



Astronautics degrees for the space industry

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Abstract

The Astronautics Program (<http://astronautics.usc.edu>) of the University of Southern California (USC) offers a full set of undergraduate and graduate degree programs in Aerospace Engineering with emphasis in Astronautics. The Bachelor of Science and Master of Science degree programs in Astronautics combine basic science and engineering classes with specialized classes in space technology. The Certificate in Astronautics targets practicing engineers and scientists who enter space-related fields and/or who want to obtain training in specific space-related areas. Many specialized graduate classes are taught by adjunct faculty working at the leading space companies. The Master of Science degree and Certificate are available entirely through the USC Distance Education Network (DEN). Today, the Internet allows us to reach students anywhere in the world through webcasting. The majority of our graduate students, as well as those pursuing the Certificate, work full time as engineers in the space industry and government research and development centers while earning their degrees. The new world of distance learning presents new challenges and opens new opportunities. Distance learning, and particularly the introduction of webcasting, transform the organization of the graduate program and class delivery. We describe in detail the program's academic focus, student reach, and structure of program components. Program development is illustrated by the student enrollment dynamics and related industrial trends; the lessons learned emphasize the importance of feedback from the students and from the space industry.

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1. Origins of the University of Southern California astronautics program

Fifteen years ago, the large majority of students in the Aerospace Engineering program at the University of Southern California (USC), both undergraduate and graduate, were employed after graduation by aerospace companies doing government and military business. The defense buildup of the 1980s absorbed a great number of new engineers in development of fighter aircraft, cruise and air-to-air missiles, laser-targeted munitions, and similar programs. After the end of the Cold War, however, our enrollment dropped precipi-

tously amid the general economic downturn in Southern California: the undergraduate student population dropped by a factor of five from its peak.

At USC, most of the Aerospace Engineering faculty have been traditionally focused on incompressible fluid dynamics research since the Department's founding in the 1960s. More recently, several faculty were added in modern areas of research such as hypersonic flight, physical kinetics, and space science. This group formed the nucleus of the Astronautics Program.

In the mid-1990s, the aerospace sector of the economy began to grow again, but this time on the space side. The commercial space business expanded sharply, while the national security programs stabilized. Commercial space was becoming particularly important, changing the way how the space industry operates and emphasizing cost efficiency over largely performance-driven government

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programs. Commercial satellites and satellite services had roughly accounted for twice as much revenue as the military and government space share of the market by 1999 (e.g., Lewis and Schlather, 2002). The number of commercial launches from Cape Canaveral Air Force Station outnumbered military and government civilian launches in 2000 (e.g., Sietzen, 2001).

Meanwhile, it had been close to thirty years since the great advances in space technology of the 1960s. Much of the expertise in the space industry was held by engineers nearing or past retirement age, so that the industry's need for space-related education became acute. A magazine of the space industry sounded an alarm in mid-1990s: "There is a growing shortage of engineers available to space-oriented businesses in the USA 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" (Brown, 1997).

University of Southern California, the oldest and largest private university on the West Coast, was and is uniquely positioned to handle this need. The heart of the American space industry is in Southern California. The university is located in Los Angeles and USC's nationally-ranked School of Engineering has broad expertise and long tradition of working with the aerospace industry. The astronautics faculty of the Aerospace Engineering Department responded to the industry's new direction in mid-1990s by introducing coursework designed to support the space industry, as well as the government research and development centers in Southern California. At first only a few space-related courses were offered, but the curriculum steadily expanded. (The Master's degree program with emphasis in astronautics was introduced as a specialization in 1997 and formally approved as a separate degree program by the university in 1998).

We began with the Master's degree program, building on the reach of USC's Distance Education Network (DEN), which broadcasts graduate classes to working engineers at their company sites. It was also practical to begin with the Master's degree because of seemingly unending but gradually subsiding, forced by market demands, resistance in academia to separate undergraduate programs in astronautics. The need for distinctive accredited undergraduate programs in space engineering reflected the needs of the space industry and was advocated in academia since early 1980s, with the first degree introduced by the Air Force Academy (Brodsky, 1985). A number of universities experimented since then in various mixes of programs in aeronautics and astronautics (e.g., Hunter and Desautel, 1993).

Today the USC Astronautics Program offers bachelor's degree, master's degree, and graduate Certificate programs in Aerospace Engineering with emphasis in

Astronautics. All undergraduate and many graduate students study full-time on-campus. Six or seven graduate astronautics classes are offered every semester, available for students throughout the country to take from their remote worksites through DEN. DEN, which has played a key role in the development of our programs, originally offered courses only to large aerospace companies in the Los Angeles area, but now reaches students worldwide.

2. Academic orientation of program

Most graduate engineering programs in the United States are oriented along academic lines, so that the areas of emphasis are those in which doctoral degrees are normally granted. In part this is because of traditional faculty hiring and promotion practice, which requires research and publication in refereed scientific journals.

Space technology contains a large number of separate areas, not all of which are directly compatible with doctoral study. For example, spacecraft design is not normally considered an academic area in an aerospace engineering context, because the knowledge base required to be an expert designer is broad rather than deep. (Design methodology, a related field of considerable current interest, is an academic area normally found in departments such as operations research and industrial/systems engineering.) 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. Examples of such areas are spacecraft power systems and spacecraft thermal control.

Because of these considerations, it is not possible to provide comprehensive astronautics degree programs focused on the needs of the space industry with instruction given only by regular university-based faculty. Even if enough regular faculty positions were available to cover the diverse course requirements, it would be academically impossible to find faculty in all the specialized areas. Moreover, the field is progressing so rapidly that degree programs offered by a relatively static full-time tenure-track faculty would not keep up with new industry-specific topics year by year.

In our program, the regular faculty primarily focuses on basic science and technology. These areas include engineering mathematics, thermal sciences, fundamentals of orbital mechanics and propulsion, space science and space environment. The program faculty are drawn from the astronautics faculty and others within the Aerospace and Mechanical Engineering (AME) Department, as well as from the Electrical Engineering and Physics and Astronomy departments (USCs Aerospace

Engineering and Mechanical Engineering Departments merged, forming the AME Department, in 1999.). Highly specialized areas of space technology are covered primarily by adjunct faculty, who are world experts in their fields of space technology. Their regular positions are typically in the space industry and NASA field centers.

The adjunct faculty has proven to be a great strength of the program. There is a wealth of first-rate experts in space technology in the greater Los Angeles area, which allows us to launch new courses with a far greater agility than could be done through the regular faculty hiring cycle. We consider having instructors that bring real-world experience into the classroom a vital component of our program. The courses taught by adjunct faculty 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.

It is important to emphasize that the graduate degrees in the Astronautics Program, whether obtained through on-campus study or remotely through the Distance Education Program, are bona fide university degrees. By contrast, programs of professional study such as UCLA's Extension Program (<http://www.ucla-extension.org>) and the short course programs offered by AIAA (<http://www.aiaa.org/professional>), LaunchSpace (<http://www.LaunchSpace.com>), or Applied Technology Institute (<http://www.aticourses.com>), do not grant degrees. The degree program emphasizes fundamentals and basic science and engineering and their role and applications in specialized topics, whereas the typical short course emphasizes a specific application. The semester-long courses taken towards advanced degrees provide much deeper penetration into a topic through extensive homework, term papers, and other course-related projects, along with feedback and corrections through graded course materials and through protracted contact with the instructors, than can be obtained in even the best-taught short course.

3. Organization of curricula

3.1. Bachelor of science in aerospace engineering (Astronautics)

In addition to the courses required of all undergraduate engineering students (mathematics, physics and chemistry, as well as humanities), specialized undergraduate courses cover the following astronautic areas: orbital mechanics; space environment; rarefied and molecular gas dynamics; the solar system; spacecraft attitude dynamics; rocket propulsion; and spacecraft design. 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.

The exception is the thermo-fluids sequence. The courses taken by non-astronautics aerospace engineering students lay strong emphasis on equilibrium processes and incompressible fluid dynamics. In space applications, however, incompressible fluids are rarely seen, while rarefied gases and plasmas, often far from thermal equilibrium, take on great importance. Study of these requires a strong base in statistical ideas as well as a modern, molecular-based approach to gasdynamics and reacting flows. We therefore developed a new set of courses taken specifically by astronautics students, which emphasizes kinetics, statistical mechanics, and high-energy gasdynamics. These courses provide a solid foundation for solving challenging technical problems faced in industry and for pursuing advanced degrees in space technology.

Space communications is an important technical area which is outside of the scope of a traditional aerospace curriculum. Our students study various aspects of space communications in several classes: orbital and ground coverage aspects are discussed in orbital mechanics; wave propagation in the ionosphere is considered in space environment; and the spacecraft design course covers communications subsystems and interactions with other subsystems. Space-related design experience is provided by a spacecraft design project, part of the spacecraft design course. In this project, students individually design, on paper, a spacecraft to meet selected mission goals, which includes sizing up the spacecraft and working out mass, power and communication link budgets, as well as performing mission and lifetime analyses. In addition to formal coursework, many students gain practical experience of working in a team by joining the student microsatellite project. This is an interdisciplinary collaboration of students, primarily undergraduates, with the goal of designing, building, and launching a small student satellite.

The required coursework for the Bachelor of Science degree is 131 units, with a typical course being 4 units in the first two years and 3 units thereafter. The typical student takes classes full-time and completes the degree work in four years or eight semesters, taking four to six courses per semester.

3.2. Master of science in aerospace engineering (Astronautics)

Our Master of Science (M.S.) program is heavily structured towards students who work full-time while earning their degrees. Most of the students are employed by the space industry and government research and development centers. The program focus has great impact both on course scheduling and on the offering the

classes to remote students through distance education, as seen in detail below.

The required coursework for the Master of Science degree consists of nine courses (27 units), with all regular graduate classes being 3 units. A full-time student not engaged in research could thus complete the degree in one year of two semesters, but in practice, full-time Master of Science students are also engaged in research towards more advanced (Engineer's or Ph.D.) degrees and complete the degree in three or more semesters.

Students must take two required core courses (6 units); one core elective (3 units) chosen from a certain list of classes (Core Elective Courses; Table 1); two courses (6 units) in engineering mathematics; and four technical electives (12 units). The technical electives may, but need not, be chosen from the core electives or from a list of recommended technical electives. In fact, many students find the diverse offering of core electives so attractive that they choose all their technical electives from this list.

Astronautics program coordinators help the students, through advisement, to select sets of courses that best fits their educational goals. Some of the students desire to get in-depth knowledge in the technical area of their current employment. Others concentrate on the areas of technology where they would like to transfer to in their companies. Specializing in the desired areas often helps in such internal moves since the space industry usually encourages continuing education of their engineers and rewards them accordingly.

The two required classes are *Spacecraft Design* and *Space Environment and Spacecraft Interactions*. Both are broad, introductory classes which survey a wide range of material. These classes serve as entrance gate-

ways both for students who come with non-aerospace engineering undergraduate majors and for those who have been some years out of school. The latter is true for quite a few of our M.S. students; in fact, during their professional careers, many students have been promoted into management of technical projects, and for them the program is a return to direct involvement with technical study. The *Spacecraft Design* course also offers an introduction into systems design of spacecraft by emphasizing interplay among major spacecraft subsystems and linking them with the mission, ground control, and launch issues.

The core elective and recommended technical elective requirement classes are listed in Table 1. As one can see, the classes offered cover a wide range of topics in astronautics and space technology and most of the key courses are offered for remote access (marked by *) through DEN. The Astronautics program is being continually modernized and we anticipate that several additional new courses will be offered in the future. Among the considered additions are courses in manned spaceflight, constellation design, space communications, space sensors, and space science. Introduction of the new courses depends on the availability of high-quality instructors, industrial interest, and other programmatic factors.

3.3. Graduate certificate in aerospace engineering (astronautics)

The Certificate program is designed for practicing engineers and scientists who enter space-related fields and who wish to obtain training in specific space-related areas. Certificate students enroll at USC as limited-

Table 1

Core, core elective, recommended elective, and applied mathematics courses for the degree of Master of Science in Aerospace Engineering (Astronautics)

<i>Core courses (required)</i>	<i>Recommended technical elective courses</i>
* Spacecraft System Design	Compressible Gas Dynamics
* Space Environment and Spacecraft Interaction	Physical Gas Dynamics I
	Physical Gas Dynamics II
	* Systems Architecting I
	Systems Architecting II
	Space Studio Architecting
	Computational Techniques in Rarefied Gas Dynamics
	Partially Ionized Plasmas
	Gas-Surface Interactions
	Engineering Vibrations II
<i>Core elective courses</i>	
* Spacecraft Propulsion	
* Systems for Remote Sensing from Space	
* Design of Low Cost Space Missions	
* Spacecraft Power Systems	
* Orbital Mechanics I	
Orbital Mechanics II	
* Spacecraft Attitude Control	
* Spacecraft Attitude Dynamics	
* Spacecraft Thermal Control	
* Space Navigation: Principles and Practice	
* Advanced Spacecraft Propulsion	
* Spacecraft Structural Dynamics	
	<i>Engineering mathematics courses (required)</i>
	* Engineering Analysis I
	* Engineering Analysis II

All courses are 3 units. A student must take two required core courses, two required engineering mathematics courses, one course from the list of core electives, and four technical electives, preferably from the lists of core electives and recommended technical electives.

Courses marked with * are available (televised and webcast) through the USC Distance Education Network.

status students, and are required to take 12 units (four classes) chosen from the core and core elective courses (excluding mathematics courses) of the Astronautics Master of Science degree program (Table 1). After completion of the 12 units, a special Certificate is awarded.

The program provides a vehicle for students who would like to undergo a significant amount of training or retraining, but who do not wish to commit to the more serious amount of work needed for the Master of Science degree. However, our experience shows that many students, upon completing the Certificate, find that their interest and ability has increased to the level where they do want to continue their studies pursuing the Master of Science degree in Astronautics. The coursework for the Certificate is fully applicable towards an advanced degree should the student choose to continue.

3.4. Engineer and Ph.D. programs in aerospace engineering

As at other research universities, our faculty maintain active research programs in science and engineering, primarily supported by NASA, the Department of Defense, and the National Science Foundation. The students involved in this research are typically Ph.D. candidates. As described previously, doctoral work is done on topics of fundamental engineering science rather than in specific application areas. Because of this, there is not the same need for a specifically astronautics-oriented Ph.D. program as there is for the other degrees.

The existing Engineer degree program in Aerospace Engineering is undergoing a revision towards an Astronautics-specific degree. The Engineer degree requires the same coursework, 60 units or 203-units courses, as the doctoral program but no advanced research work as dominates the Ph.D. degree. There appears to be a strong desire both among students and from the industry for a more advanced degree than the Master of Science, but providing greater breadth than is obtained in Ph.D. work. With the great range of astronautics courses now offered through DEN, we anticipate a significant increase in interest to the new Engineer degree. The breadth of the available courses focused on spacecraft subsystems will appeal to the students with the desire to concentrate on complex space systems.

4. Distance learning and its effect on the astronautics program

Several decades ago, USC 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, and the Aerospace Corpora-

tion. ITV was an extensive interactive one-way video, two-way audio broadcast system. A range of classes, primarily in electrical engineering and computer science, was taken by working engineers at their worksites throughout Southern California. Courses were generally offered in the evenings so that engineers' workdays would not be impacted. ITV courses in space technology introduced by one of the authors (RFB) of this article in the early and mid-1980s generated large student interest.

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 establishing special distance education centers and arranging reception of USC broadcasts. The 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. The ITV system was expanded in 1990s. More distant locations throughout the United States were served by compressed video links via ISDN lines and by geostationary satellite links. In addition, USC engineering courses were delivered by the National Technological University (NTU) as part of NTU's degree programs. These developments extended the reach of the program, but the many original limitations remained.

Three years ago, ITV was reorganized into the USC DEN. At that time courses began to be broadcast over the Internet, or "webcast", using streaming compressed video and audio over the web. The new arrangements allowed a wide range of companies to participate in the distance education programs, regardless of their location. Standard broadband Internet access already provides quality webcasting, the technology is continuously and rapidly evolving, and the quality of webcasting will only get better with time.

The lectures could be viewed, asynchronously, at any time during or after the actual lectures. The password-protected class lectures are available for the entire semester and students can log in and watch classes at their convenience. USC makes no distinction between its on-campus and distance students. Although distance students can watch their lectures 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.

Webcasting has made it feasible for students anywhere in the United States to enroll in DEN classes. The webcasting has opened a way for small companies and even individuals to join our DEN programs. Access by foreign companies and individuals is currently limited but is expected to widen in the next few years.

Under the current DEN webcasting system, 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.

With the rise in the commercial space business, demand for DEN access to astronautics courses has grown strongly. Ten years ago, only a very few astronautics courses could be taken remotely. Today the majority of astronautics core and recommended elective courses are offered through DEN, and students routinely earn their entire Master's degrees, or Certificate, without ever attending a course on campus.

5. Enrollment trends

The Astronautics Program has grown steadily since its inception in mid-1990s, and now accounts for half of all students, undergraduate and graduate, taking classes in the Aerospace and Mechanical Engineering Department. Fig. 1 shows the history of a number of graduate astronautics courses offered to date. We have reached an approximate steady state in the range of six to seven classes per semester. We believe that this is an optimal number of courses at this time that allows us to reach the program goals and efficiently serve our students. The number of offered classes may sometimes fluctuate because of sabbatical leaves or other commitments of the on-campus tenure-track faculty. The schedule of the most classes is however firmly maintained allowing students to plan their studies accordingly.

The numbers of students enrolled in graduate astronautics classes gradually grew over time (Fig. 2). The

graduate program is tied more closely to the developments in the space industry and a spike in an enrollment in 1999 was caused by dynamics of hiring at a major company in the Los Angeles area. Clearly, we did not reach the saturation yet in the numbers of students. In fact we anticipate that the student enrollment will likely double within the next five years.

The enrollment growth is expected to come from the program expansion to the space industry in other region of the United States. In addition, more working professionals from our local Southern California companies will enroll because of the unusually broad selection of courses offered by the program. While the number of classes offered each semester did not change since 1999 (Fig. 1), the class selection significantly expanded and the program structure went through profound changes. Most of the specialized elective courses in space technology are now offered every other year. This arrangement allowed us to roughly double the choice of the available courses while preserving acceptable levels of enrollment in individual classes. Financial soundness of the program, particularly in a private university without generous state subsidies, is an important element that, together with academic excellence, made the Astronautics Program a success.

The enrollment in the required *Spacecraft Design* class also serves as another useful indicator of the program trends (Fig. 3). This class, offered every year, is taken by all Astronautics students as well as by engineering students with other specialties who work or plan to work in the space industry. Those Astronautics students who take the *Spacecraft Design* class will continue their studies in our program and take a number of specialized courses in space technology. Thus the

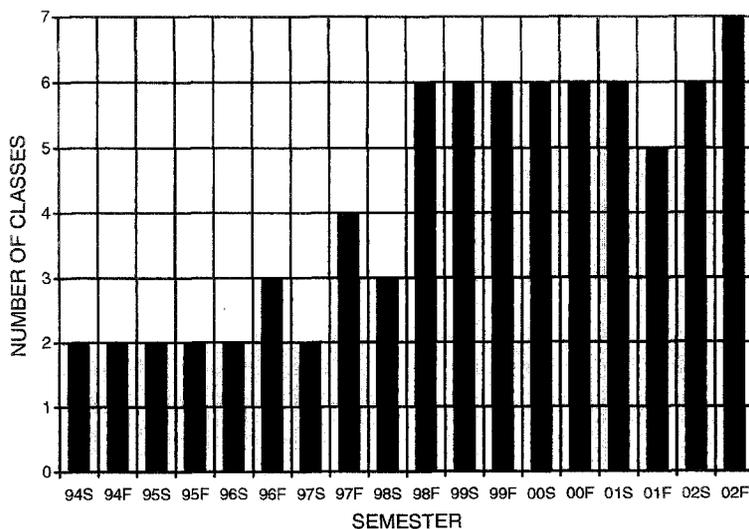


Fig. 1. Number of graduate astronautics courses, excluding mathematics, offered each semester since 1994; F, fall semester; S, spring semester. The number of offered classes sometimes fluctuate due to sabbatical leaves and other commitments of on-campus faculty.

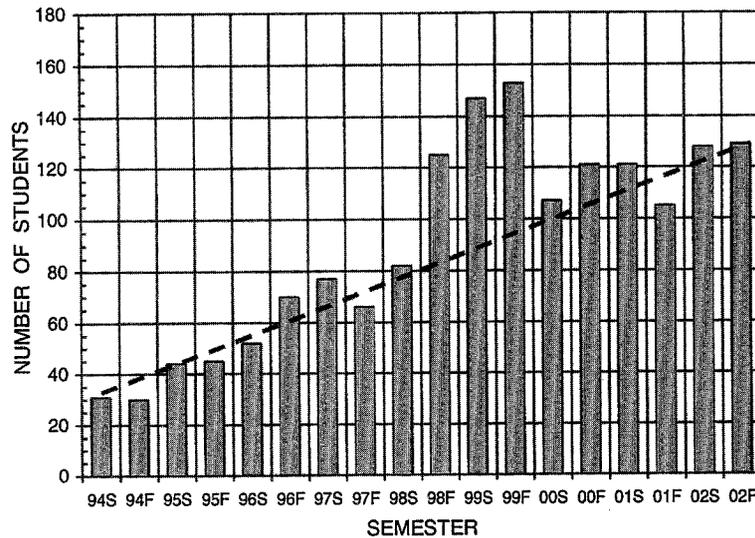


Fig. 2. Number of graduate students enrolled in astronautics classes each semester since 1994; F, fall semester; S, spring semester. An enrollment spike in 1999 was caused by a significant expansion of a major space company in Southern California. The dashed line shows the enrollment trend and does not exhibit saturation yet.

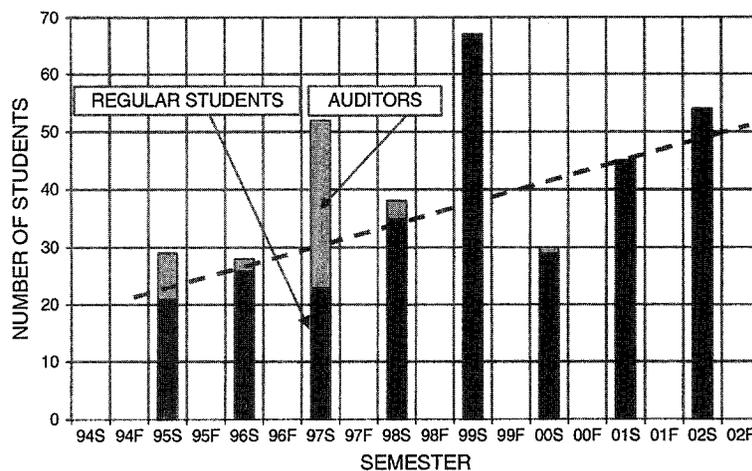


Fig. 3. Graduate student enrollment in the required course *Spacecraft Design* since 1995; F, fall semester; S, spring semester. Many students would continue study by taking specialized astronautics courses. An enrollment spike in 1999 was caused by a significant expansion of a major space company in Southern California. This class enrollment is a reliable indicator of the total student enrollment in astronautics courses during the two years in the future. The trend (dashed line) does not show saturation yet.

trend of student enrollment in the *Spacecraft Design* class serves a reliable indicator of the program state during the next two years. Fig. 3 shows a steady trend in increase of the student numbers with no saturation. A number of auditing students decreased with time as the Astronautics Program earned the reputation of quality and is now chosen by working professionals as a program of choice for continuing education and leading to an advanced degree. The enrollment trend (Fig. 3) points to the anticipated growth in student enrollment in other astronautics classes. Our program can easily absorb more students without sacrificing the quality of the instruction. Most of the specialty courses are taken by a relatively small number of students, in the range of 10–

20, and these classes could handle more students without difficulty.

Our undergraduate Bachelor of Science program is much newer than the Master of Science program. The first freshmen were directly admitted to Astronautics in the fall of 1999, although a number of students enthusiastically converted their major to Astronautics when it became possible. Only one student was admitted directly into Astronautics in 1999, but in the same year many transferred into the program, and about 12 are currently seniors who will graduate in spring 2003 in Astronautics. After only three years of program existence, Astronautics undergraduate students constitute approximately half of aerospace undergraduate students in the AME Department.

6. Lessons learned

The development of the Astronautics Program offered a number of lessons. Our typical graduate student works full-time, he or she typically takes one or two courses every semester. A Master's degree requires 27 units or nine courses. The typical time of study, then, ranges from two and a half to four years. Such a schedule makes it thus practical to offer only core courses every year, and offer many electives every other year. In this way, careful planning generally allows the student to take all the required and desired elective courses without incurring lost time due to a class not being available. Demand accumulates for elective classes during the off semesters, so the enrollment in the classes is typically sufficient for the class to be offered. The program is thus fiscally sound, which allows us to gradually build up the program experimenting with new courses. We already cover many main areas of space technology and we anticipate, as discussed above, to introduce a few new courses in the future.

Offering classes every other year requires that classes be scheduled several years in advance, so that students can plan accordingly. We now publish a schedule covering four years, from the current year through three years in the future. It is understood that the schedule is tentative and the student has always to discuss his or her plans with program graduate faculty advisors and the staff student coordinator.

We consider our adjunct faculty an important asset. The real-world experience, brought by the experts from space industry and government research and development centers, is an indispensable and vital component of a high-quality program. Another important lesson is to make no distinction between the requirements to on-campus and distance students. The latter approach is critical for maintaining the high academic standard of the program.

The feedback from our customers, the space industry and government research and development centers, plays an important role in the Astronautics Program. The program's success is to a large degree due to the attention that we paid to the opinion of leading experts in the industry. Our adjunct faculty is an outstanding source of such feedback, well thought out and insightful. Many our graduate students are mature engineers, with many years of working experience. Very often, these students provide excellent suggestions regarding the trends and the needs of the industry. In short, on-campus faculty of the program must listen to the customer and learn what the needs of the real world are. Complacency and arrogance would lead to stagnation and pose a major threat to the quality of the program.

Space technology is a dynamic area and a successful Astronautics Program must provide strong science and engineering fundamentals and be, in the same time, flexible and follow the developments in the industry and government programs. This unusually dynamic environment calls for a relative independence of the program within the traditional administrative structures of academic units.

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