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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.

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 ABET-accredited 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 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.

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
<u>required</u>
Spacecraft System Design
Space Environment and Spacecraft Interactions
Orbital Mechanics I
Spacecraft Propulsion
<u>core electives and electives</u>
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 on-campus 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

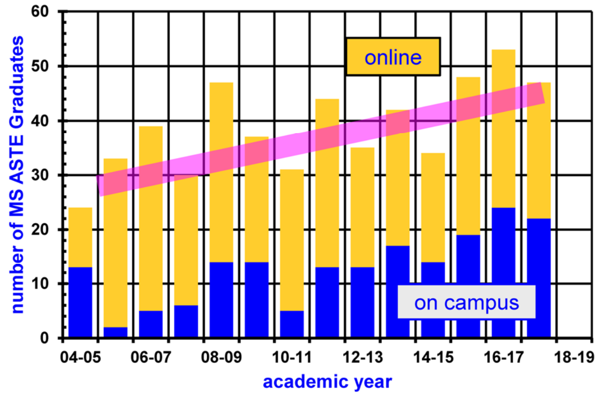

Figure 2. Annual number of the awarded Master of Science degrees to online (light orange) and on-campus (dark blue) students in astronautical engineering from the founding of the Astronautical Engineering Department at USC. The MS ASTE program accounts for more than 3% of the Master's degrees awarded 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 working engineers who balance their work responsibilities that often include lengthy travel to tests, other professional activities, and family life. The full-time 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 non-space 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.

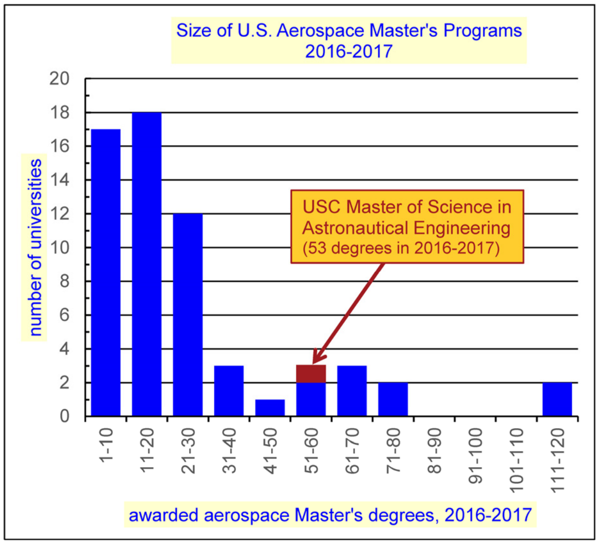

Figure 3. Distribution of the numbers of awarded Master of Science degrees in broad aerospace area in the United States in 2016-2017 academic year. The USC MS ASTE program ranked the 8-9th in size. Based on ASEE data [8].

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.

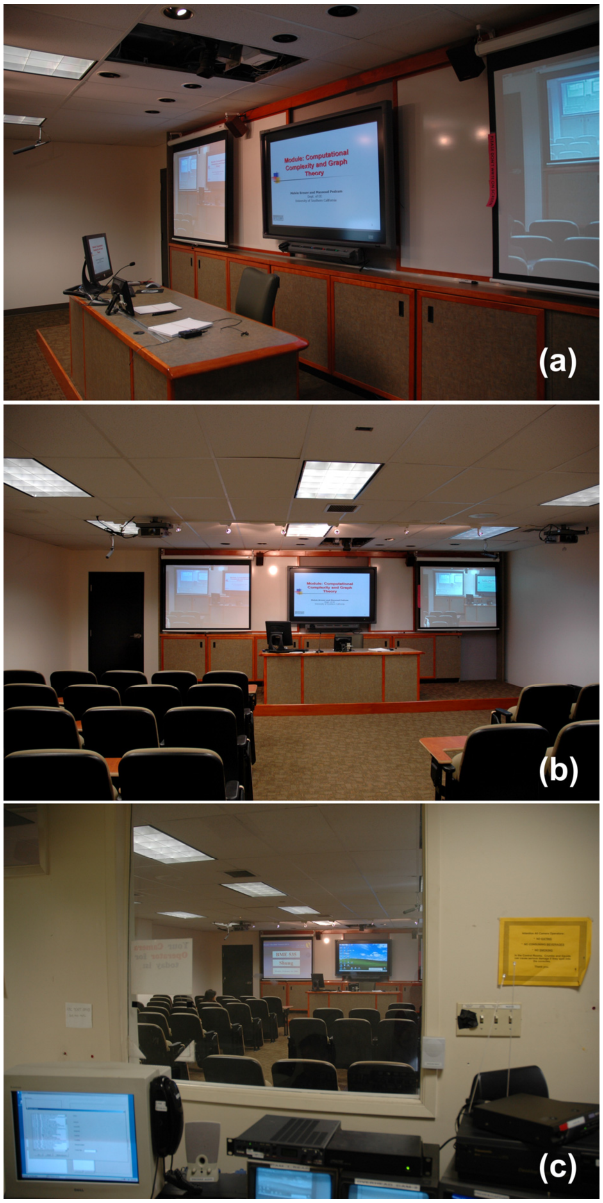

Figure. 5. Typical DEN classroom studio on USC campus. (a) Instructor's desk with a smart electronic board behind and two large screens on the sides. Streaming webcast is usually displayed on the screens for in-class students to see. The instructor can use a desktop computer or laptop for the prepared 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.

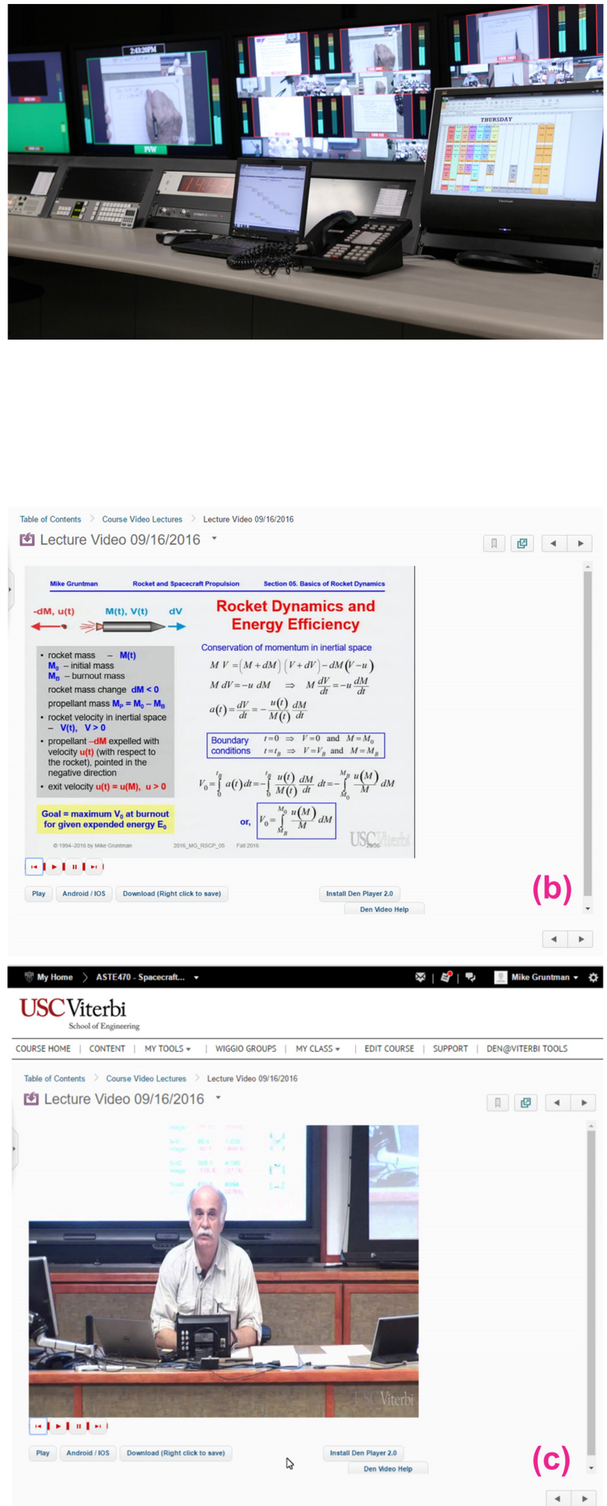

Figure 6. (a) DEN's master control center overseeing webcast and capture of lectures in multiple studios. (b,c) Screenshot examples of a lecture webcast (the author's course on rocket propulsion) as viewed by online students. As technology of streaming over the Internet evolves, the quality of webcasts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

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-and-third places with the University of California, Los 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].

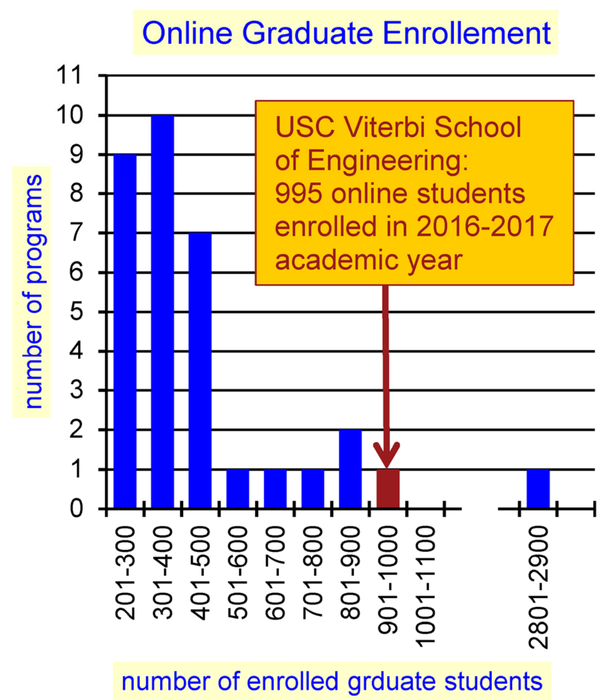

Figure 7. Distribution of enrollments in online graduate engineering programs in the United States in the 2016-2017 academic year. Programs varied from the largest with more than 2800 enrolled students to those with a few hundred students each. The USC Viterbi School of Engineering was the second largest 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].

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

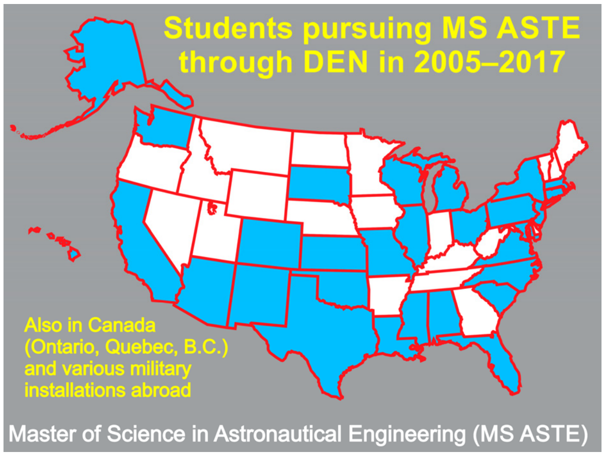

Figure 8. USC students pursuing online the degree Master of Science in Astronautical Engineering through distance education reside in many states (blue) as well as in Canada and stationed at military installations abroad.

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 high-quality 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 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 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 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!

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