of North Dakota in the United States, the International Space University in Strasbourg, France, and the University of Delft in the Netherlands [17] are among well known educational institutions in this field. In contrast, the USC program in astronautical engineering focuses on specific technical areas of importance for research, development, designing, building, and operating space systems.

#### 4.2. Program faculty and lecturers

Adjunct faculty and part-time lecturers play an especially important role in the M.S. ASTE program. Graduate

**Table 1**  
Astronautics courses offered for graduate credit.

|  |
|--|
| <b>Required courses</b>                                |
| Spacecraft System Design                               |
| Spacecraft Propulsion                                  |
| Space Environment and Spacecraft Interactions          |
| Orbital Mechanics I                                    |
| <b>Core elective and elective courses</b>              |
| Orbital Mechanics II                                   |
| Space Navigation: Principles and Practice              |
| Advanced Spacecraft Navigation                         |
| Liquid Rocket Propulsion                               |
| Advanced Spacecraft Propulsion                         |
| Space Launch Vehicle Design (to be introduced in 2015) |
| Physical Gas Dynamics I, II                            |
| Plasma Dynamics (to be introduced in 2014)             |
| Design of Low Cost Space Missions                      |
| Space Studio Architecting                              |
| Human Spaceflight (to be introduced in 2014)           |
| Safety of Space Systems and Missions                   |
| Spacecraft Attitude Dynamics                           |
| Spacecraft Attitude Control                            |
| Spacecraft Structural Dynamics                         |
| Spacecraft Structural Materials                        |
| Spacecraft Power Systems                               |
| Spacecraft Thermal Control                             |
| Systems for Remote Sensing from Space                  |
| Spacecraft Sensors                                     |

engineering programs in the United States traditionally aligned with academic pursuits in the areas in which doctoral degrees are normally granted. Some areas of space engineering are not directly compatible with doctoral study. For example, spacecraft design is not usually considered an academic area because the knowledge base required to be an expert designer is broad rather than deep. Interestingly, this particular area attracts a large number of inquiries about possibilities of pursuing doctoral degrees.

In addition, many areas of critical importance to the space industry are sufficiently specialized and rapidly evolving that no university faculty member would likely have expertise in them unless he or she had spent years working in industry. Ironically, in the latter case, such a specialist would unlikely qualify for tenure in a research university because of the overriding requirement of superb scholarly achievements, including publications in academically recognized peer-reviewed journals. Examples of such specialized areas are spacecraft power systems and spacecraft thermal control. The need of covering a large number of highly specialized areas makes it impossible to provide comprehensive astronautics degree programs responsive to the needs of the space industry with instruction given only by regular university-based faculty.

Consequently, our solution to program development was a combination of regular tenure-track faculty and adjunct faculty and part-time lecturers. The regular faculty primarily focus on basic science and technology such as dynamics, gases and plasmas, space science, and fundamentals of spacecraft design, orbital mechanics, propulsion, and space environment. The adjunct faculty, who are leading experts typically full-time employed in the space industry and government research and development centers, cover the highly specialized and rapidly changing areas of space technology. They also bring the real-world experience, a vital component of a high-quality engineering education program.

The adjunct faculty and part-time lecturers are the pride and a great strength of our program. They work at various space companies and centers, large and small, including Boeing, Lockheed-Martin, Raytheon, Aerojet-Rocketdyne, Microcosm, Space Environment Technologies, NASA Jet Propulsion Laboratory, and The Aerospace Corporation. The access to the unmatched wealth of first-rate specialists in the Los Angeles area allows us to offer a wide breadth of courses in space technology and launch new courses as needed. These courses contain current space-industry practice of particular interest to many of our M.S. and A.S.T.E. students. Some adjunct faculty also play active roles in advising Ph.D. students.

#### 4.3. Role of distance education

The opportunities offered by the VSOE's Distance Education Network played an enabling role in launching the USC Astronautics Program. DEN is among the largest engineering distance education programs in the United States, with 301 Master's degrees awarded in the 2011–2012 academic year. Astronautics distance education students accounted for about one-tenth of these degrees.

The USC School of Engineering initiated a pioneering effort in distance education, then first called the Instructional Television Network (ITV), in 1968. One year later the Federal Communications Commission approved putting television transmitters at Mount Lee in the hills above Hollywood, with broadcasts reaching the Los Angeles basin and the San Fernando Valley. With the grant from the Olin Foundation the School built technical facilities and commenced televised classes in 1972 [10].

ITV provided interactive one-way video and two-way audio broadcasts, with remote classrooms set up at local aerospace companies such as Hughes, McDonnell Douglas, Rockwell, TRW, Burroughs, Jet Propulsion Laboratory, The Aerospace Corporation, and many others. The system had limitations, however, and was costly. It required the affiliated companies to maintain special distance education centers and arrange reception of USC television broadcasts.

The ITV coverage was also limited to the Los Angeles area. A USC courier drove daily to collect homework and deliver to the remote sites graded homework, new assignments, and course handouts. Examinations were held on campus. In 1990s ITV began renting transponders on geostationary satellites to extend reach to students outside Southern California (Fig. 2).

In the late 1990s, VSOE reorganized ITV into the Distance Education Network. Course delivery has transitioned to "webcasting," streaming compressed video and audio over the Internet. Standard high-speed Internet connection allows viewing lectures from home or office or a hotel room anywhere in the world. The high-quality webcasting opened a way for small companies and individuals to enroll in DEN on-line programs. The new web technology has had a profound impact on distance education: it dramatically expanded reach and brought competition to once static programs. Continuous education on-line have become the way of life for many engineers in industry.

The full-time students attend class meetings in special DEN-equipped studios on-campus with lectures being simultaneously webcast to on-line students. Distant students can view lectures in real time over the Internet and they can call using special toll-free telephone lines to ask questions. The interaction with students in the classroom is usually limited to



Fig. 2. Antennas of the Distance Education Network in 2004.

responses to questions raised in the classroom. While distance students watching lectures in real time can call in it does not happen often. This is because many do not watch lectures in real time and also for those who do such a question sometimes involves a delay of dialing and connecting through the control room as the lecture moves on. Because of distance students, many instructors do not encourage exchanges with students in the classroom. The exception is few courses which essentially rely on interaction with the instructor and among students. Such arrangements present technical challenges at this time. We offer one such course as discussed in [Section 4.1](#) above. In general, distance education courses, especially those with large student enrollment, have significantly reduced interaction during lectures. One possible remedy could be online chat-rooms, moderated by teaching assistants and with some participation of instructors during designated hours.

After class meetings, lectures are stored on the VSOE servers and students can access them as many times as they want during the entire semester. Such asynchronous access is especially important for working professionals who balance demanding schedules of their jobs, business-related travel, families, and studies. In addition, asynchronous viewing is convenient for many students who reside in time zones different from that of Los Angeles. Consequently, some on-line students do not watch class lectures in real time unless classes require interaction.

In the studio classroom, instructors could speak to the facing them camera or show the prepared presentations in preferred format and software (such as Microsoft PowerPoint, Adobe Acrobat, specialized scientific and engineering software) from desktop computers or their laptops. Some instructors choose to use preprinted course notes, with the overhead camera zooming in on the page. The instructor can then write additional equations or add a sketch or circle some content while discussing this particular page in order to emphasize specific content and thus augment the printed material. The camera can also zoom in on a special notepad where the instructor writes and, for example, derives equations or sketches diagrams by a pen. (Special pens with somewhat thicker than conventional lines are used for better writing visibility.) Finally, the camera can show the instructor utilizing a traditional large whiteboard or electronic board. It is customary for students to download, print, and bring to class meetings instructor's course notes, adding their own notes on the printouts during lectures.

[Fig. 3](#) shows a typical DEN studio where one can see the instructor's desk with three large monitors behind on the wall continuously displaying to students attending the lecture in class the feeds from cameras, computers, and the webcast stream. A permanent desktop computer supports each studio although many instructors prefer bringing their own laptops and connect them to the projection and webcast system. In each studio, a specially trained student operator supports the lecture and follows instructor directions for switching between cameras, zooming in on papers on the instructor's desk, or switching to the feed from the laptop.

Asynchronous viewing of lectures stored on the servers offers convenient features. [Fig. 4](#) shows an example of a computer screenshot of a typical lecture webcast viewed asynchronously after the lecture has been delivered and



**Fig. 3.** Typical VSOE's Distance Education Network studio with the instructor's desk and three large monitors behind showing camera feeds and lecture webcast. Full-time on-campus students attend lectures in such studios.

stored on the DEN server. The direct real-time feed (in the top-left area) may show either a camera view of an instructor at the desk or next to the whiteboard or a camera view of materials on the desk or a direct feed from a computer. The streaming material (shown in the top-left of the computer screenshot) can also be downloaded as a video file and watched on the full computer screen.

Astronautics students studying through DEN reside in many geographical areas with rocket and space activities, installations, test and operations sites, space companies, and government centers ([Fig. 5](#)). In addition, some students live and work in Canada. We also always have students who serve in the armed forces and are stationed at various locations scattered across the globe.

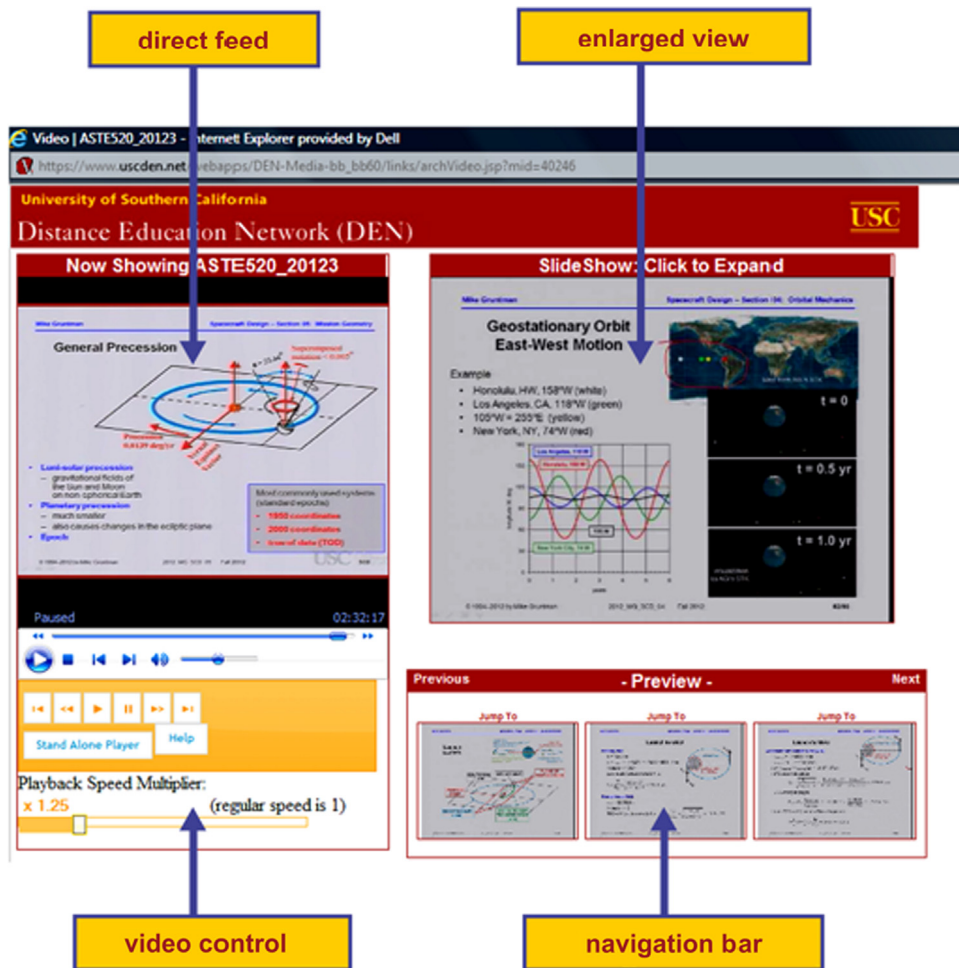
DEN staff interacts with distance students electronically, with class notes, homework assignments, and handouts downloaded from special secure servers. Students in the Greater Los Angeles area take exams on campus. At distant sites, DEN contracts local community colleges to proctor exams. Working students are sometimes sent on business-related travel during the time of exams. In such cases DEN arranges proctoring of exams locally wherever the student might be.

Some exams are closed book and some are open book, the latter allowing use of course notes, textbooks, and old homework assignments and solutions. Calculators are usually required. The calculators become increasingly powerful, with the distinction from laptop computers blurring. Some instructors thus allow laptop computers at the exams, usually requiring turning off wireless internet connection. Exam proctoring centers enforce identical exam rules for distance students.

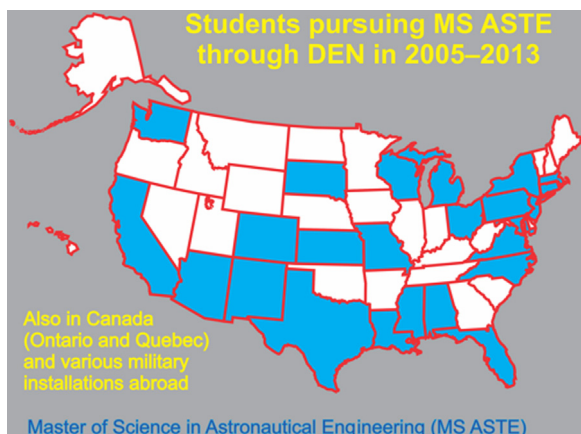
#### 4.4. Program students

The Master of Science program in astronautical engineering attracts both full-time on-campus students and students who work full-time and study part-time while earning their degrees. The latter category accounts for about three-quarters of the awarded Master's degrees in astronautics. Their fraction among enrolled students is even higher because it takes longer for them to earn the





**Fig. 4.** Four distinct areas on the computer screenshot of a typical asynchronously viewed captured lecture webcast. The top-left area shows the captured direct real-time feed of the lecture. It could be a face camera view of the speaking instructor or a notepad or other printed materials on the desk in front of the instructor or a feed from a desktop or instructor's laptop computer (as in this figure). This captured live feed can also be downloaded as a video file and played on the full screen of the computer. The top-right area shows selected images of the feed (on the left) periodically captured in high resolution. Bottom parts of the screen show a video control panel (left) and a navigation bar (right) for selection of captured high-resolution images for display in the top-right area above.



**Fig. 5.** Students pursuing Master of Science in Astronautical Engineering (M.S. ASTE) degrees through distance education reside in many states of the United States as well as in Canada and stationed at military installations across the globe.

degree compared to full-time on-campus students. About one quarter of our students (those who study full-time) achieve their degrees in 1.5 years while almost three-quarters (DEN students) obtain their degrees in 4–5 years, with a few distance students graduating faster in 2.5–3.5 years and very few in 6–7 years (if they have to temporarily interrupt studies for some reason).

A typical full-time graduate student usually earns the degree in one year and a half or three semesters. It may take longer, however, to complete the degree requirements if they start working, initially part-time, in industry. Some research-oriented students also decide, if qualified, to continue their studies towards PhD degrees after completion their Master's program. Here, the critical issue is identifying a faculty advisor to guide the student.

Full-time working students are employed by the space industry and government research and development centers. Many students work for large space companies such as Boeing, Northrop-Grumman, and Raytheon or

large government centers. In recent years we noticed an increase in students who work in smaller companies. Most full-time working students take courses through DEN, even if they live within a driving distance from the campus. The typical time of studies to complete the degree ranges from two and half to five years depending on the course load. Many distance education students today earn their degree without the need of ever visiting the campus. Some would fly to Los Angeles to attend the festive official Commencement ceremony at USC and formally receive their diplomas.

As a matter of policy, VSOE treats all students – on-campus and on-line – equally, with the identical requirements toward the degrees and standards in student admission and in evaluating student performance. Although distance students watch their lectures remotely from the comfort of their home or office, they are held to the same high standards as all USC students and are expected to show the same dedication toward their education.

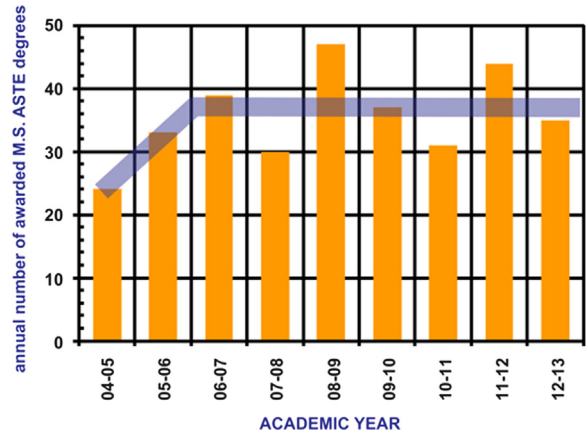
All on-campus students also have access to lecture webcasts of classes in which they are enrolled. As a result, some full-time students also choose to sometimes watch lectures from their homes at convenient times instead of attending them in classroom studios. At the same time, some distance education students from the Greater Los Angeles or travelling to Los Angeles on business come to some lectures on campus.

The faculty advisor helps graduate students to select courses that best fit their educational goals. Typically students desire to get in-depth knowledge in technical areas of their present job. Another category of students, however, concentrates on the areas of technology where they would like to transfer to in their companies. Selecting coursework in the desired areas often facilitates such internal moves after earning the degree.

The background of our students is truly diverse. The majority of students admitted to the M.S. ASTE program have Bachelor's degrees in engineering or science. Some students already have their Master's degrees in other areas of engineering and successfully work in the space industry. They often are promoted to leading technical positions and the objectives of their studies focus on gaining better understanding of entire space systems. In addition, we have students with doctorates in other fields of science or engineering. Almost each year, a medical doctor also enrolls into the program. A few students, often with M.S. or Ph.D. degrees, join the program in order to improve their chances to be selected for astronaut training.

The USC Astronautics Program has earned a solid reputation. It is highly visible in the space industry and reaches students across the country. The group of program alumni, students, and supporters on the professional network, LinkedIn, includes more than 500 members. As a result, the word-of-mouth plays today a most important role in program promotion bringing new students who first heard about it from satisfied alumni.

National statistics in the United States do not distinguish between aeronautical, astronautical, and aerospace degrees and combine all of them in one group. There are 67 institution of higher learning in the United States that



**Fig. 6.** Annual number of the awarded M.S. ASTE degrees, with the average 37 degrees (the straight line to guide the eye) during the last 8 academic years. This is approximately 3% of the M.S. degrees awarded in the United States in the broad area of astronautical, aeronautical, and aerospace engineering.

award today Master's degrees in this broad aerospace group [7].

During the last 8 academic years, our program awarded 296 Master of Science degrees in Astronautical Engineering, or on average 37 degrees annually (Fig. 6). The full-time students accounted for 72 degrees (or 24%) and distance education students for 224 degrees (76%). This breakdown between full-time on-campus and working and enrolled through DEN graduating students remained practically unchanged during the last 8 years. Correspondingly, the same ratio of 3-to-1 of DEN to on-campus students is typical in specialized Astronautics classes taken primarily by students pursuing the M.S. ASTE degree. The only exception in our program is the Spacecraft System Design course which attracts a number of on-campus students (and some DEN students) pursuing engineering degrees in other areas. A fraction of distance students in this class is usually smaller, about 60%.

Our M.S. ASTE degrees constituted more than 3% of the Master's degrees awarded to the broad group of aeronautical, astronautical, and aerospace engineers in the United States in 2005–2012 which was more than twice the average for the 67 programs. In fact, in 2011–2012, the last academic year for which national statistics were available, we awarded 44 degrees. Only 8 other institutions of higher learning in the country awarded more aerospace M.S. degrees [7].

The number of foreign students in the M.S. ASTE program is smaller than in many other engineering programs in VSOE. During the last 8 years, about two dozen international students (or about 8% of the total number of students) earned their Master's degree. This smaller fraction is explained in part by the fact that three-quarters of our M.S. degrees were awarded to domestic students who worked full time at leading space companies and government centers and who thus were either U.S. citizens or permanent residents. Among our full-time on-campus students about one-third was international. Foreign students are also usually aware of restrictions of the export control International Traffic in Arms Regulations (ITAR)

and many decide to enroll in engineering programs in other fields.

All university classes, including in astronautics, are open to students without restrictions of their nationality. Outside coursework, participation in research projects funded by external government agencies and industry may have ITAR restrictions, however, requiring involved students to be U.S. persons (in the language of the regulations). In addition, it is harder, but not impossible, for international students to find internships and later, after graduation, employment.

In spite of the ITAR effect, the M.S. ASTE program awarded degrees to students from at least 16 countries since the formation of the separate department in 2004. These countries included (alphabetically): Canada, China (both the People's Republic of China and Republic of China, Taiwan), Columbia, India, Iran, Italy, Japan, Malawi, Myanmar, Nepal, Pakistan, South Africa, South Korea (Republic of Korea), Spain, and Sweden. Many students continued studies to pursue their Ph.D.s, either at USC or elsewhere, after earning their Master's degrees. To the best of my knowledge, one European student returned to his home country after graduation where he received a prestigious post-doctoral fellowship. In addition a couple students pursued their degrees through fellowships supported by their governments and were obliged to go back. All other graduated international students stayed in the United States.

ITAR effectively limits foreign student participation in civilian commercial projects and in research and development in some areas of space science and space technology. Many industrial leaders and university administrators have been arguing for some time in favor of relaxation of these export control restrictions viewed as counterproductive and for facilitating the path for graduating foreign nationals to obtain permanent residency status and to stay in the United States. The current ITAR arrangements emerged, in part, as a result of the unanimous bipartisan report ("Cox Report") on technology export incidents by the select committee of the U.S. Congress [18]. Continuing violations of ITAR by major defense and aerospace companies [1] weaken such arguments and make it harder for Congress to enact consequential changes in the law. Academe also contributed to violations with one university professor convicted to a jail term in 2009. These realities, often ignored rather than addressed head-on by advocates of relaxation, make the meaningful ITAR reform even more complex and politically controversial.

## 5. Looking into future

Space exploration and space applications have been continuously expanding for decades. Many countries are now engaged in space activities or operate purchased commercial satellites. Global space expenditures have been steadily growing for the last ten years. They increased from \$178B in 2005 to more than \$300B in 2012, with annual increases of 7–8% during the last four years [19]. Commercial space is now at least twice as large as government-funded space programs worldwide. Annual insurance premiums for launch and operations of space

systems reached about \$1B in a clear indication of maturing commercial space. While significant expansion in space expenditures relies on many fields of engineering such as, for example, communications, computer sciences, and ground stations, the core expertise in space engineering remains the indispensable anchor that glues together and enables further advancing of this expansion.

The United States still leads the world in space. The last years of the administration of President Dwight D. Eisenhower more than half a century ago had shaped the structure of the American government space programs, which essentially survived in its main features until the present day [20]. The American economy, infrastructure, and national security depend on space more than those of any other country, which brings numerous advantages as well as vulnerabilities. It was noted ten years ago [21] that the United States had been spending on government space programs four to six times more in terms of the fraction of the gross domestic product (GDP) than Western European countries and Japan. (The only exception was France, spending more than other European countries as the fraction of the GDP.) The latest Space Report [19] shows that this substantially smaller commitment by the peoples and governments of these countries remains unchanged. Even self-inflicted loss of direction and vision by the U.S. civilian NASA program during the last five years has not altered this ratio.

What had changed, however, during the last ten years was a rapid advance of space programs, both in exploration and applications, by the People's Republic of China and India. The Chinese program in particular showed major progress and developed capabilities in human spaceflight and military space. In addition, the highly space capable Russia recently stepped up government spending in space activities, particularly in national security, and is building up its space assets.

Commercial space outgrew government programs ten-fifteen years ago. It is now dominated by direct-to-home satellite television broadcasts and communications [19]. Fig. 7 illustrates progress of satellite engineering in this area by highlighting the astounding increase in capabilities of geostationary spacecraft, using as an example one family of communications satellites built by Hughes, now part of the Boeing Company. Other new emerging areas of commercial space, such as space tourism for example, may mature and expand in a similar spectacular way in the future.

The steady increase of the role of space is also reflected indirectly in American academia. Perhaps the best indicator is the growing number of ABET-accredited B.S. programs in aerospace, astronautical, and aeronautical engineering in the United States (Fig. 8; based on ABET data, <http://abet.org>; cited December 13, 2013). One can see that 13 such new programs had earned accreditation during the time period since 1990 that was characterized by initially significant drawdown of the aerospace enterprise after the end of the Cold War. This increase means that universities have been establishing new aerospace departments or upgrading aerospace options in other degrees (such as mechanical engineering) into full-fledged aerospace degree programs although more along

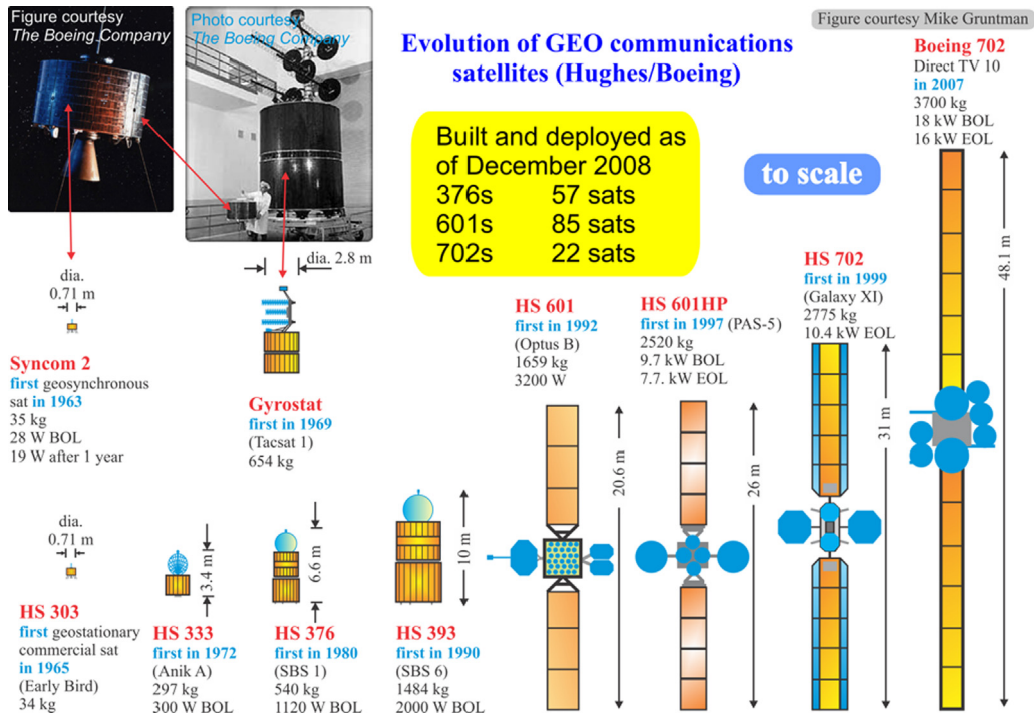


Fig. 7. Spectacular growth of communications satellite capabilities: example of geostationary satellites developed by Hughes/Boeing; BOL – beginning of life; EOL – end of life (M. Gruntman, Space System Fundamentals, Course Notes, 2008; also [20]).

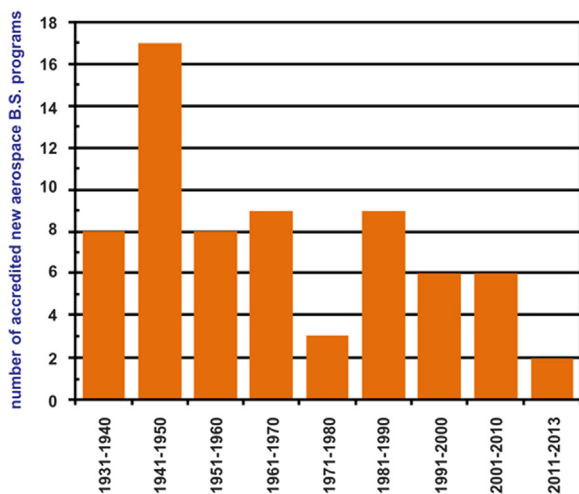


Fig. 8. The number of new bachelor of science degree programs in the broad area of aerospace, astronautical, and aeronautical engineering accredited by ABET in the United States during 10-year time intervals.

traditional aerospace lines and not necessarily focused on space.

Alarming warnings of the forthcoming shortfalls in the aging aerospace engineering workforce have become common during the last twenty years in the United States [1]. The sky has not fallen however, and the space segment of the industry has been growing. These trends suggest that the importance of space will increase with various careers available for engineers with degrees in astronautics.

Today, there are the total of 68 ABET-accredited Bachelor of Science degrees in the areas of aeronautical, astronautical, and aerospace engineering in the United States (<http://abet.org>; cited December 13, 2013). Six universities offer degrees in aeronautical engineering and 59 in aerospace engineering (called at a few universities “aeronautical and astronautical engineering”).

Forty years ago there was only one B.S. degree program in astronautical engineering in the country at the U.S. Air Force Academy, accredited in 1973. Today, there are three such accredited programs with the addition of our program at USC and the other in the Capitol College in Maryland.

In 2007, there were only three institutions offering Master of Science degree in astronautical engineering in the United States [1]. Two such degrees were offered by graduate institutions of the Military Services, the Air Force Institute of Technology (AFIT) and the Naval Postgraduate School (NPS). Our program at USC became the third to offer the M.S. ASTE degree, the first by an American civilian university. The Capitol College also recently joined this group offering its Master's degree.

Many spacefaring nations across the world established extensive educational programs in space science and engineering. Their approaches naturally differ from those in the United States and they are beyond the scope of this article. We briefly mention here that perhaps the most important example is the highly space capable Soviet Union of the past which poured enormous resources into ballistic missiles and space. The People's Republic of China largely copied the Soviet system in 1950s and developed its engineering education along similar lines.



Both countries established separate institutions of higher technical learning in particular engineering areas (railroads, aviation, metallurgy, mining, etc.) as well as polytechnic institutions combining multiple engineering fields. Only few engineering schools were within universities.

The Soviet Union created a number of colleges (faculties) focused on training scientists and engineers for ballistic missile and space programs, following the government decree of 1946 [22]. These specialized faculties were usually hosted by leading institutions of higher technical learning located near major rocket and space design bureaus and production plants (Moscow, Leningrad, Kuybyshev, Krasnoyarsk, Omsk, Dnepropetrovsk, etc.). The faculties produced many thousands of engineers educated specifically in the areas of rocketry and space technology. (Based on coursework and duration of studies, degrees of Engineer in the Soviet Union roughly corresponded to a Master's degree in the United States.)

For example, the space engineering faculty of the Moscow Aviation Institute (MAI), one of the space education institutions in Moscow, had been graduating more than 500 space engineers each year by early 1990s; it employed more than 170 full-time faculty members [23]. In Ukraine, the Physical-Technical Faculty of the Dnepropetrovsk State University (supporting the Yuzhnoe Design Bureau and the Yuzhmash rocket plant) trained 20 thousand space and rocket engineers in the 50 years since 1952 [24,25]. Space educational programs in Russia and Ukraine are currently evolving, e.g., [25,26], to adjust to changing conditions. A number of universities and technical institutions in the People's Republic of China award degrees in space engineering.

Numerous specialized graduate programs in space engineering have emerged in Europe, Asia, and South America. In an interesting experiment, six universities from six European countries – Cranfield University in England; Czech Technical University in Prague, Czech Republic; Helsinki University of Technology in Finland; University of Wurzburg in Germany; Luleå University of Technology in Sweden; and Université Paul Sabatier in Toulouse, France – combined their efforts to establish a degree program in space engineering. This Joint European Master in Space Science and Technology has expanded to include additional universities in Europe, Asia, and North America. Some European universities, e.g., [17,27], experiment with specialized space systems engineering programs in cooperation with industry.

At USC, we plan to further grow the M.S. ASTE program, extending its reach to students across the United States and abroad and offering relevant coursework. We have identified a number of new courses, listed in Section 4.1 above, that could supplement and expand the existing program. As the scope and balance of government and commercial space activities shift, it is essential to adjust our offerings. While we stay focused on the program core of satellite systems and their subsystems, the role of courses related to commercial space will expand reflecting national and international trends. In addition, we clearly see the importance of complementing the existing program by bringing attention of students to major emerging issues such as space debris as well as focusing on the most

important applications such as communications and navigational systems. As the long-term strategic U.S. national goals in space exploration eventually settle, it will be essential to offer the coursework specifically supporting such programs.

## 6. Conclusions

Today, space affects government, business, and culture [20]. Many countries project military power, commercial interests, and national image through space missions. It is a truly high-technology frontier, expensive and government-controlled or government-regulated. Space has become an integral part of everyday lives of people. The worldwide trend of growing expenditures in space exploration and applications, both government and commercial, does not show saturation. This will surely require core space engineering workforce for the space industry and government centers.

Universities contribute to expanding space activities by providing engineering education to the worldwide space enterprise. The establishment of a separate independent space-focused Department of Astronautical Engineering at USC in 2004 was a practical approach to achieve the desired flexibility within the constraints of the American academe. Highly motivated engineers who work full-time in the space industry and government centers and pursue Master's degrees part-time can freely choose among numerous available high-quality programs in the United States. Many enroll in the USC M.S. ASTE program. The program growth in this competitive environment and the number of awarded degrees validate the value of specialized astronautical engineering education and degrees for the industry. The M.S. ASTE program helps engineers to grow professionally within a highly competitive area. Providing coursework highly relevant to the needs of working professionals is the main challenge for the program and the key for attracting new students.

Our experience at USC also unambiguously shows that academic and administrative independence of the space engineering program is essential for its success. Does it suggest that each traditional aerospace department should branch off its space-focused groups of faculty? The answer is negative. It does mean however that there are circumstances when departments offering degrees in astronautical engineering could be the answer to educational challenges. Coexistence of traditional aerospace departments with the pure-space-focused astronautical engineering departments and purely aeronautical engineering programs will bring the needed diversity of options in meeting national and international educational goals. The resulting competition will force the balanced self-adjusting mix of engineering education and degrees determined by the realities of the evolving space enterprise.

The experience of the USC Department of Astronautical Engineering shows that separate pure-space-focused space engineering departments will be successful; will significantly contribute to space engineering education; and will play an important role in meeting the challenges of space engineering workforce development of the future.

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The views expressed in this article are those of the author.

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