# Astronautics at USC

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## Master of Science in Astronautical Engineering degree at the University of Southern California for the space industry



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#### ABSTRACT

The Department of Astronautical Engineering at the University of Southern California (USC) focuses on space engineering education. It is a unique space-engineering program in the United States where such studies usually constitute parts of aerospace departments. In addition to full-time on-campus students, its flagship Master of Science in Astronautical Engineering degree program reaches working professionals online through distance education. The growth of this space-focused graduate degree program led to the establishment of a new independent department at USC twenty years ago in 2004. Since its founding, this Department of Astronautical Engineering awarded nearly one thousand Master's degrees to students from across the United States, Canada, and selected locations abroad. The article describes the origin, rationale, focus, structure, coursework, and reach of USC's Master of Science in Astronautical Engineering program. It concludes with the lessons learned in program development which contributed to its success.

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#### 1. Introduction

Twenty years ago in June 2004, the University of Southern California (USC) established a new independent academic unit focused on space engineering [1-3]. This development contrasted with the dominating tradition in the academia in the United States to combine aeronautical and astronautical disciplines in aerospace engineering programs [4]. The establishment of a pure-space engineering department culminated the multi-year effort to develop a sustainable independent astronautical engineering program that had begun in the middle of the 1990s [1]. This logical step followed the earlier advocacy in the 1970s and 1980s for a separate curriculum in "pure" astronautics leading to a Bachelor of Science (B.S.) and higher degrees in astronautical engineering [1,2,5,6].

To form the new department, the growing astronautics specialization split from USC's Department of Aerospace and Mechanical Engineering and then expanded and solidified. Within one year, the Department of Astronautical Engineering (ASTE) in the Viterbi School of Engineering (VSOE) introduced the full set of degrees (Bachelor, Bachelor Minor, Master, Engineer, Ph.D., and Graduate Certificate) in astronautical engineering. (The USC School of Engineering was named after Dr. Andrew Viterbi in 2004.) The growth of the new ASTE department and student interest in its programs proved that pure-space-focused engineering academic units could

\* Corresponding author. E-mail address: mikeg@usc.edu be successful in a highly competitive educational field of more than seventy aerospace-related programs offered by U.S. universities [2].

This article describes the largest educational component of the Department, its flagship degree program Master of Science in Astronautical Engineering (M.S. ASTE). The degree specifically focuses on the workforce development needs of the space industry and government space research and development centers. In addition to traditional, "legacy" space and defense companies, the rapid growth of commercial space brought many new participants and startups pursuing various applications and developing space technology. Serving this expanding sector is among the important goals of the program. The comparison of USC's M.S. ASTE degree with other U.S. and foreign educational programs in space engineering is beyond the scope of this article. The course offerings in space safety and plans for meeting associated educational needs in the future are noted in Section 3.3.

The growth of this USC Master's program led to the establishment of the new department, an event that rarely happens in well-established engineering schools. The M.S. ASTE program combines on-campus students studying full-time and those who work full-time and study part-time through VSOE's Distance Education Network, DEN@Viterbi. Online coursework delivery has become an integral feature of workforce development and continuing education in the U.S. space and defense sectors. Today, online students account for one-half of the earned Master's degrees in astronautical engineering.

The article first briefly outlines the rationale for establishing the new independent department. Then it describes the M.S. ASTE program structure, admission requirements, coursework, students, instructors, online reach to working professionals and its place in broader aerospace education and workforce development for the global space enterprise. The article concludes by discussing the lessons learned in program development and operations which contributed to its success.

#### 2. Space engineering at USC

Earlier publications [1,2] described the USC Astronautics Program and the rationale for breaking the tradition and forming an independent pure-space-focused engineering academic department. Briefly, the beginning of the space age in the 1950s led to the expansion of the engineering field into new areas of technology and changing the names of many existing aeronautical engineering departments at universities to "aerospace" or some variant of "aeronautics and astronautics" [4]. The curriculum, however, continued to emphasize fluid sciences and engineering and aeronautical applications. Academic departments added some coursework in space-related topics, primarily in orbital mechanics and rocket propulsion, but the space curriculum remained limited in many universities.

At the same time, the U.S. space effort greatly expanded in national security, space science, and space exploration. Today, this growth trend continues, increasingly driven by commercial space. Space technology contributes to the expansion of engineering education, resulting in the establishment of new university departments and programs in the aerospace field. In 2022, the world space enterprise reached nearly \$550B annually [7]. The space sector employs now more than 200,000 people in the United States alone [8].

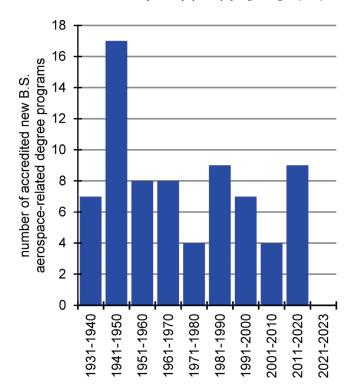
The Accreditation Board for Engineering and Technology [9], ABET, recognized astronautical engineering as separate from aerospace degree in the 1970s. ABET accredits Bachelor of Science (B.S.) degrees in engineering. Engineering Master of Science (M.S.) degrees in American universities do not undergo accreditation. The only exception is Master's degrees in a couple of military educational institutions as specifically required by law dating back to the early 1950s [1,10].

By the end of 2023, the number of ABET-accredited Bachelor of Science degrees in aerospace-related areas in the United States exceeded 70 [9]. This group includes four B.S. degrees in aeronautical engineering and three in astronautical engineering. The latter three degrees are offered by the U.S. Air Force Academy (the very first accredited B.S. degree in astronautical engineering in 1973), Capitol Technology University (formerly Capitol College), and USC. In addition, ABET also accredited three aerospace-related Master's degrees in military educational institutions in the United States and 11 Bachelor's and Master's degrees in foreign countries [9].

Fig. 1 shows the steadily growing number of accredited new aerospace-related B.S. degrees in the United States through the ups and downs of the aerospace industry since the 1930s. The trend illustrates the response of the educational field to the growth of the aeronautical and then space enterprise.

In the 1990s, aerospace engineering at USC was rather typical for the country. The university is in Los Angeles at the center of a major cluster of space and defense companies and government research and development centers. At that time, most of the faculty of the then Aerospace Engineering Department focused on fluid dynamics research in aeronautical fields since its founding in 1964 [11].

On a historical note, the first man on the moon, astronaut Neil Armstrong, was among the most renowned USC aerospace graduates of the 1960s (Fig. 2). He had studied part-time in the 1950s



**Fig. 1.** New Bachelor of Science degrees in the broad area of aerospace, aerospace-related, aeronautical, and astronautical engineering accredited by ABET in the United States during 10-year time intervals. No new programs have been accredited in the early 2020s (2021–2023). Based on ABET data [9].

and early 1960s while stationed as a research pilot at a NASA center at the Edwards Air Force Base in California [2,3,12]. Armstrong then transferred to Houston in Texas after being selected to the second group of NASA astronauts.

After rapid post-World War II growth and large enrollments, aerospace student populations in the United States had dropped by the mid-1990s, following the end of the Cold War [4]. The defiant response of a few astronautics-oriented aerospace faculty at USC to the prevailing doom-and-gloom atmosphere of the 1990s was to found the Astronautics and Space Technology Program (Astronautics Program) [1]. The initiative took advantage of the university's strategic location at a center of space and defense industries in Los Angeles and concentrated first on the Master of Science degree.

The focus on Master's students leveraged the capabilities of the Distance Education Network of the Viterbi School of Engineering that initially reached working engineers across the Greater Los Angeles area through televised classes. Advancement of the Internet allowed today's DEN@Viterbi to transition to webcasting without geographic boundaries [3].

Constrained by the realities of academia, the Astronautics Program built up its coursework relying primarily on part-time instructors, leading specialists working in local companies. Such an approach allowed finding highly qualified lecturers in specialized areas without a lengthy and uncertain process of hiring tenured faculty which would have been very limited in their numbers in any case. In 1996–1997, the faculty formed a new specialization in astronautics within the broader Master's degree in aerospace engineering. Then, the University followed by approving a new Graduate Certificate with a specialization in astronautics in 1997 and, one year later, the astronautical specialization in the Bachelor of Science degree in aerospace engineering.

In 2004, the University of Southern California split the growing Astronautics Program from the Department of Aerospace and Mechanical Engineering and formed a new independent academic



**Fig. 2.** Bronze statue of Neil Armstrong on USC campus. Sculptor: Jon Hair. Photograph (2013) by Mike Gruntman.

unit, today's Department of Astronautical Engineering [1-3]. The author of this article served as the founding chairman of the department from 2004 to 2007 and chaired it again from 2016 to 2019. He has also been directing, without interruption, the Master's program since its inception in the middle of the 1990s until this day.

The experience with the growing Astronautics Program led to a call for the establishment, in some universities, of separate pure-space-focused engineering departments to better meet the needs of the space industry and government centers [1]. Such independent astronautical engineering academic units could shift the existing (rarely fair) competition 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 that creating astronautical engineering departments presented a practical approach to achieving the desired flexibility in the broad aerospace engineering education field under the constraints of realities of the glacially-changing academia burdened with significant inertia and internal politics [1]. The resulting competition among the existing aerospace and aeronautical departments and new astronautical departments of

various universities would then naturally force a balanced mix of the offered programs, determined by national and international educational needs, and thus better respond to the engineering workforce development challenges of the global space enterprise.

During the two short decades since its founding, the new space-focused Department of Astronautical Engineering awarded (as of summer 2024) more than 270 Bachelor of Science degrees, nearly one thousand Master of Science degrees, over 50 PhDs, and nearly 20 graduate certificates in astronautical engineering.

On-campus student opportunities include participation in faculty research as well as in student groups such as the Rocket Propulsion Laboratory (RPL) which builds and launches solid-propellant rockets [13] and the Liquid Propulsion Laboratory (LPL) developing liquid-propellant rocket engines [14,15]. In 2019, RPL distinguished itself by becoming the first student group in the world sending a rocket above the Kármán line at the 100 km altitude [16]. LPL has been designing, building, and testing liquid propulsion engines with increasing sophistication [15,17-19], including regeneratively cooled 3D-printed engines using kerosene and liquid oxygen.

The Space Engineering Research Center (SERC) [20], operated jointly by the Department of Astronautical Engineering and VSOE's Information Sciences Institute (ISI), actively involves astronautics students in its programs. The Center emerged from an initiative to create a "Bell Labs of Space" in the early 2000s to advance science and engineering for cost-effective government microsatellite systems which subsequently expanded into other related areas of space technology and specialized workforce development [2]. Later, SERC changed its focus away from the initial objectives toward student-centric space projects [21,22], including cubesats and other programs.

The comparison of USC's M.S. ASTE degree with other U.S. and foreign educational programs in space engineering is beyond the scope of this article. (Some details of these programs are discussed in [2] and references therein.) We only note here that two leading spacefaring nations, the former Soviet Union (the Union of Soviet Socialist Republics, or U.S.S.R.) and the People's Republic of China (PRC), established many pure-space-focused educational institutions graduating numerous space engineers each year. After the end of the Cold War, the Russian Federation and Ukraine (the successor states of the U.S.S.R. with substantial space and rocket capabilities), scaled down these programs. At the same time, the PRC significantly expanded its space activities in national security, scientific, and application domains. Several specialized graduate programs in space engineering also emerged in Europe, South America, and elsewhere in Asia during recent decades.

We focus below on the Master of Science in Astronautical Engineering degree at USC which remains the largest program in the Department of Astronautical Engineering and can be earned by studying on campus or online.

## 3. Admission requirements and degree coursework

3.1. Admission requirements to master of science in astronautical engineering

The USC M.S. ASTE degree is open to qualified students with Bachelor of Science degrees in engineering, mathematics, and hard sciences from regionally accredited universities. In addition to satisfactory grade point average (GPA) and general record exam (GRE) test scores, applicants also provide two letters of recommendation. During the Covid pandemic, USC suspended the GRE requirements. The restoration of the quantitative GRE metric in applications is essential for preserving the quality of the program and avoiding a slide to harmful social engineering in admissions, with the associated inevitable decline.

In an important distinction from many aerospace programs, applying students do not need to have aerospace-related Bachelor's degrees. The modern space industry and government centers employ engineers of diverse backgrounds who have majored in various areas of science and engineering. Many full-time working engineers strive to continue their education part-time in the space technology field directly relevant to their industry. The M.S. ASTE program opens a path for them to earn a Master's degree in astronautical engineering without prior undergraduate aerospace coursework. Students graduating with non-aerospace Bachelor's degrees can also continue their full-time studies by enrolling in the M.S. ASTE program to prepare for careers in the space enterprise.

The M.S. ASTE degree requires taking an overview course on the fundamentals of space systems (Spacecraft Systems Design). It addresses the challenge of admitting students with non-aerospace backgrounds. The course serves the role of a "rocket-science boot camp." It provides scientific and engineering basics of space systems and rocketry, introduces nomenclature, covers fundamentals of main spacecraft subsystems, and prepares students for specialized coursework in various areas of space technology [23]. The course is also popular among engineering graduate students pursuing degrees in non-space areas but planning to gain employment in the space industry. More than 2400 graduate students have taken this course at USC since 1996 when the author of this article had begun teaching it.

Today, USC's M.S. ASTE students consist of 40% of those with an aerospace-related undergraduate background; 35% with Bachelor's degrees in mechanical engineering; 10% in physics, astronomy, and astrophysics; 5% in electrical engineering; and the remaining 10% spread across all possible flavors of engineering and science. The M.S. ASTE program also occasionally attracts students with non-technical degrees such as medical doctors.

In cases of limited science and engineering educational background, students are asked to take, before applying to the program, typical undergraduate courses in mathematics and physics required in engineering majors. The applicants usually complete such coursework, conveniently and inexpensively, in local community colleges.

## 3.2. Program coursework

The required M.S. ASTE coursework consists of nine courses, or 27 units, with semester-long graduate classes being 3 units each. The program usually offers up to a dozen astronautics courses each semester [24]. Practically all graduate courses are available online.

To earn the degree students must take (i) four required courses (a total of 12 units); (ii) three core elective courses (9 units); and (iii) two technical elective courses (6 units).

The required courses include three broad overview courses on the fundamentals of space systems; rocket and spacecraft propulsion; and space environment and spacecraft interactions. The fourth required course is in orbital mechanics. Core elective courses are chosen from the space-focused courses offered by the program.

The remaining two technical electives could be selected from these space courses or, if desired, from graduate courses outside the home department. The majority of students choose technical electives from the offerings by the M.S. ASTE program as these courses are often among the main reasons for their enrollment in the program in the first place.

Practically all graduate science and engineering courses from other departments are automatically approved as technical electives except for a small number of courses in non-traditional areas such as management of engineering projects and alike. The Master of Science in Astronautical Engineering degree is not a degree in system engineering, system architecting, or space studies [2]. Stu-

**Table 1**Astronautics courses offered for graduate credit. Elective courses are grouped thematically.

## Course required Spacecraft System Design Space Environment and Spacecraft Interactions Orbital Mechanics I Rocket and Spacecraft Propulsion core electives and electives Orbital Mechanics II Space Navigation: Theory and Practice Solar System Navigation Spacecraft Attitude Dynamics Spacecraft Attitude Control Liquid Rocket Propulsion Solid Rocket Propulsion Advanced Spacecraft Propulsion Physical Gas Dynamics I, II Space Launch Vehicle Design Spacecraft Structural Dynamics Spacecraft Structural Strength&Materials Spacecraft Thermal Control Spacecraft Power Systems Systems for Remote Sensing from Space Spacecraft Sensors Design of Low Cost Space Systems Space Studio Architecting Entry and Landing Systems for Planetary Exploration Human Spaceflight Human Factors in Spacecraft Operations Spacecraft Life Support System Safety of Space Systems and Space Missions

dents with particular interests in such areas are advised to change their major to meet their educational objectives.

Reliability of Space Systems

Safety of Space Operations

Computational Plasma Dynamics

Plasma Dynamics I, II

A typical 3-unit course consists of 13–14 weekly three-hour lectures and two exams, midterm and final. It requires approximately six hours of additional self-studies each week. Instructors and teaching assistants hold regular office hours to help students. Self-studies include required and recommended reading and weekly homework assignments as well as term papers and projects when appropriate.

Some core elective courses provide introductions to spacecraft subsystems and do not require prerequisites. More specialized courses have prerequisites. For example, a course in advanced propulsion would require, as a prerequisite, an introductory course in propulsion, and a course in space navigation would require an orbital mechanics course.

Some students, particularly those with aerospace Bachelor's degrees, have been exposed during their undergraduate studies to subjects covered by the required courses such as, for example, rocket propulsion and orbital mechanics. In such cases, the required courses are waived, and students take additional technical electives instead. A Master's thesis is not a requirement but an option for on-campus students. For online students, writing a thesis is not practical.

Table 1 shows the current list of astronautics courses offered for graduate credit. All required courses are available once or twice each year. The M.S. ASTE program offers core elective and elective courses every year or every two years, depending on student interest [24]. The existing coursework covers many space technology areas. We strive to introduce new engineering fields to close current gaps in the curriculum. For example, the areas of recent growth in-

cluded human spaceflight and safety and assurance of space missions

The availability of qualified instructors, budgets, and constraints of distance education infrastructure limit the introduction of new courses. Even maintaining the current offering of nearly 30 astronautics courses presents a major operational challenge since our instructors occasionally develop scheduling conflicts or relocate to other parts of the country to pursue their professional careers.

#### 3.3. Areas of concentration

Students themselves determine the sequence of courses to take, with the help of faculty and staff advisers. Many begin their studies with the required courses. These broad courses help them better understand the scope of space technology. The students may subsequently change their initial selections for specialized coursework based on improved knowledge of the role of various engineering areas in space systems and operations.

Typically, students focus their studies in the desired areas by selecting corresponding core and technical elective courses. The thematic grouping of currently offered courses (Table 1) suggests possible areas of concentration. The USC catalog lists such areas as spacecraft propulsion, spacecraft dynamics, space system design, spacecraft systems and operation, space applications, safety of space systems, and human spaceflight [24]. Some elective courses contribute to studies in multiple areas. For example, the program suggests a course in space launch vehicle design for those interested in spacecraft propulsion and spacecraft systems and operations

Some areas of study are traditional such as propulsion and space dynamics. Other suggested concentrations are in space technologies and operations that are becoming increasingly important. Twenty years ago, work in human spaceflight was mainly done by NASA and a small number of industrial contractors. Today, several companies advance their human spaceflight programs, fetching astronauts to orbit on a commercial basis and planning an expansion of human presence in space for work and pleasure. Realizing the importance of human spaceflight, USC and several other universities added former astronauts to their faculty to develop and offer the corresponding coursework.

Another rapidly growing area of space mission assurance, safety, and reliability [25-27] urgently needs expansion of the related engineering education. With the rapid growth of commercial space, the number of companies building and operating satellites and providing space launch services skyrocketed. Many companies entered the field, including startups, to pursue various space applications and develop space technology. Thousands of satellites are launched every year, resulting in the challenge of managing space traffic and assuring safe operations. At the same time, government agencies are slow to establish supportive regulatory environments in this highly specialized and demanding area of technology.

To respond to this need, the USC M.S. ASTE program has outlined an area of concentration in the safety of space systems. Today, three courses are offered on the safety of space missions and operations and reliability of space systems. This domain thrust is still in the development stage. The addition of a few new related courses to the already developed coursework should allow the establishment of a graduate certificate in space safety engineering in the future, which would contribute to the needs of the space enterprise.

## 4. Program instructors, students, and online education

#### 4.1. Full-time faculty and part-time lecturers

The Master of Science in Astronautical Engineering program combines regular full-time faculty and part-time instructors. The full-time faculty primarily focus on basic science and technology such as gases and plasmas, space environment and space science, human spaceflight, and fundamentals of spacecraft design and rocket and spacecraft propulsion. Instruction in many specialized topics of satellite subsystems relies on part-time lecturers who are recognized practicing experts in the industry and government space research and development centers. They bring important real-world experience in rapidly changing areas of technology. Several part-time instructors with strong academic records are promoted to adjunct faculty.

The Los Angeles area offers access to the unmatched wealth of first-rate specialists in space technology. Fig. 3 shows many books published by USC Astronautics faculty and lecturers. The part-time instructors are a great strength and pride of the program.

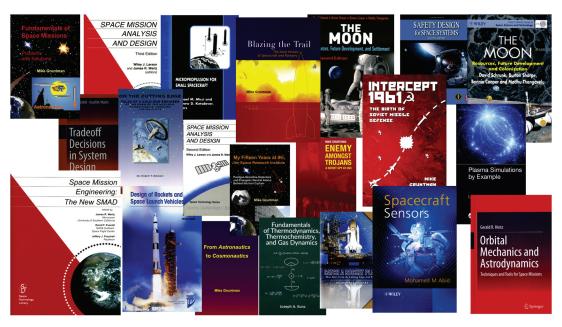
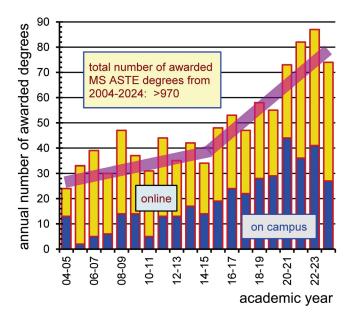


Fig. 3. Some books by USC Astronautics faculty and lecturers.



**Fig. 4.** Annual numbers of awarded Master of Science in Astronautical Engineering degrees to students studying part-time online (upper light bars) and full-time oncampus (lower dark bars) since the founding of the independent Department of Astronautical Engineering at USC in 2004. The total number of the awarded Master's degrees (as of summer 2024) approaches one thousand.

They work in government centers, industrial legacy powerhouses, and innovative small space companies, including The Aerospace Corporation, NASA's Jet Propulsion Laboratory, Boeing, Lockheed-Martin, Northrop-Grumman, Aerojet-Rocketdyne, Microcosm, and Space Environment Technologies.

## 4.2. Master's students

The M.S. ASTE program attracts both full-time on-campus students and students who work full-time and study part-time. Full-time students usually take three courses each semester and achieve their degrees in 1.5 years. Full-time working students who study part-time typically take one course (sometimes two) per semester. For them, it takes 3–5 years to earn the degree. They study through VSOE's Distance Education Network, DEN@Viterbi, even if they reside within a driving distance from the campus near downtown Los Angeles. Many Master's classes take place in the evenings which allows working students to occasionally attend lectures in person.

Online studies toward M.S. ASTE and DEN operations and facilities are described in detail in [3]. It is important that one can earn the degree without the need to ever visit the campus. Many students would fly, however, to Los Angeles to attend festive commencement ceremonies and receive their diplomas in person [28].

The educational background of astronautics students is truly diverse as the program does not require aerospace-related undergraduate coursework and admits students with Bachelor's degrees in hard sciences and all areas of engineering. Some online students already have their Master's degrees in non-space areas of engineering, and they successfully work in the space industry. Gaining a better understanding of space-specific concepts and technologies by obtaining the M.S. ASTE degree often opens pathways for advancing to leadership positions in major space programs and system engineering. In addition, students with doctorates in science and engineering as well as medical doctors sometimes enroll in the program to improve their chances of being selected for astronaut training.

Fig. 4 shows the annual numbers of the awarded Master of Science in Astronautical Engineering degrees. Today, the program graduates consist of roughly equal numbers of full-time and online part-time students. As of summer 2024, the total number of awarded M.S. ASTE degrees since the establishment of the independent department in 2004 approaches one thousand (it is larger than 970). In addition, more than one hundred Master's degrees in aerospace engineering with a specialization in astronautics had been awarded before 2004. Today, the Master's program brings about \$6 M in tuition revenues annually.

The number of students who work full-time and study online (upper light bars in Fig. 4) remained relatively steady throughout the two decades. Initially, the overwhelming majority of such students worked at legacy space and defense companies (Boeing, Northrop-Grumman, and others) and government research and development centers (NASA, Air/Space Force). Today, increasing numbers of students have been coming from smaller, space-focused companies.

Since the inception of the department, the number and fraction of full-time on-campus students increased significantly (lower dark bars in Fig. 4). This reflects the growing program reputation which has overcome the initial reluctance by "freshly" graduating students with Bachelor's degrees to enroll in a pure spacefocused astronautical engineering program, viewed as a smaller niche by some. Then, they chose the departments awarding traditional aerospace degrees. The space industry significantly expanded during the last two decades (Section 6 below), and students now feel comfortable pursuing a degree in astronautical engineering. In addition, students are eager to participate in the department's student groups, particularly the Liquid Propulsion Laboratory [14,15], and take advantage of research opportunities at the Space Engineering Research Center [20]. Interactions with and mentorship by full-time faculty remain indispensable for the educational experience of on-campus students.

A fraction of full-time on-campus M.S. ASTE students are in the Progressive Degree Program, or PDP (sometimes referred to as the 4 + 1 program). In this program, high-performing upper-division undergraduate USC students can earn some credits toward engineering Master's degrees by enrolling in graduate courses while completing their Bachelor's degrees. Consequently, a student can obtain both a Bachelor's degree and a Master's degree after 5 years of full-time studies rather than after the typical 4 years of undergraduate studies followed by 1.5 years in a graduate program. Students can also combine their non-aerospace Bachelor's major with a Master's degree in astronautical engineering to prepare for space-engineering careers. Today, PDP students account for one-quarter of Master's degrees awarded to full-time on-campus students.

Many space-related government and industrial programs in the United States are subject to export control International Trafficking in Arms Regulations (ITAR) [29]. These regulations resulted, in part, from the evaluation (unanimous bipartisan "Cox Report") of technology export incidents by the select committee of the U.S. Congress [2,30]. Violations of ITAR by aerospace and defense companies [1] make any meaningful reform of these regulations politically controversial and thus unlikely in the near future.

All university classes, including in astronautics, are open to students regardless of their nationality. Outside the coursework, participation in research and development projects that are externally funded by government agencies and industry must often comply with the ITAR restrictions. These regulations require involved students to be U.S. persons (in the language of the statutes). In addition, it is harder, but not impossible, for international students to find internships and later, after graduation, employment in the space industry.

Publications [1-3] discuss some effects of ITAR on the Master's program in astronautics. The overwhelming majority of our on-

line students work in the United States. Consequently, they are U.S. citizens or permanent residents. The fraction of foreign nationals among full-time on-campus M.S. ASTE students is smaller than in many other engineering departments of the university. Students from foreign countries are aware of the ITAR restrictions and thus often choose other engineering majors. Nevertheless, foreign students enroll in the M.S. ASTE program. They also include those on government fellowships from their home countries. Since 2004, students from nearly twenty countries in Asia, the Americas, Europe, and Africa earned degrees in astronautical engineering [2,3].

#### 4.3. Role of distance education

Continuing education with high-quality online coursework delivery plays a particularly important role in workforce development in the U.S. industries. Student interest in online education continues to grow. At the same time, changes in industry have made a Master's degree desirable and even indispensable for a successful lifelong technical career. Consequently, many leading technology-oriented companies and government centers hire graduating engineers with Bachelor's degrees and support their pursuit of Master's degrees part-time while working full-time. Tuition coverage for such studies has become part of standard compensation in space and defense industries.

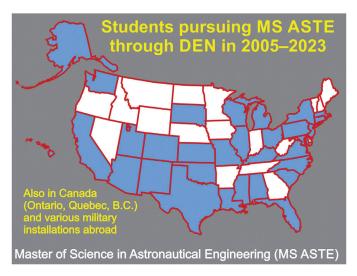
Online education also opens a way for engineers who obtained their Bachelor's degrees five, ten, or more years ago to resume their education part-time and earn a graduate degree. Such studies improve chances for "lateral moves" to more attractive and interesting areas of work within large companies as well as for promotion in a highly competitive environment.

The USC Viterbi School of Engineering began developing modern distance education, a concept of a "university without walls," in the late 1960s [12]. The Federal Communications Commission granted permission for using transmitters on Mount Lee located only one hundred meters away from the iconic Hollywood Sign seen from Los Angeles. VSOE's Instructional Television Network (ITV) inaugurated direct television broadcasting (telecasting) of courses to local aerospace companies in the Greater Los Angeles area in 1972. The course delivery technology has been evolving throughout the years. In the 1990s, transponders on geostationary satellites extended ITV's reach to students outside Southern California. Finally, the Distance Education Network, today's DEN@Viterbi, transitioned to "webcasting," streaming compressed video and audio over the Internet [2,3]. Today, the Viterbi School offers over 40 graduate engineering degrees online.

Distance education is particularly convenient for working professionals who balance their work responsibilities (sometimes with lengthy job-related travel), other professional activities, and family life. The full-time students attend class lectures on campus that are being simultaneously webcast live to online students. DEN technicians then place the captured webcasts on the School's servers. While some online students watch lectures live on their desktop computers, laptops, tablets, and mobile devices, others view them asynchronously at convenient times.

All students, on-campus and online, have full unlimited access to all class-related lectures and other materials. They submit their homework and receive graded homework electronically. Full access to the recorded lectures until the final exam at the end of the semester offers excellent opportunities for reviewing various topics, especially those presenting difficulties, as many times as desired. These well-developed distance education capabilities proved particularly helpful during the recent Covid pandemic when remote learning temporarily replaced in-person instruction.

As a matter of policy, the Viterbi School of Engineering does not distinguish between on-campus and online students. The requirements for the degrees, admission to the programs, course-



**Fig. 5.** Students pursuing Master of Science in Astronautical Engineering degrees online through DEN@Viterbi reside in many states (dark color) as well as in Canada and are stationed at military installations abroad.

work, homework, exams, and evaluation of student performance are identical for all students. Online students have access to instructors, teaching assistants, and classrooms as their on-campus peers. All graduate students are held to the same standards and are expected to show the same dedication toward their education.

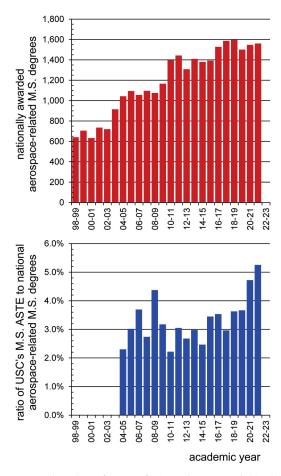
Today, about one-half of M.S. ASTE graduates are online students (Fig. 4). Fig. 5 shows the geographic reach of the program. Astronautics students work all over the United States as well as in Canada. Students on active military duty sometimes study in foreign countries where they are deployed. In addition to early career officers, the M.S. ASTE program attracts those who plan to leave the military service in their 30s and 40s. They prepare for new civilian careers in industry, with space engineering being among the appealing areas. More details of the structure and operations of the online education program in astronautics are provided in [3].

## 5. M.S. ASTE and national aerospace programs

The American Society for Engineering Education, ASEE [31], compiles the national statistics in aerospace engineering education [32]. In addition to more than 70 ABET-accredited aerospace-related Bachelor's degree programs in the United States (Fig. 1), ASEE identified 52 programs that awarded aerospace-related Master's degrees in the academic year 2021–2022 [33]. This number of programs includes aerospace engineering and aeronautical engineering degrees as well as degrees in "aeronautics and astronautics." In a quirk of accounting, ASEE lists M.S. ASTE among "other engineering disciplines" [32]. (ASEE counts the Master's program in astronautical engineering at the Air Force Institute of Technology in the aerospace category. The Institute usually awards one dozen degrees annually.)

Fig. 6 (top) shows the annual numbers of nationally awarded Master's degrees (without USC M.S. ASTE) in the United States in aerospace-related areas from 1999 to 2022 [34-40]. (Note that statistical data become available with delays, especially on the national level.) The numbers were nearly flat at the levels of 700 and 1100 per year during 1998–2003 and 2005–2010, respectively. They reached 1400 per year around 2011 and remained constant for several years. The last five years show a small uptick to 1500 in the annually awarded degrees.

Fig. 6 (bottom) shows the ratios of USC's M.S. ASTE degrees to the number of aerospace-related degrees awarded annually in the

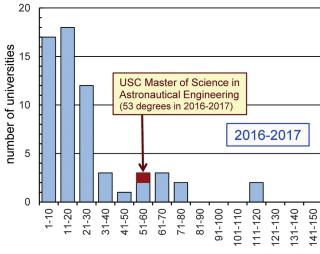


**Fig. 6.** Top: annual numbers of Master of Science degrees awarded in the United States in aerospace-related areas from 1999 to 2022 (based on ASEE data [34-40]). USC's M.S. ASTE is not included in these numbers in a quirk of accounting. Bottom: the ratios (expressed in percentages) of USC's M.S. ASTE degrees to the number of aerospace-related degrees (figure top) awarded annually in the United States since the founding of the independent Department of Astronautical Engineering in 2004. For 52 programs listed by ASEE, the average aerospace engineering program would account for about 2% of the total number of Master's degrees.

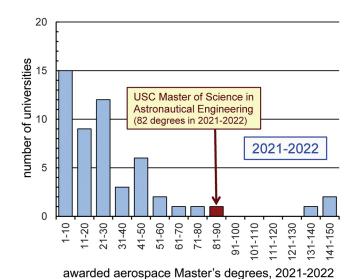
United States since the founding of the independent Department of Astronautical Engineering in 2004. For many years, this fraction was at the level of nearly 3 % which is larger than the average aerospace-related program in the country. (The average size would be close to 2 % for 52 programs.). During the last two years of the available national data, academic years 2020–2021 and 2021–2022, the ratio of USC's degrees accounted for 4.5–5 %, more than twice as large as the average aerospace-related Master's degree program. The USC share would be 5 % or above in the academic year 2022–2023.

ASEE does not capture the separate numbers of awarded degrees in space-focused engineering. Therefore, one can only compare USC's M.S. ASTE program with other Master's programs in the broad aerospace-related field dominated by non-space areas. Fig. 7 shows the size distributions of such programs in awarding aerospace-related Master's degrees in the United States in the academic year 2016–2017 [3,41] and the year with the latest available data, 2021–2022 (based on [33]).

These latest data for the academic year 2021–2022 show that three Master's programs dominate the aerospace field in the United States: Purdue University (awarded 149 Master's degrees in 2021–2022), Georgia Institute of Technology (143 degrees), and the University of Colorado in Boulder (131 degrees). Purdue and Georgia Tech were also the largest in 2016–2017, awarding 117 and 113



awarded aerospace Master's degrees, 2016-2017



**Fig. 7.** Distribution of the numbers of Master of Science degrees awarded by universities in the broad aerospace area in the United States in academic years (top) 2016–2017 [3,41] and (bottom) 2021–2022 (based on ASEE data [33]). The USC's M.S. ASTE program advanced from sharing the eighth and ninth places in size in 2016–2017 to the fourth pace in 2021–2022.

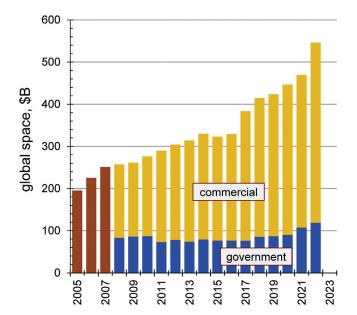
Master's degrees, respectively. University of Washington (78 Master's degrees) and the University of Colorado in Boulder (74 degrees) also stood out in size at that time [3].

The M.S. ASTE program at USC awarded 53 degrees in 2016–2017. It then shared the eighth and ninth places in size. The program advanced to the fourth place (82 degrees) in 2021–2022 (Fig. 7). One can only speculate how it would have ranked in size if only space-engineering specializations were counted—clearly, it would be among the largest.

## 6. Growing space enterprise and education

Today, many countries project military power, commercial interests, and national image through activities in space. It is a truly high-technology frontier, expensive and government-controlled or government-regulated due to security and safety considerations. Space-enabled technologies have become an integral part of people's everyday lives.

Space science, space exploration, and space applications have been expanding for decades. An elite club of countries that have



**Fig. 8.** Annual expenditures on space activities worldwide in billions of current (not adjusted for inflation) U.S. dollars from 2005 to 2022. The average annual growth during these 17 years was 6–6.5%. Beginning from 2008, the figure shows the breakdown between the government and commercial space activities. Based on annual data in Space Reports [43-53] compiled by the Space Foundation [42].

launched their own satellites on their own space launchers has also grown (chronologically): Soviet Union (with its space capabilities inherited by today's Russian Federation and Ukraine), United States, France, Japan, People's Republic of China, United Kingdom, India, Israel, Iran, North Korea, and South Korea. In addition, a number of European countries formed the European Space Agency which has been launching satellites since 1979.

Global space activities have dramatically grown and accounted for nearly \$550B worldwide in 2022 [7]. The fast expansion of commercial space overtook government programs in the 1990s and constitutes today three-quarters of all expenditures on space. Fig. 8 shows the annual increase of 6.0–6.5 % in global space activities during the two decades since 2005 [42-53]. Such data compiled annually by the Space Foundation [42] and published in its Space Report should be viewed as approximate, illustrating the trend. Their methods of assessing expenditures by governments and industry have been evolving with time, some space programs and activities are obscure, and exchange rates of currencies fluctuate. Nevertheless, the data unmistakably show (Fig. 8) a steady increase in spending on satellite systems, space applications, and space launchers, especially in commercial space.

The growing space enterprise relies on a qualified scientific and engineering workforce. The dynamics of steadily increasing expenditures on space thus serves as a leading indicator for the size of the needed supporting educational programs. While a significant rise in space activities draws on many fields of engineering such as communications, materials, structures, and computer sciences, the core expertise in astronautical engineering (space engineering) remains the indispensable anchor that glues together the enterprise and enables further progress. The noted growth in the number of accredited undergraduate aerospace-related programs (Fig. 1) reflects this trend.

During the last two decades, a number of developing countries formed national space agencies, realizing the importance of space for the modern economy, national security, and society. Many more governments and private companies engaged in space activities by purchasing and operating commercially-built satellites for various applications. This development manifests itself in the growing

representation of these entities in the International Astronautical Federation [54]. Traditional space powerhouses dwarf government space programs of the newcomers, however.

Despite the rise of commercial space (Fig. 8), government programs continue to play critically important roles. Large U.S. programs still dominate government space expenditures in the world, accounting for 59 % of a total of \$118.6B in 2022 [55]. They offer broad employment opportunities with the associated need for space science and engineering education. It was noted 20 years ago that governments of industrialized countries in Europe and Japan spent in space, as a fraction of the gross domestic product, four to six times less than the United States [56]. (Historically, France has been spending somewhat more than other European peer countries.) This disparity remains today. Also, as it was twenty years ago, limited budget transparency in two very active in space countries, Russia and China, does not allow accurate assessment of their effort

Commercial space skyrocketed since 2000 (Fig. 8), driven by the deployment of satellite constellations, series manufacturing of satellites, expanding commercial space applications, and gradually declining costs of space launch. New approaches and business practices, in particular by SpaceX and its founder Elon Musk, have played a major disruptive role, catalyzing changes and accelerating progress. Annual insurance premiums for the launch and operations of space systems have been fluctuating between \$400 M and \$800 M annually during the last two decades [57] in another indication of the maturing commercial space.

A large number of new companies emerged during the last two decades to pursue various commercial endeavors in space. Being often called "New Space," they advance applications that emphasize low-cost and sometimes nontraditional approaches. These companies employ many engineers and managers, including those without prior exposure to space technology. It is important for engineering educational programs to reach these "newcomers" in the growing field of space.

The space budgets of governments did not change significantly during that time (Fig. 8). Nevertheless, government programs, particularly in national security, remain critically important for the space enterprise. These programs are often performance-driven rather than focused on cost as common in the commercial world. This emphasis on performance leads to consequential associated advances in the science and engineering of spaceflight.

The last years of the administration of U.S. President Dwight D. Eisenhower more than half a century ago had shaped the structure of the American government space program, which essentially survived in its main features until the present day [56]. The program consists of three main components, civilian space, military space with some unrecognized (in public domain) elements, and space reconnaissance with largely classified budgets.

The Space Foundation assesses the U.S. government space budget at \$69.9 in 2022 [58]. Its civilian component, primarily NASA (\$24B) and smaller contribution of other agencies, accounts for \$26.6B The space activities of the Department of Defense are estimated at \$42.9, including \$17.1B in unclassified spending. These military programs include space reconnaissance. Space Foundation's data also show smaller but growing government military space at \$10.8B in other countries in 2022 [59].

In 2010, the Space Foundation explicitly listed three distinct U.S. space programs in its assessment. It estimated that civilian programs (dominated by NASA) accounted for 33 % of the total government expenditures in space (\$64.4B at that time), military space (Department of Defense) for 41 %, and space reconnaissance (National Reconnaissance Office and National Geospatial-Intelligence Agency) for the remaining 26 % [60]. It is not unreasonable to assume that this ratio between these three U.S. government programs remains approximately the same to this day.

The budgets allocated to missile defense, about \$10B annually in the United States, should also be added to space activities. Missile defense heavily relies on space. Its original programs initiated in the late 1950s led to the emergence of various space-related activities such as space situational awareness (space domain awareness), space-based systems for early warning of ballistic missile attack, and antisatellite weapons [61,62]. More and more countries invest today in strategic missile defense with significant indispensable space components and this trend will continue in the future.

The development of an engineering workforce for government programs with their inherent demand for advanced science and technology is an important consideration for any space education program.

#### 7. Lesson learned and conclusions

The expansion of the global space enterprise during the last decades required an increase in a core engineering workforce for the space industry and government centers, with universities playing a leading role in space engineering education. The establishment of an independent space-focused Department of Astronautical Engineering at USC in 2004 was a practical approach to bringing flexibility to the educational field within the constraints of American academia. The program's steady growth in a highly competitive environment confirms the value of specialized astronautical engineering degrees for the space enterprise. The demand for space-engineering education will continue to grow, especially for companies, including New Space, pursuing commercial applications.

Online distance education helps validate the usefulness of the offered degrees. Continuing education has become the way of life for many engineers in industry, particularly in space and defense. Practicing engineers at legacy companies choose the best online Master's programs to enroll in. Their choice is often influenced by the opinions of senior engineering colleagues with much industrial experience. Therefore, if an online component of a Master's program attracts practicing engineers, then it is an indication that its degrees provide tangible value. Consequently, Internetenabled market competition in distance education among universities is essential for assuring the quality of engineering programs. It provides a test of whether programs meet the needs of the real world. Moreover, pressures of true competition among online programs result in an additional benefit of somewhat mitigating the inevitable harm of a non-merit-based approach to education sweeping U.S. academia, e.g. [3,63-65].

The experience with the development and growth of the Master of Science in Astronautical Engineering degree program at USC points to certain features and approaches that contributed to its success. Among them is administrative independence of the program which is indispensable to reduce unproductive local "political battles" so widespread among fragmented faculty in universities. Then, the availability of qualified outside specialists from the space industry to teach specialized courses as part-time lecturers is highly beneficial and necessary but not sufficient. There should also be dedicated and knowledgeable core tenured faculty to build the program up and navigate it through the university degree and curriculum approval and maintenance processes. The program must respond to the evolving industrial needs and thus show an understanding of current industrial practices. Such knowledge is not widespread among tenured faculty who by the nature of hiring and promotion in academia focus primarily on fundamental science.

Another essential lesson is the importance of building the program's identity. This requires a clear identification of the "customer," that is parts of the space enterprise and types of engineers who would particularly benefit from the offered coursework and

degrees. Clearly defining the areas of technology and putting together, "packaging," the coursework focused on these areas attract students who are searching for programs to achieve their educational objectives. In fact, their objectives are sometimes vague, and an offered well-defined path sometimes helps them in their decisions. The outlined areas of concentration in the USC M.S. ASTE program in traditional fields of propulsion, space dynamics, and space systems and in emerging areas of human spaceflight and space mission safety and reliability serve this purpose. Very few universities have responded to the clear need for educational programs in the latter two engineering areas.

Attention to student feedback represents another indispensable characteristic. Many online students have been working in the space industry for a number of years. Listening to these mature engineers and actively seeking their views could provide important insights into needs in rapidly evolving fields.

On an internal-to-university level, the financial soundness of a program in a highly competitive national and international environment is another critically important feature. Such considerations are alien, however, to many scholars in academia. It is obviously easier to obtain administrative support for experimentation and further program growth if it brings money to an academic school rather than being a burden. The financial strength can only be achieved when a program reaches a certain "critical mass" of students and continuously strives to maintain the interest of potential new students. The student experience during their studies becomes crucial as well because the program's graduates turn, with time, into its best ambassadors. Many new students from space companies and government centers learn about the program and its value from their colleagues who had received our degrees in the past.

To conclude, the experience of the Master of Science in Astronautical Engineering degree program at USC shows that it responds to the needs of space engineering workforce development. Pure space-focused departments and programs can and will contribute in an important way to the global space enterprise.

Ad Astra!

## **Declaration of competing interest**

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## **CRediT authorship contribution statement**

**Mike Gruntman:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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## References

- M. Gruntman, The Time for Academic Departments in Astronautical Engineering, AlAA Space-2007, Long Beach, Calif., 2007, AlAA-2007-6042; also http://astronauticsnow.com/2007aste.pdf (accessed October 20, 2023), doi:10.2514/6.2007-6042.
- [2] M. Gruntman, Advanced degrees in astronautical engineering for the space industry, Acta Astronaut. 103 (2014) 92–105 also http://astronauticsnow.com/ 2014aste.pdf, doi:10.1016/j.actaastro.2014.06.016. (accessed October 20, 2023).

- [3] M. Gruntman, Master of Science degree in astronautical engineering through distance learning, 69-th International Astronautical Congress, Bremen, Germany, 2018 IAC-18-E1.4.11; also http://astronauticsnow.com/2018aste.pdf (accessed October 20, 2023).
- [4] B.W. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, Virginia, 2004.
- [5] R.F. Brodsky, Some ideas for an undergraduate curriculum in astronautics, in: ASEE Annual Conference Proceedings, 1984.
- [6] R.F. Brodsky, The Time Has Come For the B.S. in Astronautical Engineering, Engineering Education, 76, December 1985, pp. 149–152.
- [7] Space Report, Q2 (second quarter), 2023, p. 7 https://www.thespacereport.org/ (accessed November 6, 2023).
- [8] Space Report, Q3 (third quarter), 2023, p. 11 https://www.thespacereport.org/ (accessed on November 6, 2023).
- [9] Accreditation Board for Engineering and Technology, ABET. http://abet.org (accessed October 20, 2023).
- [10] P.J. Torvik, The evolution of Air Force aerospace education at the Air Force Institute of Technology, in: B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, Va. 2004, pp. 786–799.
- ston, Va, 2004, pp. 786–799.
  [11] R.E. Kaplan, Aerospace engineering at the University of Southern California, in:
  B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education
  During the First Century of Flight, AIAA, Reston, Va, 2004, pp. 540–552.
- [12] R.E. Vivian, The USC Engineering Story, USC Press, Los Angeles, Calif, 1975.
- [13] Rocket Propulsion Laboratory. RPL; https://www.uscrpl.com/ (accessed October 20, 2023).
- [14] Liquid Propulsion Laboratory, LPL, Accessed October 20, 2023. https://www.usclpl.com/.
- [15] J.A. Targonski, M.J. Moruzzi, P. Prochnicki, J. Fessl, The objective & strategy behind the University of Southern California's Liquid Propulsion Laboratory, Joint Propulsion Conference, AIAA, Cincinnati, Ohio, 2018 AIAA-2018-4804, doi:10.2514/6.2018-4804.
- [16] D.J. Coote, V. Ahuja, Commercial Crew, Engine Tests Mark an Active Year, Aerospace America, 57 (No. 11), 2019, p. 52.
- [17] J. Fessl, H. Shen, N. Patel, T.W. Chen, S. Ghirnikar, M. Van Den Berghe, Liquid rocket engine design for additive manufacturing, 69-th International Astronautical Congress, 2018 Bremen, Germany, IAC-18-C4.5.10.
- [18] N. Ang, S. Alexandi, J. Tobar, E. Betady, S. Tallapragada, Testing and verification of an additively manufactured liquid rocket engine injector, AIAA Propulsion and Energy 2020 Forum, 2020 AIAA-2020-3784, doi:10.2514/6.2020-3784.
- [19] J. Zarate, N. Hirsch, F. Razo, O. Berra, M. Mastrangelo, D. Martino, C. White-sell, M. Sola, Rapid Design of a Small Scale KeroLOx Flight Vehicle Propulsion System, 73-rd International Astronautical Congress, 2022 Paris, France, IAC-22-C4.IP.37.
- [20] Space Engineering Research Center, SERC. https://www.isi.edu/centers-serc/ (accessed October 20, 2023).
- [21] D. Barnhart, J. Sullivan, P. Will, M. Gruntman, Advancing Exploration Risk Reduction and Workforce Motivation Through Dynamic Flight testing, Space-2007, 2007 Long Beach, Calif., AIAA-2007-6040, doi:10.2514/6.2007-6040.
- [22] T. Barrett, D. Barnhart, J. Kunc, R. Karkhanis, E. Vartanian, M. Guzman, S. Hesar, USC's approach to satellite-based, hands-on, training: The engineering teaching hospital, Space-2011 Conference, Long Beach, Calif., 27-28 September, AIAA-2011-7226, 2011, doi:10.2514/6.2011-7226.
- [23] M. Gruntman, Fundamentals of Space Missions: Problems with Solutions, Interstellar Trail Press, 2022 ISBN 979-8985668742.
- [24] Astronautics Master's Program Update (Semiannual Newsletter). http://astronauticsnow.com/msaste-update.pdf (accessed December 15, 2023).
- [25] F. Allahdadi, I. Rongier, P. Wilde (Eds.), Safety Design for Space Operations, Butterworth-Heinemann, 2013.
- [26] B.G. Kanki, T. Sgobba, J.-F. Clervoy, G. Sandal, Space Safety and Human Performance, Butterworth-Heinemann, 2017.
- [27] T. Sgobba, G.E. Musgrave, G. Johnson, M.T. Kezirian, Safety Design for Space Systems, 2nd ed., Butterworth-Heinemann, 2023.
- [28] USC Astronautics Graduate Commencement. https://youtu.be/iTQkv45E1yl, 2016; https://youtu.be/dfZeZuhVyo0, 2017; https://youtu.be/QBjY5\_SxE6c, 2018 (accessed November 10, 2023).
- [29] ITAR and Export Controls, U.S. Department of State, Directorate of Defense Trade Controls. https://www.pmddtc.state.gov/ddtc\_public/ddtc\_public (accessed July 28, 2024).
- [30] Report of the select committee on the U.S. National security and military/commercial concerns with the People's Republic of China. 105th Congress, 2nd Session, House of Representative, Report 105-851, U.S. Government Printing Office, Washington, DC, 1999.
- [31] American Society for Engineering Education (ASEE), Washington, DC. http://asee.org (accessed October 21, 2023).
- [32] Profiles of Engineering and Engineering Technology; American Society for Engineering Education (ASEE), Washington, DC. http://profiles.asee.org (accessed October 21, 2023) and https://americansocietyforengineeringeducation. shinyapps.io/profiles/ (accessed December 8, 2023).

- [33] Profiles of Engineering and Engineering Technology, 2022 edition, American Society for Engineering Education (ASEE), Washington, DC, 2023, p. 143.
- [34] Profiles of Engineering and Engineering Technology Colleges, 2007 edition, American Society for Engineering Education (ASEE), Washington, DC, 2008, p. 38
- [35] Profiles of Engineering and Engineering Technology Colleges, 2015 edition, American Society for Engineering Education (ASEE), Washington, DC, 2016, p. 38.
- [36] Profiles of Engineering and Engineering Technology, 2018 edition, American Society for Engineering Education (ASEE) Washington DC 2019 p. 40
- Society for Engineering Education (ASEE), Washington, DC, 2019, p. 40.

  [37] Profiles of Engineering and Engineering Technology, 2019 edition, American Society for Engineering Education (ASEE), Washington, DC, 2020, p. 28.
- [38] Profiles of Engineering and Engineering Technology (2020 edition), American Society for Engineering Education (ASEE), Washington, DC, 2021, pp. 27, 145.
- [39] Profiles of Engineering and Engineering Technology (2021 edition), American Society for Engineering Education (ASEE), Washington, DC, 2022, pp. 27, 144
- [40] Profiles of Engineering and Engineering Technology (2022 edition), American Society for Engineering Education (ASEE), Washington, DC, 2023, pp. 28, 143.
- [41] Profiles of Engineering and Engineering Technology Colleges (2017 edition), American Society for Engineering Education (ASEE), Washington, DC, 2018, pp. 143.144.
- [42] Space Foundation. https://www.spacefoundation.org/ (accessed December 15, 2023).
- [43] Space Report, 2012, p. 6.
- [44] Space Report, 2013, pp 5,26.
- [45] Space Report, 2014, p. 4.
- [46] Space Report, 2015, p. 1.
- [47] Space Report, 2016, p. 1.
- [48] Space Report, 2017, p. 1. [49] Space Report, 2018, p. 1.
- [50] Space Report, Q2 (second quarter), 2019, p. 3.
- [51] Space Report, Q2 (second quarter), 2020, p. 3.
- [52] Space Report, Q2 (second quarter), 2021, p. 3.
- [53] Space Report, Q2 (second quarter), 2022, p. 3.
- [54] IAF Members, International Astronautical Federation. https://www.iafastro.org/membership/all-members/ (accessed November 29, 2023).
- [55] Space Report, Q2 (second quarter), 2023, pp. 7, 16. https://www.thespacereport.org/ (accessed November 6, 2023).
- [56] M. Gruntman, Blazing the Trail: The Early History of Spacecraft and Rocketry, AIAA, Reston, Va, 2004, doi:10.2514/4.868733.
- [57] Space Report, Q2 (second quarter), 2023, p. 11 https://www.thespacereport.org/ (accessed November 6, 2023).
  [58] Space Report, Q2 (second quarter), 2023, pp. 27, 28. https://www.
- thespacereport.org/ (accessed November 6, 2023).
- [59] Space Report, Q2 (second quarter), 2023, p. 16 https://www.thespacereport. org/ (accessed November 6, 2023).
- [60] Space Report, 2011, p. 43.
- [61] R. Sturdevant, From satellite tracking to space situational awareness: the USAF and space surveillance, 1957-2007, Air Pow. History V 55 (4) (2008) 4–23.
- [62] M. Gruntman, Intercept 1961, The Birth of Soviet Missile Defense, American Institute of Aeronautics and Astronautics (AIAA), Reston, Va., 2015, doi:10.2514/ 4.103506.
- [63] M. Gruntman, in: My Fifteen Years At IKI, the Space Research Institute: Position-Sensitive Detectors and Energetic Neutral Atoms Behind the Iron Curtain, Interstellar Trail Press, 2022, pp. 111, 251–253. ISBN 979-8985668704.
- [64] J.A. Coyne, A.I. Krylov, The 'hurtful' idea of scientific merit, Wall Street J. CCLXXXI (98) (2023) A17 April 28, 2023.
- [65] Editorial, Antiracist vs. academic freedom, Wall Street J. CCLXXXII (18) (July 22, 2023) A12.



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#### IAC-18-E1.4.11

## Master of Science Degree in Astronautical Engineering Through Distance Learning

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#### Abstract

The Department of Astronautical Engineering at the University of Southern California (USC) focuses on space engineering education. In addition to full-time on-campus students its flagship program Master of Science in Astronautical Engineering reaches working professionals online through distance education. Since its founding in 2004, the Department awarded more than 500 Master's degrees to students from across the United States, Canada, and military installations abroad. Online students account for two thirds of the earned degrees. Continuing education with online coursework delivery has emerged as an integral feature of workforce development in the U.S. space industry and government centers. This article discusses the origin, rationale, focus, structure, coursework, reach, and achievements of the USC Astronautics program, particularly its specifics in serving a large population of online students. It concludes with the lessons learned and outlines trends in program evolution.

**Keywords:** astronautical engineering; space engineering; graduate degrees; online education

## **Acronyms/Abbreviations**

ABET – Accreditation Board for Engineering and Technology

ASEE – American Society for Engineering Education

ASTE - Astronautical Engineering Department

AY – academic year

DEN - Distance Education Network

ITAR – International Trafficking in Arms Regulations

MS ASTE – Master of Science in Astronautical Engineering

USC – University of Southern California VSOE – Viterbi School of Engineering, USC

#### 1. Introduction

In June 2004, the University of Southern California (USC) established a new independent academic unit focused on space engineering [1,2]. This development broke a tradition in the academia in the United States [3] to combine aeronautical and astronautical disciplines in departments of aerospace engineering or in joint departments with other engineering areas.

The new Department of Astronautical Engineering (ASTE) in the USC Viterbi School of Engineering (VSOE) successfully introduced the full set of degrees (Bachelor, Bachelor Minor, Master, Engineer, Ph.D., and Graduate Certificate) in astronautical engineering. Growth of the new Department and student interest in its programs proved that focused pure-space-engineering academic units could be successful in a highly competitive educational field of about seventy aerospace programs [1] offered by U.S. universities.

This article concentrates on the largest educational component of the Department, its flagship program Master of Science in Astronautical Engineering (MS ASTE), specifically oriented on meeting needs of the space industry and government space research and development centers. Continuing education, particularly with online coursework delivery, has become an integral feature of workforce development in the U.S. space sector. Online students account for two thirds of the earned Master's degrees in this USC program.

The article first outlines the rationale for establishing the new department and describes its programs. Then it concentrates on the MS ASTE program structure, coursework, students, instructors, and online reach to working professionals, practicing engineers, through distance education. The article concludes with discussing the lessons learned and trends in program evolution.

## 2. Space engineering at USC

The rationale for breaking the tradition and establishing a focused pure-space-engineering academic department was described in significant detail in [1,2]. Briefly, the beginning of the space age in 1950s led to expanding the field and changing the names of many existing aeronautical engineering departments to "aerospace" or some variant of "aeronautics and astronautics" [3]. The curriculum, however, remained concentrated in fluid sciences and engineering and aeronautical applications. Universities added some coursework in space-related topics, primarily in orbital mechanics and rocket propulsion. At the same time, the U.S. space effort greatly expanded in space science, exploration, and national security.

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The Accreditation Board for Engineering and Technology (ABET) recognized astronautical engineering as a separate from aerospace degree in 1980s. By the end of 2013, the number of ABETaccredited Bachelor of Science degrees in the areas of aeronautical, astronautical, and aerospace engineering in the United States had reached 68 [1]. Space technology drives to a significant degree the continuing establishment of new university departments and programs in the aerospace field. In spite of progress, fluid sciences with aeronautical applications and astronautics are not of equal status in many present-day aerospace programs. The space curriculum in many universities is limited, and the old question "Is there any space in aerospace?" [4] remains.

Aerospace engineering at USC was rather typical for the country. The university is located in Los Angeles at the center of a major cluster of space companies and government research and development centers. At the same time most of the faculty of the new Aerospace Engineering Department, founded in 1964, focused on fluid dynamics research in aeronautical fields [5]. They had little incentive to take an interest in space technology.



Figure 1. Bronze statue of Neil Armstrong on USC campus. Sculptor: Jon Hair. Photo (2013): Mike Gruntman.

On a historical note, the first man on the moon, Neil Armstrong, was among most renowned USC aerospace graduates of those times (Fig. 1). He had studied part time in early 1960s while stationed at the Edwards Air Force Base in California as a test pilot [1,6].

After rapid growth and large enrollments, aerospace student populations in the United States had dropped by mid 1990s, following the end of the Cold War [3]. The response of USC astronautics-oriented faculty to the prevailing doom-and-gloom atmosphere of 1990s was to found the Astronautics and Space Technology Program (Astronautics Program). We took advantage of our strategic location in Los Angeles and concentrated first on the Master of Science degree.

The focus on Master's students leveraged the capabilities of the Distance Education Network (DEN) of the USC Viterbi School of Engineering reaching working engineers across the country. In addition, we built up coursework relying primarily on part-time instructors, leading specialists working in the local companies. The latter allowed engaging highly qualified instructors in specialized areas without a lengthy and uncertain process of hiring a very limited number of tenured faculty.

In 2004, the University reorganized the growing Astronautics Program within the USC Department of Aerospace and Mechanical Engineering into a new independent academic unit, today's Department of Astronautical Engineering [1,2]. The author of this article served the founding chairman of the department from 2004-2007 and chairs it again from 2016-2019. He has also been directing, without interruption, the Master's program since its inception in mid 1990s.

Based on our experience with the growing successful program, we called for the establishment, in some universities, of separate pure-space-engineering departments to better meet the needs of the space industry and government centers [2]. Importantly, such independent astronautical engineering academic units would shift the existing (rarely fair) competition 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 [2] that creation of astronautical engineering departments was a *practical approach* to achieve desired flexibility within constraints of realities of the glacially-changing academia burdened with significant inertia and internal politics. The resulting competition among the departments and universities would force a balanced mix of the offered programs, determined by national and international educational needs and better respond to the engineering workforce development challenges of the global space enterprise.

In a short period of time since its founding, the new space-focused Department of Astronautical Engineering awarded (as of August 2018) 133 Bachelor of Science

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degrees, 545 Master of Science degrees, 33 PhD's, and 11 graduate certificates. On-campus student opportunities include participation in faculty research as well as in student projects such as the Rocket Propulsion Laboratory that builds and launches solid-propellant rockets and the Liquid Propulsion Laboratory developing liquid-propellant engines. The Space Engineering Research Center, operated jointly with the Viterbi School's Information Sciences Institute, involves astronautics students in its programs [1].

We focus below on the Master of Science degree that remains the largest program in the department and can be earned by studying on campus or online.

## 3. Master of Science in Astronautical Engineering

## 3.1 Admission requirements

The MS ASTE degree is open to qualified students with Bachelor of Science degrees in engineering, mathematics, and hard sciences from regionally accredited universities. In addition to satisfactory grade point average (GPA) and general record exam (GRE) test scores, applicants are also required to provide two letters of recommendation.

In an important distinction from many aerospace programs, students do not need to have an aerospace-related Bachelor's degree. This program feature is particularly important for working professionals who pursue the degree online through distance education.

The modern space industry and government centers employ engineers of diverse background who had majored in various areas of science and engineering. Many strive to continue their education in a space-technology field directly relevant to their industry. Our program opens a path for them to earn a Master's degree in astronautical engineering without being exposed to undergraduate aerospace coursework.

The required overview course on fundamentals of space systems (Spacecraft Systems Design) serves a role of a "boot camp" for students. It introduces main concepts and nomenclature and covers key areas of space technology and rocketry. The course is also popular among graduate students pursuing degrees in non-space areas but planning to gain employment in the space industry. More than 1800 graduate students took this course at USC since 1996 when the author of this article had begun teaching it.

In addition to scientists and engineers, the MS ASTE program also attracts each year one or two new students with non-technical backgrounds such as, for example, medical doctors. In cases of limited science background students are asked to take, prior to applying to the program, undergraduate courses in mathematics and physics required in engineering majors. The applicants usually take such coursework, conveniently and inexpensively, in community colleges.

### 3.2 Coursework

The required MS ASTE coursework consists of nine courses, or 27 units, with typical semester-long graduate classes being 3 units each. While the USC Viterbi School of Engineering is transitioning its undergraduate programs to 4-unit courses, 3-unit courses will constitute the coursework of our Master program in the foreseeable future. The program usually offers 9–11 astronautics courses each semester. All graduate courses are available online, with the exception of a very few specialized courses designed primarily for PhD students.

To earn the MS ASTE degree students must take (i) four required courses (12 units); (ii) three core elective course (9 units); and (iii) two technical elective courses (6 units).

The required courses include three broad overview courses on fundamentals of space systems; rocket and spacecraft propulsion; and space environment and spacecraft interactions. The fourth required course is in orbital mechanics. Core elective courses are selected from the list of space-focused core electives courses which includes most of graduate astronautics courses.

The remaining two technical electives could be selected from graduate courses outside the home department or from the list of core electives. Majority of students choose electives from the space-focused core electives as these courses are the reason for their enrollment in the program in the first place.

Practically all graduate science and engineering courses offered by other departments are approved as technical electives with the exception of a small number of courses in non-traditional areas such as management of engineering projects and alike. Master of Science in Astronautical Engineering is a traditional engineering degree and not a program in system engineering, system architecting, or space studies [1]. Students with particular interest in such areas are advised to change the major in order to meet their educational objectives.

A typical 3-unit course consists of 12-13 weekly three-hour lectures and two exams, midterm and final. Studies include weekly homework assignments as well as term papers and/or projects if appropriate. Some core elective courses provide introduction to spacecraft subsystems and do not require prerequisites. More specialized courses have prerequisites. For example, a course in advanced propulsion would require a prerequisite course in propulsion, and a course in space navigation would require an orbital mechanics course.

Students themselves determine the sequence of courses to take, with the help of faculty advisors. Many choose to begin their studies with the required courses. These broad courses help them to better understand the scope of space technology. They may subsequently change their plans for specialized coursework based on better understanding of the role of various areas in space systems and operations.

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Table 1 shows the current list of astronautics courses offered for graduate credit. All required courses are available once or twice each year. The department offers core elective and technical elective courses every year or every two years, depending on student interest. Since online students typically take one course per semester they stay 4-5 years in the program in order to earn the degree. With proper planning they can enroll in courses that interest them most.

Table 1. Astronautics courses offered for graduate credit. Elective courses are grouped thematically.

#### Course

#### required

Spacecraft System Design Space Environment and Spacecraft Interactions Orbital Mechanics I Spacecraft Propulsion

## core electives and electives

Orbital Mechanics II
Space Navigation: Theory and Practice
Solar System Navigation
Spacecraft Attitude Dynamics
Spacecraft Attitude Control

Liquid Rocket Propulsion
Solid Rocket Propulsion
Advanced Spacecraft Propulsion
Space Launch Vehicle Design

Spacecraft Structural Dynamics
Spacecraft Structural Strength and Materials

Spacecraft Thermal Control
Spacecraft Power Systems
Systems for Remote Sensing from Space
Spacecraft Sensors
Spacecraft Cryogenic Systems and Applications

Design of Low Cost Space Systems Space Studio Architecting Human Spaceflight Entry and Landing Systems for Planetary Exploration

Safety of Space Systems and Space Missions Reliability of Space Systems

At this time the program covers many space technology areas. However, we always strive to develop new coursework to close existing gaps in the curriculum and build up areas of growing interest. We are adding, for example, new coursework in human spaceflight, the area posed for growth. As of September 2018, the United States could not launch humans to orbit for more than 2600 days. This politically inflicted embarrassment will

end soon, as the national human spaceflight embarks on exploration beyond low earth orbit, and new commercial spaceflight capabilities emerge.

Availability of qualified instructors, budgets, and constraints of distance education infrastructure limit introduction of new courses. Even maintaining the current offering of more than two dozen astronautics courses presents a major administrative challenge since our instructors occasionally develop scheduling conflicts or relocate to other parts of the country, pursuing their professional careers.

Some students, particularly with aerospace Bachelor's degrees, have been exposed to subjects covered by the required courses such as, for example, propulsion and orbital mechanics, during their undergraduate studies. In these cases, the required courses are waived, and students take additional technical electives instead. A Master's thesis is not a requirement but an option for on-campus students. For online students writing a thesis is not practical.

## 4. Program instructors and students

## 4.1 Faculty and part-time lecturers

The Master of Science program in Astronautical Engineering combines regular full-time faculty and part-time instructors. The regular faculty primarily focus on basic science and technology such as gases and plasmas, space environment and space science, and fundamentals of spacecraft design and rocket and spacecraft propulsion. Instruction in specialized topics and satellite subsystems relies on part-time lecturers who are leading experts employed in the industry and government space research and development centers. They bring the important real-world experience in rapidly changing areas of technology.

The Los Angeles area offers access to the unmatched wealth of first rate specialists in space technology. These part-time lecturers are a great strength of the program. They work in government centers and large and small space companies, including Boeing, Lockheed-Martin, Raytheon, Northrop-Grumman, Aerojet-Rocketdyne, Microcosm, Space Environment Technologies, The Aerospace Corporation, and NASA Jet Propulsion Laboratory.

## 4.2 Master's Students

The MS ASTE program attracts both full-time oncampus students and students who work full-time and study part-time. Full-time students usually take 3 courses each semester and achieve their degrees in 1.5 years. Part-time students usually take one course per semester. It takes them 4-5 years to earn the degree. They enroll in courses through the Distance Education Network even if they reside within a driving distance from the campus. One can earn the degree without the need of ever visiting the campus. Some students would fly, however, to Los

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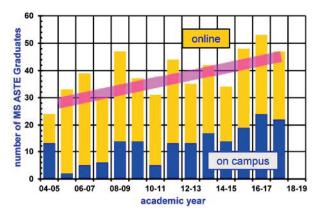


Figure 2. Annual number of the awarded Master of Science degrees to online (light orange) and on-campus (dark blue) students in astronautical engineering from the founding of the Astronautical Engineering Department at USC. The MS ASTE program accounts for more than 3% of the Master's degrees awarded in the United States in the broad area of astronautical, aeronautical, and aerospace engineering.

Angeles to attend the festive on-campus Commencement ceremony and receive their diplomas [7].

Online course delivery is particularly convenient for engineers who balance their responsibilities that often include lengthy travel to tests, other professional activities, and family life. The fulltime students attend on-campus class lectures which are being simultaneously webcast live to online students. DEN technicians then place the captured webcasts on the School's servers. In practice, few online students watch lectures live and majority view them asynchronously at convenient times. On-campus students have full unlimited access to the recorded lectures as well, which offers an excellent opportunity for reviewing particular topics, especially those presenting difficulties.

As a matter of policy, the Viterbi School of Engineering does not distinguish between on-campus and online students. The requirements to the degrees, admission to the programs, and evaluation of student performance are identical for all students. Online students have access to the instructors and classroom as their on-campus peers. All graduate students are held to the same high standards and are expected to show the same dedication toward their education.

The educational background of our students is truly diverse as the program admits students with Bachelor's degrees in hard sciences and all areas of engineering. Some our online students already have their Master's degrees in non-space areas of engineering and they successfully work in the space industry. Gaining better understanding of space-specific concepts and technologies by obtaining a Master's degree in astronautical engineering often opens a pathway for

advancing to leadership positions in major space programs.

In addition, occasionally students with doctorates in other fields of science and engineering and medical doctors enroll into the MS ASTE program. Some of them join the program to improve their chances to be selected for astronaut training.

Figure 2 shows the annual number of the Master of Science degrees in astronautical engineering awarded by the department. The fraction of full-time students (dark blue bars) has been continuously growing, On average, the program awarded nearly 42 degrees annually during the last 10 years and 545 degrees since the establishment of the department.

The American Society for Engineering Education, ASEE, compiles the national statistics in engineering education [8]. It combines astronautical, aeronautical, and aerospace degrees in one broad category. During the last decade USC Astronautics accounted for more than 3% of Master's degrees awarded in this combined broad area.

There are nearly 70 aerospace-related Bachelor's degree programs in the United States [1]. ASEE identifies 61 programs in the country that award aerospace-related Master's degree. (In a quirk of statistical accounting, ASEE lists the USC Master's program in astronautical engineering among "other engineering disciplines" [8].) Hence, an average aerospace Master's program accounts for about 1.7% of nationally awarded degrees. The USC Astronautics program is twice as large.

ASEE does not capture the separate numbers of awarded degrees in astronautics (space engineering). Therefore, one can only compare the program size with others in the broad aerospace field dominated by nonspace areas. Among these aerospace peers, USC Astronautics was the 8-9th largest program in the country in the 2016-2017 academic year in the number of awarded Master's degrees (Fig. 3).

Two U.S. aerospace programs are significantly larger than others: Purdue University (117 Master's degrees) and Georgia Institute of Technology (113). Then, there is a group of 9 universities, including USC Astronautics, separated by a gap from the smaller programs: (in the decreasing order of the number of awarded degrees) University of Washington (78), University of Colorado in Boulder (74), University of Michigan (66), Massachusetts Institute of Technology (63), Stanford University (61), USC Astronautics (53), Air Force Institute of Technology (53), University of Illinois at Urbana-Champaign (51), and Embry-Riddle Aeronautical University at Daytona Beach (50).

One can only speculate how our program would have ranked in size if only space-engineering specializations were counted—clearly, it is among largest.

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Figure 3. Distribution of the numbers of awarded Master of Science degrees in broad aerospace area in the United States in 2016-2017 academic year. The USC MS ASTE program ranked the 8-9th in size. Based on ASEE data [8].

Majority of our online students work in the United States and they are consequently U.S. citizens or permanent residents. The fraction of foreign nationals among full-time on-campus astronautics students is smaller than in many other engineering departments in the university [1, 2]. This results from awareness about the restrictions of the export control International Trafficking in Arms Regulations (ITAR). Nevertheless, students from nearly twenty countries earned degrees in astronautical engineering. The specific effect of ITAR on the Master's program is discussed in some detail in [1,2].

All university classes, including in astronautics, are open to students without restrictions of their nationality. Foreign students play very active roles in the Department's Liquid Propulsion Laboratory designing and building liquid-propulsion rocket engines. This program primarily engages Astronautics Master's students. We also explore possibilities of offering the online degree program to working professionals residing in foreign countries.

#### 5. Distance education

## 5.1 Distance education at VSOE

Continuing education with high-quality online coursework delivery plays a particularly important role in workforce development in the U.S. space, aerospace, and defense industries and government centers. Student interest in distance education continues to grow.

Changes in industry have made a Master's degree desirable and even indispensable for a successful technical career in the United States. Consequently, many leading industrial companies and government centers hire young graduating engineers with Bachelor's degrees and support their pursuit of Master's degrees part-time while working full-time. Tuition coverage for such studies has become part of standard compensation in defense and space industries.

Online education also opens a way for engineers who had graduated five, ten, or more years ago with the Bachelor's degree to resume their education and earn the Master's degree. Such a degree improves chances for changing specialization to more attractive and interesting areas of work within large companies and for promotion in highly competitive environment.

The USC Viterbi School of Engineering engaged in distance education in the late 1960s [1,6]. The course delivery technology has been evolving through the years. It began with direct broadcasting of televised courses to a network of local aerospace companies in the Greater Los Angeles area. Then, in 1990s, transponders on geostationary satellites extended reach to students outside Southern California (Fig. 4).

Finally, the Distance Education Network transitioned to "webcasting," streaming compressed video and audio over the Internet. Today, Viterbi School's DEN offers nearly 40 Master's degrees entirely online.

Full-time students attend lectures on campus in DEN studios (Fig. 5). There, instructors could speak to facing them cameras, or use the white board or smart electronic board, or show the prepared presentations in preferred format and software (such as Microsoft PowerPoint, Adobe Acrobat, specialized scientific and engineering software) from studio's desktop computers or their own laptops.



Figure 4. Antennas of the Distance Education Network connecting to transponders on geostationary satellites in 2004. Today compressed video and audio are streamed over the Internet. Photo courtesy of Mike Gruntman.

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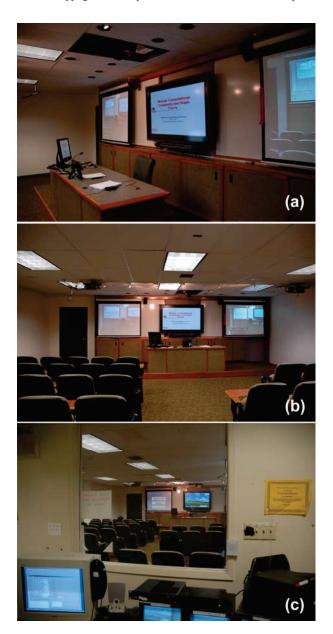


Figure. 5. Typical DEN classroom studio on USC campus. (a) Instructor's desk with a smart electronic board behind and two large screens on the sides. Streaming webcast is usually displayed on the screens for in-class students to see. The instructor can use a desktop computer or laptop for the prepared presentations or speak to facing him or her camera. An overhead camera can zoom on a notepad on the desk where the instructor writes by a thick pen. (b) Studio as seen by on-campus students attending class lectures. (c) Each studio is supported by a trained operator behind a glass wall who controls cameras, microphones, and computer feeds in the room and maintains communications with the master control center. Photos: Mike Gruntman.

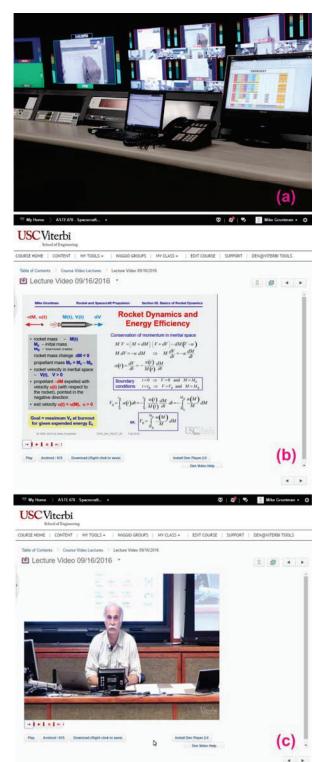


Figure 6. (a) DEN's master control center overseeing webcast and capture of lectures in multiple studios. (b,c) Screenshot examples of a lecture webcast (the author's course on rocket propulsion) as viewed by online students. As technology of streaming over the Internet evolves, the quality of webcasts continuously improves.

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Some instructors choose to use preprinted course notes, with the overhead camera zooming in on a page on the desk. The instructor can then write additional equations or circle some content while discussing this particular page in order to emphasize specific content and expand the printed material. The camera can also zoom in on a notepad where the instructor writes and, for example, derives equations or sketches diagrams by special thicker (for better visibility) pens. Finally, the camera can show the instructor utilizing a traditional large white board or a smart 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.

In each studio, a trained operator supports the lecture from behind a glass wall (Fig. 5) and follows instructor directions for selecting cameras, zooming in on papers on the instructor's desk, and switching the feed between the desktop computer and laptop.

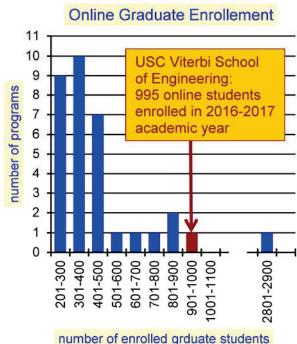
The lectures are webcast live using DEN's proprietary Internet-delivery system (Fig. 6). They are captured in high quality and stored on the School's servers, available for asynchronous viewing via streaming and download until the end of the semester. Students can watch archived lectures on their desktop computers, laptops, tablets, and mobile devices.

DEN staff interacts with students electronically. Students download course notes, homework assignments and solutions, and handouts from password-protected secure servers. Students in the Greater Los Angeles area take exams on campus. At distant sites, DEN contracts local community colleges to proctor exams. Many large companies and government centers have on-site educational coordinators who could also 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 homework assignments and solutions. Calculators are usually required. The calculators become increasingly powerful and sophisticated, with differences from laptop computers blurring. Some instructors thus allow laptop computers at the exams, usually requiring turning off wireless Internet connection. Exam proctoring centers enforce the rules for online students making them identical to those on campus and assuring integrity of the program. Integrity of exams is also a major operational challenge for enrolling online students residing in foreign countries.

## 5.2 Engineering online education in the U.S.

A number of leading engineering schools in the United States offer Master's degrees online. The USC Viterbi School of Engineering shares the second-andthird places with the University of California, Los



number of enfolied gradate students

Figure 7. Distribution of enrollments in online graduate engineering programs in the United States in the 2016-2017 academic year. Programs varied from the largest with more than 2800 enrolled students to those with a few hundred students each. The USC Viterbi School of Engineering was the second largest with 955 students pursuing Master's degrees online, including 99 in astronautical engineering. A large number of programs enrolled fewer than 200 students each. Based on *United States News and World Report* survey [9].

Angeles (UCLA) in the latest *U.S. News and World Report* national ranking of the best online graduate engineering programs in the United States [9].

The size of online programs varies greatly (Fig. 7). The largest online program in the Whiting School of Engineering of the Johns Hopkins University enrolled 2853 students in the 2016-2017 academic year. At the same time many universities enroll only a few hundred students. (An enrolled student is defined as a student that has taken at least one course in an academic year.)

The USC online program combines the size and quality. While sharing the second-and-third places in the U.S. News and World Report national ranking, it is the second largest in the nation (Fig. 7), with 955 students enrolled in 2016-2017 AY. The best ranked program at the Columbia University is significantly smaller with 305 students; the UCLA program that shared the ranking with USC enrolled 474. The largest Johns Hopkins University program ranked the 19th [9].

Nationally, ASEE statistics shows 1152 students pursuing Master's degrees in aerospace field part time in

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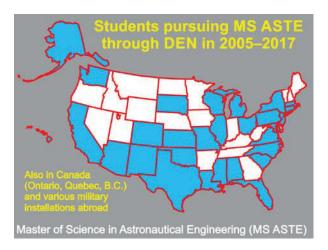


Figure 8. USC students pursuing online the degree Master of Science in Astronautical Engineering through distance education reside in many states (blue) as well as in Canada and stationed at military installations abroad.

2016-2017. This number does not include, in an accounting quirk, 99 students in the online USC Astronautics program. In general, statistical data from different sources are not uniformly detailed and consistent. For example, a few students could pursue the online program full-time.

In any event it is fair to say that USC Astronautics accounts for about one-twelfth of the national enrollment of students pursing Master's degree in the broad aerospace area part time. One can only guess what this fraction, but certainly large, would be among students specializing in space engineering.

Online students accounted for two-thirds of the Master of Science degrees awarded by USC Astronautics (Fig. 2). The students reside everywhere in the United States (blue color states in Fig. 8) where one finds space companies, large and small; satellite operators; and government space research and development centers. We also have students in Canada as well as those stationed at military installations abroad.

Standard high-speed Internet connection allows highquality viewing of lectures from home or office or a hotel room anywhere in the world. The new technology opened a way for engineers in small companies and individuals to enroll in DEN online programs. It also makes possible to reach students in foreign countries and effectively partner with foreign educational institutions.

## 6. Lesson learned. Trends, and conclusions

The Internet-based technology has profoundly transformed distance education. In particular, it brought true competition to once static programs dominated in the "television past" by university "monopolies" owning the microwave band for broadcasts. Continuous education

online has become the way of life for many engineers in industry, particularly in space and defense.

Internet-enabled market competition among universities is essential for assuring quality of online engineering programs. It provides a test whether the programs meet the needs of the real world. Practicing engineers conveniently choose the best online programs to enroll.

Not only is academia burdened with inertia and internal politics, but universities in the United States are increasingly consumed by ideologically-driven destructive political correctness and identity politics. Party voter registration of faculty in many professional schools is tilted overwhelmingly left (e.g., [10]) in a country with the electorate evenly divided between the two main political parties. Therefore, pressures of true competition among programs for online students encourage common sense and somewhat mitigate the inevitable resulting harm of this creeping non-merit-based approach to education.

Today, many countries project military power, commercial interests, and national image through activities in space. It is a truly high-technology frontier, expensive and government-controlled or government-regulated. Space-enabled technologies have become an integral part of everyday lives of people. The worldwide space enterprise has grown by more than 50% during the last decade and exceeds today \$330B annually, with commercial space being larger than government programs. This continuing expansion requires core engineering workforce for the space industry and government centers, with universities playing a critically important role in space engineering education.

The establishment of a separate independent spacefocused Department of Astronautical Engineering at USC in 2004 was a practical approach to achieve the desired flexibility within the constraints of the American academia. The program growth in a highly competitive environment validates the value of specialized astronautical engineering education and degrees for the industry.

Administrative independence of space engineering departments is indispensable as it reduces unproductive local "political battles" so widespread among fragmented faculty. In addition, our experience points to some other features that made the program a success.

Clearly, the availability of qualified external specialists from industry to teach courses as part-time lecturers is necessary but not sufficient. There should also be dedicated and knowledgeable tenured faculty to build the program and navigate through the university degree and curriculum approval processes. The program has to be responsive to the industrial needs and show understanding of current industrial practices. Such knowledge is not widespread among tenured faculty who

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by the nature of hiring and operation of academia are focused primarily on fundamental science.

The on-campus tenured faculty should show leadership in identifying interested outside experts and introducing new courses in highly-specialized areas, responding to changes in the space enterprise. They also should insulate and protect the program and external instructors to a maximum degree possible from internal university politics.

Another essential lesson is importance of building the program identity. This requires a clear identification of the "customer," that is a part of the space enterprise and type of engineers who would particularly benefit from the offered coursework and degrees. The focus on clearly-defined areas of technology and putting together, "packaging," the coursework focused on these areas attracts working students who are searching for programs to advance their educational objectives. In fact, these objectives are sometimes vague, and a well-defined packaged program may be helpful to them.

One has also to be open to the feedback from the students. Listening to mature students and actually seeking their advice could provide important insight into industrial needs.

On a practical level, financial soundness of the program is another important feature. It is easier to obtain administrative support for experimentation and further program growth if the program brings money to the school rather than being a burden. Such financial strength can only be achieved when the program reaches a certain "critical mass" of students and continuously strives to maintain sustainable student interest.

The latter requires unrelenting marketing reach to the industry and potential new students. Program quality and student experience here become crucial as program graduates become with time its best ambassadors. Many new students from large "legacy" space companies tell us that they learned about the program and its value from their colleagues who had graduated with our degrees in the past.

To conclude, the experience of the online Master of Science program in Astronautical Engineering shows that it meets the existing real needs of space engineering workforce development and contributes in an important way to the space enterprise.

Ad Astra!

## Acknowledgements

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

## References

[1] M. Gruntman, Advanced degrees in astronautical engineering for the space industry, Acta Astronautica 103 (2014) 92–105; http://dx.doi.org/10.1016/j.actaastro.2014.06.016, also http://astronauticsnow.com/2014aste.pdf

(accessed April 24, 2018).

- [2] M. Gruntman, The Time for Academic Departments in Astronautical Engineering, AIAA-2007-6042, AIAA Space-2007, Long Beach, Calif., 2015; http://dx.doi.org/doi:10.2514/6.2007-6042; also http://astronauticsnow.com/aiaa-2007-6042.pdf (accessed April 24, 2018).
- [3] B.W. McCormick, C. Newberry, and E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, Virginia, 2004.
- [4] R.F. Brodsky, On the Cutting Edge. Tales of the Cold War Engineer at the Dawn of the Nuclear, Guided Missile, Computer and Space Ages, Gordian Knot Books, 2006 (p.148).
- [5] R.E. Kaplan, Aerospace engineering at the University of Southern California, in: B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, VA, 2004, pp. 540–552.
- [6] R.E. Vivian, The USC Engineering Story, USC Press, Los Angeles, Calif., 1975.
- [7] USC Astronautics Graduate Commencement: 2016, https://youtu.be/iTQkv45E1yI, (accessed on March 10, 2018); 2017, https://youtu.be/dfZeZuhVyo0, (accessed on March 10, 2018); 2018, https://youtu.be/QBjY5\_SxE6c, (accessed on June 1, 2018).
- [8] Profiles of Engineering and Engineering Technology Colleges, American Society for Engineering Education (ASEE), Washington, DC, 2018; also http://profiles.asee.org; (accessed Feb 28, 2018).
- [9] The Best Online Graduate Engineering Programs, U.S. News and World Report, http://www.usnews.com; (accessed on February 15, 2018).
- [10] M. Langbert, A.J. Quain, and D.B. Klein, Faculty Voter Registration in Economics, History, Journalism, Law, and Psychology, Econ Journal Watch: Scholarly Comments on Academic Economics 13(3) (2016) 422–451.
- [11] M. Gruntman, The history of spaceflight, in: J.R. Wertz, D. F. Everett, J.J. Puschell (Eds.), Space Mission Engineering: The New SMAD, Microcosm Press, Hawthorne, California, 2011, pp. 4–10; also http://astronauticsnow.com/2011spaceflight.pdf, (accessed April 24, 2018).

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# 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 purespace-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 ( $\sim 80\%$ ) the satellite segment of the market [14]. California remains the home of a major space effort to this day.

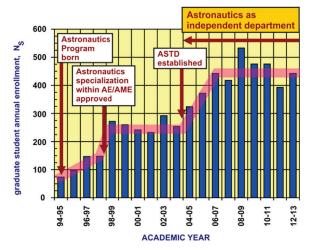
Second, we initially concentrated on the Master of Science program. Three-four decades ago engineers with Bachelor's degrees could have rewarding and fulfilling technical careers. Today, changes in industry have made Master's degrees desirable (sometimes called "the terminal degree") for a successful 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,  $N_{\rm S}$ , 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  $N_{\rm S}$  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<sub>S</sub>*, 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 oncampus 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

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

#### Required courses

Spacecraft System Design Spacecraft Propulsion

Space Environment and Spacecraft Interactions

Orbital Mechanics I

#### Core elective and elective courses

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 Structural Material Spacecraft Power Systems

Spacecraft Thermal Control

Systems for Remote Sensing from Space

Spacecraft Sensors

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

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 our M.S. ASTE 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 online 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.

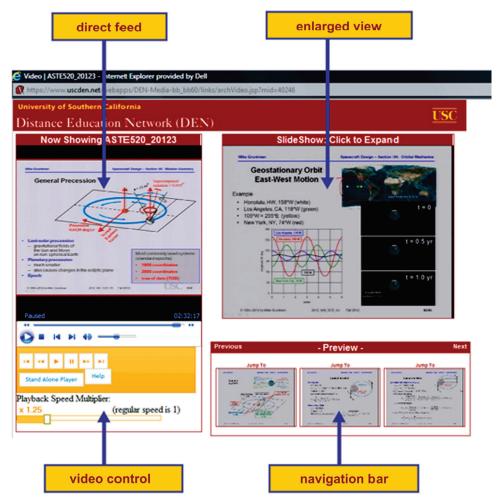
Astronautics students studying through DEN reside in many geographical areas with rocket and space activities, installations, test and operations sites, space companies, and government centers (Fig. 5). In addition, some students live and work in Canada. We also always have students who serve in the 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.

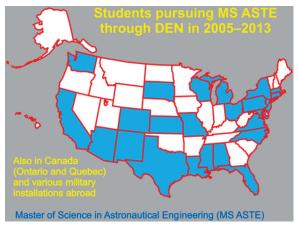
Some exams are closed book and some are open book, the latter allowing use of course notes, textbooks, and old homework assignments and solutions. Calculators are usually required. The calculators become increasingly powerful, with the distinction from laptop computers blurring. Some instructors thus 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 – oncampus 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.

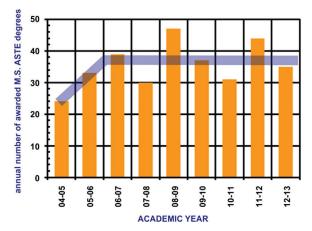
All on-campus students also have access to lecture webcasts of classes in which they are enrolled. As a result, some full-time students also choose to sometimes watch lectures from their homes at convenient times instead of attending them in classroom studios. At the same time, some distance education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

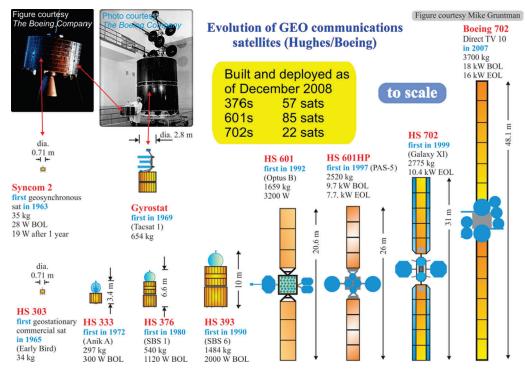
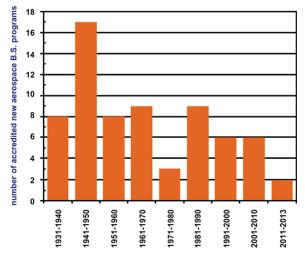


Fig. 7. Spectacular growth of communications satellite capabilities: example of geostationary satellites developed by Hughes/Boeing; BOL – beginning of life; EOL – end of life (M. Gruntman, Space System Fundamentals, Course Notes, 2008; also [20]).



**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.

#### References

- [1] M. Gruntman, The time for academic departments in Astronautical Engineering, AIAA 2007-6042, AIAA Space-2007 Conference, Long Beach, California, 18-20 September 2007; http://dx.doi.org/10.2514/ 6.2007-6042; available for download at: <a href="http://astronauticsnow.">http://astronauticsnow.</a> com/SpaceEducation/> or directly(http://astronauticsnow.com/mg\_ pubs/gruntman\_aiaa-2007-6042.pdf>.
- [2] B.W. McCormick, The growth of aerospace education following its beginning, in: B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, VA, 2004, pp. 18–28.
- [3] R.F. Brodsky, Some ideas for an undergraduate curriculum in astronautics, in: Proceedings of the ASEE Annual Conference Proceedings,
- [4] R.F. Brodsky, The time has come for the B.S. in astronautical engineering, Eng. Educ. 76 (1985) 149-152.
- [5] L.S. Fletcher, Aerospace engineering education for the 21st century, Acta Astronaut. 41 (1998) 691-699, http://dx.doi.org/10.1016/S0094-5765(98)00067-8.
- [6] P.J. Torvik, The evolution of Air Force aerospace education at the Air Force Institute of Technology, in: B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, VA, 2004, pp. 786-799.
- [7] Profiles of Engineering and Engineering Technology Colleges, American Society for Engineering Education (ASEE), Washington, D.C., 2013.
- [8] E. Teller, J.L. Shoolery, Memoirs: A Twentieth Century Journey in Science and Politics, Perseus Publishing, Cambridge, MA, 2001.
- [9] R.F. Brodsky, On the Cutting Edge. Tales of the Cold War Engineer at the Dawn of the Nuclear, Guided Missile, Computer and Space Ages, Gordian Knot Books, 2006 (p. 148). [10] R.E. Vivian, The USC Engineering Story, USC Press, 1975.
- [11] M. Gruntman, R.F. Brodsky, D.A. Erwin, J.A. Kunc, Astronautics degrees for the space industry, Adv. Space Res. 34 (10) (2004) 2159–2166, http://dx.doi.org/10.1016/j.asr.2003.04.070.
- [12] R.E. Kaplan, Aerospace engineering at the University of Southern California, in: B. McCormick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, AIAA, Reston, VA, 2004, pp. 540-552.
- [13] B. McCOrmick, C. Newberry, E. Jumper (Eds.), Aerospace Engineering Education During the First Century of Flight, 2004, AIAA, Reston, VA.
- [14] Spacebound!, Vol. 13, California Space Authority, Summer, 2003.
- [15] D. Barnhart, J. Sullivan, P. Will, M. Gruntman, Advancing exploration risk reduction and workforce motivation through dynamic flight

- testing, AIAA-2007-6040, Space-2007 Conference, Long Beach, California, 2007, http://dx.doi.org/10.2514/6.2007-6040.
- [16] T. Barrett, D. Barnhart, J. Kunc, R. Karkhanis, E. Vartanian, M. Guzman, S. Hesar, USC's approach to satellite-based, hands-on, training: the engineering teaching hospital, AIAA 2011-7226, Space-2011 Conference, Long Beach, California, 27-28 September 2011, http://dx.doi.org/10.2514/6.2011-7226.
- [17] F.J. de Bruijn, E.W. Ashford, W.J. Larson, SpaceTech postgraduate space education, Acta Astronaut. 63 (2008) 486-492, http://dx.doi. org/10.1016/j.actaastro.2007.12.015.
- [18] Report of the Select Committee on the U.S. National Security and Military/Commercial Concerns with the People's Republic of China, 105th Congress, 2nd Session, House of Representative, Report 105-851, U.S. Government Printing Office, Washington, DC, 1999.
- [19] The Space Report, Space Foundation, 2013.
- [20] M. Gruntman, The history of spaceflight, in: J.R. Wertz, D. F. Everett, J.J. Puschell (Eds.), Space Mission Engineering: The New SMAD, Microcosm Press, Hawthorne, California, 2011, pp. 4-10. (Chapter 1.2); available for download at: <a href="http://">http://</a> astronauticsnow.com/smadhistory/spaceflight-history\_sme-smad\_ with\_cover\_2011.pdf>.
- [21] M. Gruntman, Blazing the Trail: The Early History of Spacecraft and Rocketry, AIAA, Reston, VA, 2004 (p. 462).
- [22] M. Gruntman, Blazing the Trail: The Early History of Spacecraft and Rocketry, AIAA, Reston, VA, 2004, 275-277.
- Moskovskii Aviatsionnyi Institut ot A do Ya (Moscow Aviation Institute from A to Z), MAI, 1994, p. 49.
- [24] V. Prisniakov, N. Sitnikova, The peak of rocket technology: designer of ballistic missiles V.F. Utkin, IAC-02-IAA.2.1003, 53rd International Astronautical Congress, Houston, Texas, 2002.
- [25] O. Novykov, V. Perlik, N. Polyakov, V. Khytornyi, Continuous space education system and its role in increasing efficiency of engineering staff training for Ukraine space rocket industry, Acta Astronaut. 64 (2009) 33-35, http://dx.doi.org/10.1016/j.actaastro.2008.06.010.
- [26] V. Mayorova, Integration of educational and scientific-technological areas during the process of education of aerospace engineers, Acta Astronaut. 69 (2011) 737-743, http://dx.doi.org/ 10.1016/j.actaastro.2011.04.007.
- [27] E. Vallerani, G. Chiocchia, P. Messidoro, M.A. Perino, N. Viola, SEEDS - the international postgraduate master program for preparing young systems engineers for space exploration, Acta Astronaut. 83 (2013) 132-144, http://dx.doi.org/10.1016/j.actaastro.2012.10.021.



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# The Time for Academic Departments in Astronautical Engineering

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Alarming warnings of the forthcoming shortfalls in aerospace engineering workforce have become common. At the same time, the space segment of the industry continues to grow. The space industry is critically important for national security and for economic competitiveness. Non-space faculty traditionally dominate aerospace engineering departments in universities, with changes in their focus coming at a glacial pace. The time has come for separate academic departments in astronautical engineering. To meet the industrial demand, the University of Southern California established such a new academic unit – Astronautics and Space Technology Division – three years ago in the Viterbi School of Engineering. The current status of the Division, its accomplishments and challenges are reviewed.

# I. Twenty Years After

"Practitioners in the field of astronautics (space engineering) believe that spacecraft design is now a mature endeavor, and the design of space stations is fast approaching the same degree of maturity. Yet, we find that educational resources, other than on-the-job training, available to the many student engineers who yearn for a career in space have not kept pace. The academic world is almost devoid with experience in the space industry ... A just published National Research Council study on NASA-university relationships .... notes that 'interest in space-related disciplines is burgeoning among undergraduates, but the universities are ill-prepared to capitalize on the opportunity.'"

Does the above quote look familiar? Is it an excerpt from a recently published alarming report on workforce development requested by Congress or industry? No. It appeared in an article¹ in "Engineering Education" more than 22 years ago. The article's author, Professor Robert F. Brodsky, argued that the time had come for establishing curriculum in "pure" astronautical engineering leading to a Bachelor of Science (B.S.) degree in astronautical engineering. He hoped that this move would give "astronautics" equal status with "aeronautics" in aerospace engineering departments.

Many important changes have occurred in the ensuing twenty plus years. The Accreditation Board for Engineering and Technology (ABET) now recognizes astronautical engineering as a separate degree. Many aerospace departments across the country offer space-related courses to undergraduate and graduate students. One could argue that astronautical engineering has thus been accepted. A more precise characterization would rather be that aerospace engineering departments "tolerate" space engineering to varying degrees. Aeronautics and astronautics are certainly not of equal status in most present day aerospace engineering departments.

The American Society for Engineering Education (ASEE) does not list astronautical engineering as a separate engineering discipline category<sup>2</sup> and includes the degree into generic "aerospace engineering." With a very few notable exceptions, the degrees are offered in "aerospace engineering" or "aeronautics and astronautics" or in some other similar mix of terms of aeronautics and astronautics. Traditional aeronautics-centered courses still dominate the curricula (though more diverse than in the past) of many aerospace departments, with pure-space-focused programs practically nonexistent. Job opportunities in academe, as manifest by advertising in AIAA's Aerospace America, do not suggest forthcoming changes in emphasis or transformation of aerospace departments.

Does the current status of space engineering education – twenty years after – fully meet the needs of the space industry and government research and development centers in space technology? The answer is no. *The time has come for separate academic space departments offering degrees in astronautical engineering* to better respond to the workforce development challenges of the American space enterprise.

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# II. Educational Programs and Industrial Needs

Twenty years ago there was only one B.S. degree program in astronautical engineering in the country. Today, ABET lists this program at the U.S. Air Force Academy as the only accredited pure astronautics B.S. degree program (<a href="http://abet.org">http://abet.org</a> [cited 31 May 2007]). (ABET groups all aerospace, aeronautical, astronautical, and possible combinations thereof in one "aerospace engineering" category.)

To the best of my knowledge, only two other B.S. degree programs in astronautical engineering exist today: one in the Capitol College in Maryland and the other in the University of Southern California (USC) in Los Angeles. Capitol College is located a few miles from NASA's Goddard Space Flight Center. Its astronautics Bachelor's degree requirements – in addition to several space engineering courses – are substantially loaded with the electrical engineering curriculum, including courses in circuit design, digital electronics, microprocessors, and communications (<a href="http://www.capitol-college.edu">http://www.capitol-college.edu</a> [cited 23 July 2007]). The program focuses on space operations; the web site promotes it as a path to "joining NASA's team." ABET does not list this degree as an accredited aerospace degree program. The University of Southern California approved the full set of degrees (see Section V below) in astronautical engineering two years ago and its Bachelor's degree in astronautical engineering is ABET-ready and will undergo accreditation after graduation of a few cohorts of undergraduates.

So, twenty years after Prof. Brodsky's call to arms, only three programs in the United States offer pure-space-focused B.S. degrees in astronautical engineering. At the same time, ABET lists 56 accredited aerospace engineering degrees and five aeronautical engineering degrees (<a href="http://abet.org">http://abet.org</a> [cited 31 May 2007]). The ASEE database for 2005–2006 academic year (private communications, Michael T. Gibbons, ASEE, 2007) shows only three pure-space-focused Master of Science (M.S.) degrees in astronautical engineering. Two degrees are offered by graduate institutions of the Services, the Air Force Institute of Technology (AFIT) and the Naval Postgraduate School (NPS). (In contrast to universities, the M.S. degrees offered by AFIT and NPS are also accredited by ABET – see text box below.) USC offers the third Master's degree program: it seems to be the only pure-space-focused graduate degree program in astronautical engineering offered by American universities. Students (reflecting the needs of the industry that employs them) show strong interest in the M.S. degree in astronautical engineering which caused remarkable growth of the USC program – see Section VI below.

The focus of the American aerospace academe is not exactly on space. At the same time, the economy, infrastructure, and national security of the United States depend on space more than those of any other country in the world. Our country leads the world in space exploration and space applications. Only France (and the Soviet Union in the past) approaches the U.S. space expenditures in terms of the fraction of the gross domestic product (GDP). Most other industrialized countries in Europe and Japan spend in space, as fraction of GDP, four to six times less than the United States.<sup>3</sup>

## ABET Accreditation of M.S. degrees

The ABET list of accredited aerospace programs includes only four Master of Science programs: two in aeronautical engineering and two in astronautical engineering. Graduate schools of the Services offer these programs, the Air Force Institute of Technology (AFIT) at White-Patterson Air Force Base in Ohio and the Naval Postgraduate School (NPS) in Monterey, California. Why do military institutions of higher learning undergo accreditation of their graduate degrees? Peter J. Torvik of AFIT explains,<sup>4</sup>

The Department of Defense submitted to the Bureau of Budget in 1952 and in 1953 proposed legislation authorizing the award of master's and doctor's degrees to students in the Resident College [of AFIT]. But there were difficulties. The regional accrediting agency (North Central) was reluctant to support the granting of undergraduate degrees by institutions that were primarily technical or scientific. It initially recommended that USAFIT concentrate its effort on the graduate programs rather than seeking authority to grant undergraduate degrees. The U.S. Office of Education was unconvinced that government-supported schools should grant degrees at all, and there were those in the Office of the Secretary of Defense who did not feel that the Air Force should be conducting 'schools of higher education.' But on August 30, 1954, President Dwight Eisenhower signed Public Law 733 of the 83rd Congress, giving degree granting authority for programs completed in the Resident College of the United States Air Force Institute of Technology, subject to accreditation by a nationally recognized accreditation association or authority.

Arrangements for an accreditation visit were made, and in October of 1955, [the ABET predecessor the Engineers Council for Professional Development] ECPD granted accreditation for both curricula.

NASA primarily focuses on astronautics, with only 3.2% of its 2008 fiscal year budget allocated to aeronautics. Space exploration enjoys enthusiastic support of many Americans. National security space has expanded beyond the national assets addressing strategic objectives: space has become an integral part of military operations, directly supporting warfighter on the ground. The concepts of responsive space and tactical space assets are gradually moving into implementation. Satellites contribute to the maturing missile defense system. Satellite capabilities enable new commercial applications. The Space Foundation reports that worldwide space industry revenues reached \$180 billion in 2005, including \$110 billion in commercial activities.<sup>5</sup> The importance of space and its role in national security and national economy will continue to grow. The U.S. space industry is strong, with exciting careers for astronautical engineers readily available.

Clearly, the importance of space will increase and the opportunities for engineers with degrees in astronautics are abundant. A degree in astronautical engineering is a natural path to becoming with time a

# **Americans Support Space Exploration**

A majority of Americans – 63% – believe humans will establish a permanent colony on the moon someday, with 39% holding the belief it will come within 50 years...

[66% of Americans] are interested in space exploration.

... Four in five [of Americans] said that it's important to America's international prestige to have a space program, and 71% oppose any cut to NASA's budget ...

While 80% of Americans see a space program as vital to America's international prestige, a lower 75% believe a *manned* program is necessary to this purpose.

Zogby poll press release, 3 May 2007 Zogby International, <a href="http://www.zogby.com">http://www.zogby.com</a> [cited 9 May 2007]

systems engineer in the space industry and then to technical and managerial leadership positions in space programs. At the same time, 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<sup>6</sup> "is there any space in aerospace" remains.

## **Space Education**

While recognizing that the U.S. system of higher education is unique, we note approaches to space engineering education in other spacefaring nations. The most important example is obviously the highly space capable Soviet Union of the past which poured enormous state resources into ballistic missiles and space. (It is reasonable to assume that the People's Republic of China copied the Soviet system in 1950s and developed its space education along analogous lines, reflecting fundamental similarities of communist totalitarian states.)

Following the government decree of 1946,<sup>7</sup> the Soviet Union created a number of engineering departments (faculties) focused on training scientists and engineers for ballistic missile and space programs. These specialized faculties were usually hosted by leading universities and other technical institutions of higher learning located near major rocket and space design bureaus and production plants (Moscow, Leningrad, Kuybyshev, Krasnoyarsk, Omsk, Dnepropetrovsk, etc.). These faculties produced thousands of engineers educated specifically in the areas of rocketry and space technology. (Based on coursework and duration of studies, the degree of engineer in the Soviet Union roughly corresponded to a Master's degree in the United States.) For example, the Physical-Technical Faculty of the Dnepropetrovsk State University (supporting Yuzhnoe Design Bureau and Yuzhmash plant) in Ukraine trained 20,000 space and rocket engineers in the 50 years since 1952.<sup>8</sup> The space engineering faculty of the Moscow Aviation Institute (MAI), one of several space education institutions in Moscow, graduated each year more than 500 space engineers by early 1990s; it employed more than 170 full-time faculty members.<sup>9</sup> Today, MAI enrolls annually more than 300 freshmen in its space engineering program (private communications, Prof. Oleg M. Alifanov, 2006).

Several specialized graduate education programs in space engineering have emerged in Europe. The International Space University in Strasbourg, France, offers a one-year Master's program. The joint space department, located in Kiruna, of Umeå University and Luleå University of Technology offers a Master's program in Space Engineering in Sweden. 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 two-year degree program Joint European Master in Space Science and Technology, with students taking courses in any of the participating universities.

#### **Aerospace Engineering Departments**

The final major influence on education in aeronautics and astronautics came in the '50's with the launching of the space age. After Russia shocked the world on October 4, 1957 with the launching of Sputnik, the West hurried to catch up and duplicate their feat. Many of the engineers attempting to do this were aeronautical engineers who knew little about rocket propulsion, orbital mechanics and such. The academic community hurried to fill this void and most of this effort was done within the existing departments of aeronautical engineering. It was a natural transition then to find that these departments, beginning around 1957 to about 1965, changed their names to reflect activities in astronautics. Those that adopted something like "Aeronautics Astronautics" were realistic. The term "Aerospace Engineer" immediately brings to mind, to the man on the street, a "rocket scientist." There are still many of us who would rather be called "aeronautical engineers" but that went out of fashion in the first half of the 60's.

Barnes W. McCormick, 2004<sup>10</sup>

Diversity of arrangements and flexibility to experiment remain a vital strength of the American system of higher education. In 2004, the USC Viterbi School of Engineering (VSOE) created a new purespace-focused academic unit, Astronautics and Space Technology Division (ASTD), in order to take advantage of rapidly growing opportunities in space.<sup>11</sup> The division operates as an independent academic department, offering a full set of university-approved degrees (Bachelor of Science, Bachelor of Science Minor; Master of Science, Engineer, PhD) in astronautical engineering. It is anticipated that the division will formally assume the name of a department in a few years. Student interest and enrollment in degree programs in astronautical engineering are rapidly growing. Academic and administrative independence of the division has enabled success of this experiment (see Section VI below).

ASTD experience shows that independent academic units focused exclusively on space engineering can significantly contribute to meeting the existing educational needs of the space industry. Realities of academe are such that university departments do not change their focus 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 expands.

Does the disconnection between existing educational programs and industrial needs mean that each traditional aerospace department should branch off its space-focused groups of faculty? No, not necessarily. It does mean however that there are circumstances when the pure-space-oriented departments offering degrees in astronautical engineering are *the answer* to the educational challenges and they will prosper. Co-existence of traditional aerospace and pure-space-focused astronautical departments will bring the needed diversity and competition in meeting national educational needs. Similarly, purely aeronautical engineering programs, as they are offered today by at least four universities, complement the mix of available options. (The accredited Bachelor's degrees in *aeronautical engineering* are offered by the University of California in Davis, Clarkson University, Rensselaer Polytechnic Institute, Western Michigan University, and also by the United States Air Force Academy; AFIT and NPS offer accredited Master's degrees in *aeronautical engineering*.)

Establishment of independent academic departments in astronautical engineering will shift the existing competition (which is rarely fair) from between the groups of faculty within aerospace departments to a (much more even-leveled) competition between aerospace, astronautical, and aeronautical departments. This is a practical approach to achieve flexibility within constraints of realities of the academe. The competition among the departments of various universities will force the balanced mix of the offered programs, determined by national educational needs. The American space enterprise and the American student will win.

The time has come for independent academic space departments offering degrees in astronautical engineering to meet the educational needs of the space and defense industries and government research and development centers in space technology. What follows below describes the motivation and the focus of a pure-space-focused academic unit established at USC, its current status, accomplishments and challenges.

# III. National Space Workforce Challenges

Alarming warnings of the forthcoming shortfalls in aerospace engineering workforce have become common during the last ten years. At the same time, the space segment of the industry continues to grow. Space technology and applications are critically important for national security and for economic competitiveness. Many government and industrial leaders point at the acute need to improve space-related education as a major challenge for the American space enterprise.

More than thirty five years has passed since the great advances in space technology of the 1960s. Much of the expertise in the space industry and government research and development centers is held today by engineers nearing or past retirement age. The report (2002) of the *Commission on the Future of the United States Aerospace Industry*, chaired by former congressman Robert S. Walker, noted<sup>12</sup> that "the industry is confronted with a graying workforce in science, engineering and manufacturing, with an estimated 26 percent available for retirement within the next five years." The Commission recommended<sup>13</sup> that "the nation immediately reverse the decline in, and promote the growth of, a scientifically and technologically trained U.S. aerospace workforce." In 2003, NASA's Associate Administrator for Education described the situation as a national crisis<sup>14</sup>: "this year [2003], [NASA] potentially may have 200 to 300 engineers and scientists exit the workforce because they will be retirement-eligible. Also, in the next three to five years, roughly 25 to 30% of that skill set also will be retiring, and that's a national crisis."

This challenge was recognized already in mid-1990s. A magazine of the space industry sounded an alarm<sup>15</sup> in 1997: "There is a growing shortage of engineers available to space-oriented businesses in the U.S. and Canada. The shortage, because of industry predictions of rapid and sustained growth in commercial space activities and low student enrollment rates at engineering schools, is likely to adversely affect the industry for a decade or more." In another chilling observation, an editorial in AIAA's *Aerospace America* noted<sup>16</sup> that "80% [of aerospace workers] said that they would not recommend aerospace careers for their own children."

Very recently, Aviation Week and Space Technology emphasized the workforce problems in the cover story, 17 "aerospace companies aren't attracting nearly enough engineers to replace the wave of baby boomers nearing retirement. The gap could have a profound effect on the future of the [aerospace] industry – and the nation." The presented dynamics of the evolution of the aerospace workforce unmistakably points at the particularly significant increase of the older workers and decline in the middle age group: 17

Age group	35 yr and younger	35–44 yrs	45 yrs and older
1998	22%	39%	39%
2005	18%	27%	55%

In addition, my personal observation based on anecdotal evidence points to another consequential trend of transferring high-performing and most technically-capable engineers into management positions. This trend calls for stepping up training and education, including pursuit of advanced degrees, of the engineering workforce. Fortunately, many leading space companies and government centers recognize the need and include coverage of tuition towards Master's degrees as part of standard compensation packages.

Note that undergraduate and graduate engineering education is part of a broader challenge facing the United States today. The Walker Commission emphasized<sup>13</sup> that "the nation must address the failure of the math, science and technology education of Americans. The breakdown of America's intellectual and industrial capacity is a threat to national security and our capability to continue as a world leader." (As part of a research university, Astronautics Program at USC concentrates its effort on the undergraduate and graduate engineering components of the educational challenge.)

The immediate consequences of the growing older aerospace workforce were complicated, and perhaps partly mitigated, by deep impact of the end of the Cold War which caused substantial shrinking of the defense industry. Total aerospace-related employment in the United States decreased<sup>16</sup> by 45%, from 1,280,000 to 700,000 workers, between 1987 and to 2002, and stabilized afterwards.

Enrollment in nation's engineering schools declined in 1990s. In the mid-1990s, the space side of the aerospace sector of the economy began to grow again. The commercial space business expanded, while the national security programs stabilized. By 1999, commercial satellites and satellite services accounted for twice as much revenue as the military and government space share of the market. The number of commercial launches from Cape Canaveral Air Force Station outnumbered military and civilian government launches in 2000. While the grand vision of communication satellite constellations has not materialized, commercial space applications steadily expand. Satellite systems have limited lifetime and need to be periodically reconstituted. Therefore, even maintaining existing national security space capabilities would keep the space industry busy. In addition, NASA's space exploration programs enjoy solid support of the Americans and will continue.

This turnaround in fortunes of the space and defense industries also shows in aerospace engineering enrollment statistics in undergraduate and Master's programs between 1999 and 2006 (Table 1). While the total engineering enrollments (presented here as a reference for comparison) edged up by 10–15%, enrollment in aerospace programs increased by 60%. Note that "aerospace" here includes aerospace, aeronautics, and astronautics.

A large fraction of engineering students in the United States are foreign nationals, which presents a special challenge for the space industry and government research and development center. In 2006, about 5.1% of enrolled undergraduate engineering students (all majors) were in this category; the fraction was much higher in Master's

Table 1. Aerospace and Total Undergraduate and Master's Enrollment (based on Ref. 2).

	1999	2000	2001	2002	2003	2004	2005	2006
Undergrad Enrollment								
Aerospace Engineering	7,962	8,842	9,756	9,772	11,310	12,145	16,470	16,599
Total	364,858	373,073	389,993	397,878	408,766	409,778	397,437	404,504
Master's Enrollment								
Aerospace Engineering	1,495	1,755	1,741	1,631	1,984	2,162	2,428	2,385
Total	70,752	75,368	78,947	89,442	91,665	87,194	82,991	83,515

Note that ASEE has changed the way it collected data between 2004 (enrollment at the department level) and 2005 (enrollment at the degree program level). In particular, "some aerospace data was grouped with mechanical data prior to 2005 because mechanical engineering departments often award aerospace degrees. Consequently, the aerospace total is much larger in 2005." While the 36% jump in undergraduate enrollment in 2004–2005 is partly an artifact, the trend is obvious – the undergraduate enrollment in aerospace programs increased by at least 60% between 1999 and 2006. The effect of change in data collection is much smaller in Master's enrollment. "Aerospace" includes enrollment in aerospace, aeronautics, and astronautics.

(36.3%) and especially doctoral (54.1%) programs.<sup>2</sup> In the aerospace field, foreign nationals accounted for 5.5% of Bachelor's degrees awarded in academic year 2005–2006; at the same time 24.5% of Master's degrees went to foreign nationals (private communications, Michael T. Gibbons, ASEE, 2007).

In physics (a traditionally important field for the space industry), according to the American Institute of Physics, first-year foreign graduate students for the first time outnumbered U.S. nationals in 1998–2002. In 2003 and 2004, U.S. citizens had edged up back into majority. In 2004, the most numerous groups of foreign students came from the People's Republic of China (33%), India (12%), and Eastern Europe (11%). In the time period from 1999 to 2004, the fraction of students from China increased from 26% to 33%, the fraction of students from India doubled from 6% to 12%, and the fraction of students from Eastern Europe dropped from 21% to 11%.

Not only are graduating foreign nationals largely ineligible for defense contractor employment and the military services, but the International Traffic in Arms Regulations (ITAR) effectively limit their participation in civilian commercial projects. Foreign students are also excluded from research and development in many areas of space science and space technology. Many industrial leaders and university administrators have been arguing for relaxation of ITAR restrictions and for facilitating the path for graduating foreign nationals to obtain permanent residency status and stay in the United States permanently. It does not make much economic sense to educate foreign students and then send them back to their home countries which sometimes are openly hostile to the values of the free world and to the United States. One does not have to be a rocket scientist to realize that such practice helps those adversarial states in building capabilities in the areas of critical importance to U.S. national security and economic competitiveness.

The issue is a complex one, however. During last several years, major federal civil penalties were assessed for ITAR-related and other similar violations<sup>20</sup> to a number of major space and defense contractors, including Space Systems Loral, Inc. (\$14.0M in 2002); Hughes Electronics Corp and Boeing Satellite Systems (\$12.0M in 2003); EDO Corporation (\$3.0M in 2004); ITT Corporation (\$3.0M in 2004); General Motors Corporation (\$8.0M in 2004); Orbit Advanced Technologies Inc. (\$0.5M in 2005); The Boeing Company (\$15.0M in 2006); Goodrich Corporation (\$1.25M in 2006); and L-3 Communications (\$2.0M in 2006). In March of 2007, ITT pleaded guilty and was fined \$100M for transfer of night vision technology to the People's Republic of China. The continuing ITAR violations will certainly weaken arguments for relaxing ITAR restrictions and the recent ITT case in particular may actually lead to strengthening their enforcement.

Accommodating ITAR-restricted research and development programs on campuses, with numerous foreign students and open class enrollments, presents a challenge to university administrators. Supporting ITAR-restricted

programs is especially important for maintaining excellence in the areas of space science and space technology. Accommodating classified research in space technology poses even a greater challenge to universities. While some faculty and administrators, particularly from disciplines other than science and engineering, may argue against classified work, restrictions on classified research infringe on academic freedom. Faculty members who are willing, capable, and qualified for such work should be given the opportunity to conduct it.

Whether the alarming government, Congressional, and industrial findings and reports on the state of the U.S. space workforce collect dust on library shelves or translate into changes depend on a concerted effort by all stakeholders of the American space enterprise, including the space industry, civilian and national security elements of the government, academe, and professional societies, especially AIAA.

The Air Force's Space Command recently made major steps in addressing challenges of space workforce development. The Space Professional Development Program seeks to provide education and training in space technology and operations to the Air Force officers.<sup>21</sup> The Space Command identified more than 7000 personnel (Credentialed Space Professionals) that constituted the "space cadre." To better appreciate the magnitude of the challenge, one only needs to note that most of the cadets graduating from the Air Force Academy major in the fields other than science and engineering. Many of these officers will later operate complex national security space missions and manage acquisition of space systems.

The Space Command created a space education and training organization by activating on 18 October 2004 the National Security Space Institute (NSSI) as the Department of Defense's single focal point for space education and training. NSSI complements existing space education programs at the Air University, Naval Postgraduate School, and Air Force Institute of Technology. Some space fans may call NSSI the beginning of the "Starfleet Academy." The Space Command also established the Space Education Consortium (coordinated by the University of Colorado in Colorado Springs, Co., and including a dozen of universities) as the primary source for civilian space-related educational programs.

Whether NASA, industry, and academe match this Air Force initiative in national security space remains to be seen.

The universities can and should contribute to meeting the educational challenges and reversing alarming trends in the nation's space workforce by determined and focused actions. We report below how establishing an independent academic unit focused exclusively on

astronautics and space technology have made a difference in one particular university, the University of Southern California. 11,22-25

# IV. Challenges in Academe and Astronautics at USC

At major research universities, the faculty members largely determine the fields of their concentration and change in the areas of faculty interests does not come easily. Edward Teller once noted<sup>26</sup> "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 course requires determined effort by visionary and powerful administrators.

Aerospace engineering at USC was rather typical for the country. Most of the aerospace engineering faculty have been traditionally focused on incompressible fluid dynamics research since the Department's founding in 1964. Only a very few courses in space technology were offered in 1980s to graduate students by adjunct faculty. By early 1990s, however, several tenure-track faculty had been added in modern areas of research

# The Trouble in Academia

Although astronautical engineering logically could be adopted by mechanical engineering (structures, heat transfer, controls), electrical engineering (power, communications, controls), or aerospace engineering (structures, aerodynamics, controls, orbital mechanics), it appears almost by default to have become the neglected offspring of the aerospace departments. It gives the faculties of most aerospace engineering departments great comfort to believe that since their curriculum teaches "basics," their proffered education already "covers" the field of astronautics. This is not surprising since profiles of the faculties of the 50odd departments giving some kind of an aerospace degree show that only a handful have worked in the space industry for any significant time, and that few consult with industry. Moreover, most are wellestablished in research and devoted to aeronautics and thus have little incentive to take an interest in space technology. It is easy for them to rationalize their arguments, since they don't know what an astronautical engineer needs to know.

Robert F. Brodsky, 1984<sup>28</sup>

such as hypersonic flight, physical kinetics, space science, and space instrumentation. This group formed the nucleus of the Astronautics Program within the Aerospace Engineering Department. (The Aerospace Engineering Department merged with the Mechanical Engineering Department in 1998–1999, forming Department of Aerospace and Mechanical Engineering.<sup>27</sup>)

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 penned by its former chairman only once casually mentions the Astronautics Program,<sup>27</sup> though already at the time of his writing the courses offered by this pure-space-focused program accounted for 80% of the total 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 rapidly growing and approaching half of the total enrollment in the aerospace program. (When this rendition of history by the former department chairman was mentioned in our another publication<sup>11</sup> the reviewer rhetorically asked in his comments, "what is special here?" This is exactly the problem: many "mainstream" senior aerospace faculty focus on fluid mechanics and aeronautics, tolerate some elements of astronautics, and consider it "normal." We cannot provide the space engineering education without challenging and changing this attitude.)

The USC aerospace engineering program was also rather typical for American universities<sup>29</sup> in other respects: after program rapid growth in 1980s, the undergraduate student population dropped in mid-1990s, following the end of the Cold War, by a factor of five from its peak.<sup>27</sup>

There were some obvious opportunities, however. USC, the oldest and largest private university on the West Coast, is strategically positioned in the heart of the American space industry in Southern California. California accounts for roughly one half of the revenues of the U.S. space enterprise and California dominates (~80%) the satellite segment of the market.<sup>30</sup> The university is located in Los Angeles and USC's Viterbi School of Engineering has broad expertise and long tradition of working with the aerospace and defense industries. (During the last several years, *U.S. News and World Report* consistently ranked the Viterbi School among top ten engineering schools in the United States.) As part of a private research university, the Viterbi School is dynamic, innovative, and entrepreneurial. Clearly, the *University of Southern California was a natural home for an initiative in space technology*.

So, our response to the doom-and-gloom atmosphere of mid-1990s was to found the Astronautics and Space Technology Program (Astronautics Program) focused on providing engineering degrees in the area of spacecraft technology for the space industry and government research and development centers.

We described the early history of the program in some detail elsewhere. 11,22-25 Briefly, in the mid-1990s, the astronautics faculty of the Aerospace Engineering Department began introducing coursework designed to support the space industry and government research and development centers in Southern California. In addition to the core faculty of the Astronautics Program, the program faculty included several USC faculty from the Aerospace and Mechanical Engineering, Electrical Engineering, and Physics and Astronomy Departments as well as part-time lecturers and adjunct faculty. We started with only a few selected space-related courses taught by regular and adjunct faculty and steadily expanded the curriculum. The Master's degree program with emphasis in astronautics was introduced first as a specialization in 1997 and was formally approved by the University as a degree program in Aerospace Engineering (Astronautics) with a separate postcode in 1998. The approval of the Graduate Certificate and the Bachelor of Science degree in Aerospace Engineering (Astronautics) followed. This astronautics specialization degree went with flying colors through ABET accreditation as part of the aerospace program.

This step-by-step development of the program in space engineering laid the foundation to what would follow in 2004.

## V. Astronautics and Space Technology Division at USC

Following the initial success of the USC Astronautics Program, the University has taken a major step in further program development. In order to position the USC Viterbi School of Engineering to take full advantage of rapidly growing opportunities in space, Dean of Engineering Professor Max Nikias announced in August 2004 the creation of a new pure-space-focused academic unit, the Astronautics and Space Technology Division. (Prof. Nikias was appointed Provost of USC in 2005.) ASTD, the reorganized Astronautics program, is an independent academic unit within the Viterbi School of Engineering and functions in a manner similar to an academic department. I was privileged to be appointed the first (founding) chairman of ASTD for the three-year term 2004–2007. Two aerospace engineering professors, Daniel A. Erwin and Joseph A. Kunc, became other founding faculty of ASTD. The University approved the new academic title, *Professor of Astronautics*, for the Division faculty.

ASTD assumed immediate charge of all degree programs in aerospace engineering (astronautics) and astronautics-related courses. The Division is responsible for programs in astronautics and space technology in the Viterbi School. In 2005, ASTD obtained University approvals of the full set of new degrees in *astronautical engineering*: Bachelor of Science, Bachelor of Science Minor, Master of Science, Engineer, and PhD. In addition, the University approved the Graduate Certificate in astronautical engineering. It is anticipated that the Division will assume the name of a "department" after graduating a few cohorts of undergraduates.

(Parenthetically, building a new academic unit is a prodigious task. It does not happen often in universities, so many arrangements have to be re-invented. In addition, a sheer number of administrative loose ends that need to be tied up is staggering. Naturally, not every faculty member outside the new unit is happy with the changes and thus particularly collegial and helpful. It took more than two years to achieve the state of a smoothly operating academic unit.)

Today, ASTD offers the full set of degrees in astronautical engineering and also manages old degrees in aerospace engineering (astronautics) that are being phased out. Freshmen enrollment varies between 10 and 20 students, being capped by the University. The typical undergraduate student takes classes full-time and completes the degree work in four years or eight semesters, taking four to six courses per semester. In addition to the courses required of all undergraduate engineering students (mathematics, physics, chemistry, and humanities), specialized undergraduate courses cover the following astronautics areas: orbital mechanics; space environment; compressible, rarefied, and molecular gas dynamics; spacecraft attitude dynamics; rocket propulsion; and spacecraft design. The Bachelor's degree program in astronautical engineering is ABET-ready – it is based on the astronautics specialization in aerospace engineering that was ABET-reviewed during earlier accreditation of the aerospace program.

The underlying basic science and engineering courses, along with engineering design and laboratories, are for the most part the same as taken by aerospace and mechanical engineering undergraduates. A notable exception and significant difference are in the thermo-fluids course sequence that emphasizes modern statistical concepts, compressible gasdynamics, and rarefied gases and plasmas. Space communications is another important technical area which is outside of the scope of a traditional aerospace curriculum but required for program ABET accreditation. Astronautics students are exposed to various aspects of space communications in several courses: orbital mechanics classes address orbital features and ground coverage; space environment lectures deal with wave propagation in the ionosphere; and the spacecraft design course covers communications link budgets, communications subsystems, and constraints and effects on other spacecraft subsystems.<sup>11</sup>

Creating opportunities for exiting team projects designing and building space-related systems and components is of particular importance in engineering education. Astronautics undergraduates are involved in student projects, including sounding rockets and microsatellites. ASTD works jointly with VSOE's Information Sciences Institute (ISI) in bringing new opportunities for astronautics undergraduates in hands-on experience in space technology.<sup>31</sup>

A few astronautics students pursue doctoral degrees and the Division graduated the first PhD in astronautical engineering earlier this year. ASTD faculty presently includes three full-time tenured senior faculty, two research faculty, two adjunct professors, and a number of part-time lecturers. Several engineering and physics faculty hold joint appointments in ASTD. A search for new tenure-track faculty members is under way.

The Master of Science program in astronautical engineering grew up significantly and it remains the flagship of the Astronautics Program. The program played the key role in development of astronautical engineering at USC and it has achieved national recognition. *Its successful record also strongly argues in favor of establishing pure-space-focused degrees and academic units nationwide.* We review the program in some detail in the next section.

# VI. Master of Science in Astronautical Engineering

The USC Viterbi School of Engineering has traditionally strong ties to the defense industry. For many years, VSOE's Distance Education Network (DEN) offered Master's degree programs in various areas of engineering. Working full-time engineers enroll in the program as part-time students. In 2005–2006 academic year, the Viterbi School awarded 1190 Master of Science degrees in engineering, more than any other engineering school in the United States.<sup>2</sup>

# A. Initial Focus on Master's Degree

There were several reasons for our initial focus in early 1990s on the Master of Science program. It was practical to begin development of the space engineering specialization with the Master's degree because of interest by students from the industry in Southern California. DEN provided a powerful tool to conveniently reach these students.

Another 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. and three M.S. degrees in astronautical engineering in existence nationally. The last but not the least reason for the focus on the Master's program was its reliance on adjunct faculty and part-time lecturers. Bringing new highly-specialized classes was thus practical and possible without hiring new tenure-track faculty.

## **B.** Adjunct Faculty and Part-Time Lecturers

Adjunct faculty and part-time lecturers play an important role in the M.S. program. Graduate engineering programs in the United States are traditionally oriented along academic lines in the areas in which doctoral degrees are normally granted. Some areas of space technology 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, spacecraft design attracts a large number of inquiries by students and engineers about the possibility of pursuing doctoral degrees.

Moreover, many areas critical to the space industry are sufficiently specialized and rapidly evolving that no university faculty member would be likely to possess a real command of them unless he or she had spent years working in industry. Ironically, in the latter case, such a person would unlikely qualify for tenure in a research university because of the overriding requirement of superb academic 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. The field is progressing so rapidly that degree programs offered by a relatively static full-time tenure-track faculty would not keep up with industrial developments.

# **Distance Learning at USC**

Around 1970, the USC School of Engineering initiated a pioneering effort in distance education called the Instructional Television Network (ITV). Remote classrooms were set up at local aerospace companies such as Hughes, McDonnell Douglas, Rockwell, TRW, the Aerospace Corporation, and many others. ITV was an extensive interactive oneway video, two-way audio broadcast system.

ITV was very successful and cemented close ties between USC and the local companies. However, the system had limitations and was costly, with the affiliated companies maintaining special distance education centers and arranging reception of USC broadcasts. ITV had eight F.C.C.-licensed digital television channels transmitted from two mountain top locations in the Los Angeles area. The system coverage was limited to the Los Angeles and Orange Counties. A USC courier daily collected homework and delivered to the remote sites graded homework, new assignments, and course handouts. Examinations were held on campus and required that students traveled to USC.

In the late 1990s, ITV was reorganized into the Distance Education Network (DEN). Since that time, courses are broadcast over the Internet, or "webcast," using streaming compressed video and audio over the web. Standard high-speed Internet connection allows viewing lectures from home or office anywhere in the world. Consequently, new technology has expanded the program reach. The webcasting opened a way for small companies and even individuals to enroll in our DEN programs. The password-protected lectures could be viewed, asynchronously, at any time during or after the actual lectures during the entire semester. Class notes, homework assignments, and handouts are transmitted to students electronically. Exams are taken on campus by students in the greater Los Angeles area. At distant sites, the exams are typically proctored at local community colleges.

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, engineering mathematics, and fundamentals of spacecraft design, orbital mechanics, propulsion, and space environment. The adjunct faculty, who are typically have full-time positions in the space industry and NASA field centers, primarily cover the highly specialized and rapidly changing areas of space technology.

The adjunct faculty and part-time lecturers are a great strength of our program. The access to the unmatched wealth of first-rate experts in space technology in the greater Los Angeles area allows us to launch new courses as needed. The courses taught by lecturers are primarily aimed at students in the Master's degree program and contain much more current space-industry practice than could be offered by a regular university faculty.

# C. Program Students

The Master of Science program in astronautical engineering focuses on students who work full-time while earning their degrees. These students (about 80% of the total number) are employed by the space industry and government research and development centers and take their classes through DEN. The remaining 20% of our students are full-time on-campus students. A full-time graduate student not engaged in research could complete the degree in one year of two semesters. In practice, full-time graduate students are also engaged in some research projects and complete the degree requirements in three or four semesters. Some students decide to continue their studies towards the PhD degree after completion their Master's program. Here, the critical issue is identifying a faculty advisor to guide the student.

Most of the students working full time take one or occasionally two courses every semester. The students are highly motivated and their workload at the main job determines the possible load. Consequently, their typical time of studies ranges from two and half to four years. Many distance education students today earn their degree without the need of ever visiting the campus.

Astronautics program graduate advisors help the students to select sets of courses that best fit their educational goals. Usually students desire to get in-depth knowledge in the technical area of their present job. There is another category of students, however, that concentrates on the areas of technology where they would like to transfer to in their companies. Specializing in the desired areas often facilitates such internal moves.

Graduate degrees in astronautical engineering, whether obtained through on-campus study or remotely through the distance education program, are bona fide university degrees. There is a significant difference between a university degree program and short courses in specialized areas such as those offered by UCLA's Extension Program, AIAA, LaunchSpace, or Applied Technology Institute which do not grant degrees. A degree program emphasizes fundamentals and basic science and engineering and their role and applications in specialized topics, whereas a typical short course emphasizes specific applications. The semester-long courses taken towards advanced degrees last three-four months and provide much deeper penetration into the topic through extensive homework, term papers, and other course-related projects. In addition, the feedback and corrections through graded course assignments and continuous contact – live and/or electronic – with the instructors and teaching assistants offer much more than can be usually obtained in even the best-taught short course.

As a matter of policy, VSOE treats all students – on-campus and remote – 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. This policy is an effective mechanism of quality control.

Access to webcast courses is also open to on-campus students enrolled in those classes. As a result, some full-time students choose to watch classes from their homes instead of attending the lectures in classrooms. At the sane time, some local distance education students prefer attending some lectures on campus.

#### **D.** Enrollment Dynamics

Figure 1 shows the dynamics of graduate student enrollment in astronautics courses. We started the program in 1994 by packaging few available astronautics courses in an informal specialization within the Aerospace Engineering Department and began introducing new coursework. Initially, only two astronautics-related courses were available each semester. Today, we offer half a dozen astronautics courses each semester. (This number does not include the required engineering mathematics courses.) By 1998, graduate students enrolled in astronautics courses of the Aerospace Engineering Department outnumbered by a factor of 4 students enrolled in other (non-astronautics) aerospace classes. This ratio remained roughly the same in the next several years.

The Astronautics Program attracted significant student interest and generated positive feedback from the space industry. It became clear that administrative and academic independence of the program was indispensable for further growth. In the summer of 2005, Dean of Engineering Prof. Max Nikias and the University administration established ASTD as an independent academic unit. In the ensuing three years, the program showed remarkable growth, on average about 20% per year (80% growth in three years), in the number of students enrolling in its courses. The growth was achieved at the time of accomplishing numerous academic and administrative tasks of creating the new academic unit, such as approval of new degrees in curriculum committees, creating new entries in catalogs, establishing student admission and advising systems, enrolling first cohorts of freshmen into the new program and guiding them, developing an innovative internship program jointly with VSOE's ISI, and completing numerous administrative tasks of new mail codes, financial accounts, web sites, listings, etc.

The remarkable growth of the Astronautics Program at USC convincingly confirms the wisdom and timeliness of establishing a new independent academic unit in astronautical engineering.

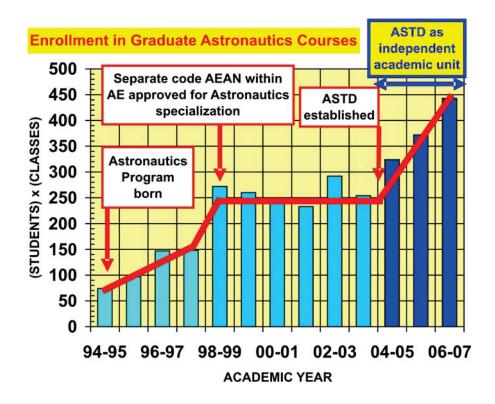


Figure 1. Enrollment dynamics of graduate students in astronautics classes at USC. The program began in 1994. In 1998–1999 academic year the university approved an astronautical specialization *aerospace engineering (astronautics)* with a separate postcode AEAN within the aerospace engineering program.

Today, almost 160 graduate students are enrolled in our Master's program in astronautical engineering: this is about 6–7% of the national enrollment in the broadly defined area of aerospace/astronautical/aeronautical engineering. One quarter of the aerospace/astronautical/aeronautical students nationwide study part-time and work full time. In this latter category, our share is about 20% of national enrollment.

The required introductory course of the Astronautics Program is *Spacecraft System Design*. This is the perhaps the largest graduate course in spacecraft design in the country; Figure 2 shows the dynamics of enrollment in the course. Many astronautics students take this course in the beginning of their studies. (Establishing the individual sequence of courses of study is usually up to a student, with the help of a graduate advisor.) Those astronautics students who take the Spacecraft System Design class will continue their studies in our program and take a number of specialized courses in space technology. Therefore, the enrollment in this class serves as a reliable indicator of the program state during the next two years. The dynamics of enrollment (Fig.1 and Fig. 2) suggest further program growth in the near future.

We graduated 34 students with the degrees *M.S. in astronautical engineering* in 2005-2006 academic year. In this period, we thus accounted for about 3% of M.S. degrees awarded nationally in the broadly defined area of aerospace/astronautical/aeronautical engineering. In astronautical engineering, for comparison, AFIT granted 12 M.S. degrees in 2005–2006 (private communications, Michael T. Gibbons, ASEE, 2007). In 2006–2007 we graduated 37 students. Because part-time students are significant majority in our program and it takes about four years for them to complete studies and graduate, the annual number of our graduates will significantly increase in the next two-three years.

## E. Program Reach

I personally teach the required course in the program, Spacecraft System Design (Fig. 2). In addition to astronautics students, this class is also taken by many engineering students with other specializations who work or plan to work in the space industry. Student surveys in the class provide useful statistics on program reach.

Today, about one half of students enrolled in the spacecraft design class pursue the space-focused degree in astronautical engineering. This fraction of pure-space-focused students was significantly smaller five—ten years ago. The enrollment to the astronautical program began to grow especially rapidly after establishing of independent ASTD. The program has earned the solid reputation and is highly visible in the space industry; the students are satisfied; and the word-of-mouth plays today perhaps the most important role in the program promotion.

The other half of the students in the class pursues various degrees in engineering. The most numerous group – about 20% – are from the M.S. program in Systems Architecting and Engineering. Electrical Engineering students account for about 12–15% and Mechanical Engineering students and Aerospace Engineering students contribute about 8–10% each. Sometimes we have a few civil engineering, computer engineering, and physics students as well as engineering students from the "undecided" category. (VSOE DEN allows qualified students to begin their studies without being formally admitted to the Master's program. Up to four courses taken as such "limited status" students are later credited toward the degree. This is a convenient way for students to begin studies immediately while having their applications for admission to degree programs being processed.)

Webcasting opened the program to students "from sea to shining sea" across the United States. During the last three years, about 20% of the students in the class were located outside California. Astronautics program at USC has become a truly national program. Each year, the students in the Spacecraft System Design class hail from 10–14 States of the Union.

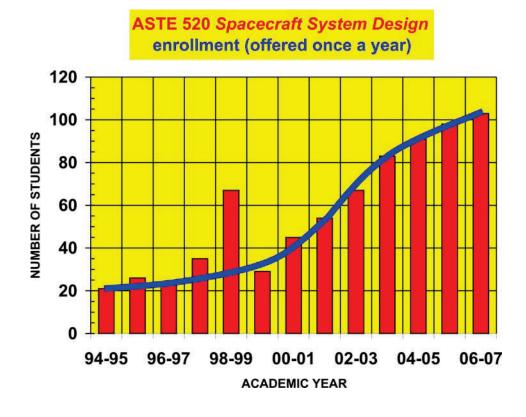


Figure 2. Annual enrollment is the required course Spacecraft System Design since 1994–1995 academic year. A significant expansion by a major company in Southern California caused an enrollment spike in 1998–1999. Many students enrolled in this class would continue studies towards the M.S. degree in astronautical engineering by taking specialized courses. The class enrollment is a reliable indicator for the total student enrollment in astronautics courses during two years in the future.

Many our students work for leading space companies. The list includes many branches of Boeing and Northrop-Grumman. The students also come from Lockheed-Martin, United Space Alliance, Raytheon, Aerojet, Orbital Sciences, ATK, RAND, BAE, Rockwell Collins, Goodrich, Scitor, Sparta, Swales, Microcosm, Stellar Solutions, Honeybee Robotics, and many others. Many students work at NASA centers, especially in JPL in Pasadena and JSC in Houston. A number of students are from the Aerospace Corporation and Air Force's Space and Missile Systems Center (SMC). Several officers (Air Force, Army, Navy, Marine Corps) on active duty stationed elsewhere in the country and overseas are enrolled in our program.

## F. Program Coursework

The required coursework for the Master's degree in astronautical engineering consists of nine courses (27 units), with all regular graduate classes being 3 units. In addition to the required mathematics classes, a half a dozen graduate astronautics classes are offered to students every semester. Many specialized courses are taught by our adjunct faculty and part-time lecturers who are leading specialists working in the space industry and government centers. These specialists bring the real-world experience, a vital component of a high-quality program.

To earn the Master's degree, students must take two required core overview courses (6 units) in spacecraft design and space environment and spacecraft interactions; two required courses (6 units) in engineering mathematics; one core elective course (3 units) chosen from a list of core elective classes; and four technical elective courses (12 units). While most of graduate non-astronautics science and engineering courses can be approved as technical electives, many students, however, find the diverse offering of core electives so attractive that they choose all or almost all their technical electives from this list.

Table 2. ASTD courses offered for graduate credit.

Available through DEN	Offered each year	Offered every other year	Course
*	*		Spacecraft System Design (required)
*	*		Space Environment & Spacecraft Interaction (required)
*		*	Design of Low Cost Space Missions
*	*		Spacecraft Propulsion
*		*	Advanced Spacecraft Propulsion
*		*	Liquid Rocket Propulsion
		*	Physical Gas Dynamics I
		*	Physical Gas Dynamics II
*		*	Near Space Flight (first time offered in spring 2008)
*	*		Orbital Mechanics I
	*		Orbital Mechanics II
*	*		Space Navigation: Principles and Practice
*		*	Spacecraft Attitude Control
*		*	Spacecraft Attitude Dynamics
*		*	Spacecraft Structural Dynamics
*		*	Systems for Remote Sensing from Space
*		*	Spacecraft Sensors
*		*	Spacecraft Power Systems
*		*	Spacecraft Thermal Control
	*		Space Studio Architecting

The two required classes, Spacecraft System Design and Space Environment and Spacecraft Interactions, are broad survey-type courses. The Spacecraft Design course also serves as an entrance gateway both for students with non-aerospace engineering undergraduate majors and for those who have been some years out of school. Students of the latter category have often been promoted into management of technical projects and for them this course program is a return to direct involvement with technical study. (Robert F. Brodsky introduced perhaps the first spacecraft design course in the United States at the Iowa State University in 1972; he began teaching this course at USC – as an adjunct professor – in 1982.<sup>32</sup>)

ASTD-offered courses cover a wide range of topics in astronautics and space technology. Most of the courses are webcast by DEN. All required courses offered every year as well as a few elective courses, such as orbital mechanics. Many highly specialized courses offered every other year. The latter arrangement allows us to use the same number of precious DEN slots for a larger number of available courses. Demand accumulates for elective classes during the off semesters, resulting in a larger number of students enrolled in these classes. The program is thus fiscally sound, which allows to gradually build the program up, experimenting with new courses. Since it takes about four years for most full-time-working students to complete their studies, careful planning of their coursework usually allows them to take all the desired courses.

Table 2 shows ASTD courses presently offered for graduate credit. We anticipate addition of several new courses in the future, subject to availability of qualified instructors, DEN slots, and programmatic needs. Among possible additions are courses in reliability of space systems, space launch systems, manned spaceflight, constellation design, responsive space systems, space communications, and space science.

## VII. Ad Astra!

The workforce development for the American space industry and government research and development centers is a major national challenge. We, at USC, have built a comprehensive educational program in space engineering. The University demonstrated the vision and established a new independent academic unit, Astronautics and Space Technology Division, which offers a full set of degrees in astronautical engineering. ASTD is highly successful and has achieved national recognition; it rapidly grows.

The story of Astronautics at USC clearly shows that the space industry needs the pure-space-focused education. It also shows that academic and administrative independence of the program is indispensable for its success. The time has come for separate academic space departments offering degrees in astronautical engineering to better respond to the workforce development challenges of the American space enterprise.

## References

<sup>1</sup>Brodsky, R.F., "The time has come for the B.S. in astronautical engineering," *Engineering Education*, December 1985, pp.149–152.

<sup>2</sup>Profiles of Engineering & Engineering Technology Colleges, ASEE, Washington, D.C., 2007.

<sup>3</sup>Gruntman, M., Blazing the Trail: The Early History of Spacecraft and Rocketry, AIAA, Reston, Va., 2004, p. 462.

<sup>4</sup>Torvik, P.J., "The evolution of Air Force aerospace education at the Air Force Institute of Technology," *Aerospace Engineering Education During the First Century of Flight*, edited by B. McCormick, C. Newberry, and E. Jumper, AIAA, Reston, Va., 2004, pp. 786–799.

<sup>5</sup>Aviation Week and Space Technology, Vol. 165, No.20, 2006, p. 16.

<sup>6</sup>Brodsky, R.F., On the Cutting Edge. Tales of the Cold War Engineer at the Dawn of the Nuclear, Guided Missile, Computer and Space Ages, Gordian Knot Books, 2006, p. 148.

<sup>7</sup>Gruntman, M., Blazing the Trail: The Early History of Spacecraft and Rocketry, AIAA, Reston, Va., 2004, pp. 275–277.

<sup>8</sup>Prisniakov, V., and N. Sitnikova, "The peak of rocket technology: designer of ballistic missiles V.F. Utkin," 53rd International Astronautical Congress, IAC-02-IAA.2.1.003, Houston, Tex., 2002.

<sup>9</sup>Moskovskii Aviatsionnyi Institut ot A do Ya (Moscow Aviation Institute from A to Z), MAI, 1994, p. 49.

<sup>10</sup>McCormick, B.W., "The Growth of Aerospace Education following its Beginning," *Aerospace Engineering Education During the First Century of Flight*, edited by B. McCormick, C. Newberry, and E. Jumper, AIAA, Reston, Va., 2004, pp. 18–28.

<sup>11</sup>Gruntman, M., D.A. Erwin, and J.A. Kunc, "USC Astronautics Program: from humble beginning to new academic unit," Proceedings of the ASEE Annual Conference, 2005.

- <sup>12</sup>Walker, R.S. (Chairman), Final Report of the Commission on the Future of the United States Aerospace Industry, December 2002, p. v.
- <sup>13</sup>Walker, R.S. (Chairman), Final Report of the Commission on the Future of the United States Aerospace Industry, December 2002, p. xvi.
  - <sup>14</sup>Loston, A.W., interview with, NASA Tech Briefs, Vol. 27, No. 6, June 2003, pp. 14–16.
  - <sup>15</sup>Brown, D.A., "Help wanted: the engineering job market," *Launchspace*, October/November 1997, pp. 22–27.
  - <sup>16</sup>Durocher, C., "Our future, our hands," Aerospace America, Vol. 41, No.2, February 2003, p. 3.
  - <sup>17</sup>Anselmo, J.C., "Vanishing act," Aviation Week and Space Technology, Vol. 166, No. 6, 5 February 2007, pp. 44-46.
  - <sup>18</sup>Lewis, J. and E. Schlather, *Preserving America's strength in satellite technology*, The CSIS Press, 2002.
  - <sup>19</sup>Sietzen, F., "Commercial space: A global commons?," Aerospace America, Vol. 39, No. 8, August 2001, pp. 35–41.
  - <sup>20</sup>Performance and Accountability Report, FY 2006, Department of State, 2006, pp. 324, 325.
- <sup>21</sup>Grier, P., "The Air Force's goal is a 'space-oriented culture of professionals' who will advance US power," *Air Force Magazine*, Vol. 87, No. 6, June 2004, pp. 57–59.
- <sup>22</sup>Gruntman, M., R.F. Brodsky, D.A. Erwin, J.A. Kunc, and E.P. Muntz, "USC Astronautics Program," 38th AIAA Aerospace Sciences Meeting, AIAA 2000–0801, 2000.
- <sup>23</sup>Gruntman, M., R.F. Brodsky, D.A. Erwin, and J.A. Kunc, "Advanced degrees in astronautics through distance learning," 53rd International Astronautical Congress, IAF–02–P.2.06, Houston, Tex., 2002.
- <sup>24</sup>Gruntman, M., R.F. Brodsky, D.A. Erwin, and J.A. Kunc, "Workforce development for the space industry," AIAA–2003–6309, Space–2003, Long Beach, Calif., 2003.
- <sup>25</sup>Gruntman, M., R.F. Brodsky, D.A. Erwin, and J.A. Kunc, "Astronautics degrees for the space industry," *Adv. Space Res.*, Vol. 34, issue 10, 2004, pp. 2159–2166.
  - <sup>26</sup>Teller, E., with J.L. Shoolery, *Memoirs: A Twentieth Century Journey in Science and Politics*, Perseus Publ., 2001.
- <sup>27</sup>Kaplan, R.E., "Aerospace Engineering at the University of Southern California," *Aerospace Engineering Education During the First Century of Flight*, edited by B. McCormick, C. Newberry, and E. Jumper, AIAA, Reston, Va., 2004, pp. 540–552.
  - <sup>28</sup>Brodsky, R.F., "Some ideas for an undergraduate curriculum in astronautics," ASEE Annual Conference Proceedings, 1984.
- <sup>29</sup>McCormick, B., C. Newberry, and E. Jumper, editors, *Aerospace Engineering Education During the First Century of Flight*, AIAA, Reston, Va., 2004.
  - <sup>30</sup>Spacebound!, Vol. 13, California Space Authority, Summer 2003.
- <sup>31</sup>Barnhart, D., J. Sullivan , P. Will, and M. Gruntman, "Advancing Exploration Risk Reduction and Workforce Motivation through Dynamic Flight Testing," AIAA–2007–6040, Space–2007, Long Beach, Calif., 2007.
- <sup>32</sup>Brodsky, R.F., On the Cutting Edge. Tales of the Cold War Engineer at the Dawn of the Nuclear, Guided Missile, Computer and Space Ages, Gordian Knot Books, 2006, pp. 144–150.