Int. J. Engng Ed. Vol. 13, No. 4, p. 285–303, 1997
Printed in Great Britain.
0949-149X/91 $3.00+0.00

The Development of a Mature External Master's Degree Program in Aeronautical Engineering: A University/Industry Partnership*

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In the summer of 1984 the Northrop Grumman Corporation notified California State Polytechnic University, Pomona (Cal Poly, Pomona; CSPUP) that the CSPUP proposal for an on-site external Master's degree program had been accepted. This paper reviews the development of this program, admission requirements, course offerings, annual quality reviews (by both Northrop Grumman and Cal Poly, Pomona), fee assessments, matriculation summaries, evolutionary program changes and keys to the program's success. Since its inception in the fall of 1984, the program has evolved and matured in terms of curriculum development, student advising and degree requirements into a highly successful, streamlined and focused graduate aeronautical engineering external degree program. Possible changes in the program's future direction(s) are also discussed.

INTRODUCTION

OVER the years, the Northrop Grumman Corporation has found that it is desirable for its engineers to be educated at least to the Master's level. The Northrop Grumman experience is that engineers with a Master's degree tend to be more valuable in their area of specialty and are quicker to adapt to changing competitive technology and/or new assignment areas than are engineers with only a baccalaureate degree. The company, therefore, has a policy of aggressively hiring at the Master's level and, in addition, encourages employees with only a baccalaureate degree to obtain an engineering Master's degree. This corporate encouragement takes various forms, including the financial incentive of a fee reimbursement program.

Universities within the greater Los Angeles area provide a number of high-quality after-hours Master's degree programs that are utilized by Northrop Grumman employees. However, these programs typically have curricula that are intended to attract students with a wide range of backgrounds and needs, rather than incorporating the knowledge skills needed by a particular industry. As a result, the Northrop Grumman Military Aircraft Division decided to explore the possibility of developing an in-plant or on-site Master's degree program in aeronautical engineering that would reflect Northrop Grumman's specific needs for advanced technical knowledge in critical skill areas, as well as provide employees with a convenient and easily accessed classroom location.

In mid-1983 the Northrop Grumman management formed a five-member committee of company specialists in the fields of aerodynamics, structures, materials and processes, flight controls, propulsion and aircraft design together with a member of the training department. The committee charter was to develop a tentative curriculum that would address the particular requirements of the airframe manufacturing industry. The committee included members who possessed significant experience as engineering faculty members at some of the nation's major universities.

NORTHROP GRUMMAN INITIATIVE

The committee first conducted a survey of its engineers and learned that a minimum of 30 employees would strongly consider enrolling in an on-site graduate aeronautical engineering program. The committee then adopted guidelines considered necessary to achieve company goals:

- The program should be 100% on-site at Northrop Grumman training facilities.
- The program should be of high quality and should meet normal university standards, in addition to Northrop Grumman's special requirements.
- The curriculum should not be specialized to

* Accepted 5 May 1997.

Northrop Grumman but should meet the needs of the aircraft industry as a whole.

- The program should be open to all qualified applicants and should not be restricted to Northrop Grumman employees.
- The participating university should be encouraged to utilize qualified industry instructors, in addition to regular faculty.

These guidelines were considered to be sufficiently general for the development of an advanced degree program in aeronautical engineering. Such a program would encourage and easily permit the participation of employees of other nearby aircraft firms. With increased program enrollment, a greater variety of elective courses could be offered for the enrichment of all students.

University Response

Within this initiative framework, the committee developed a tentative (albeit sketchy) curriculum. An informal review of this tentative curriculum was made by a number of universities in the Los Angeles area. The result was a refined but still sketchy Master's degree program curriculum. With the comments and subsequent curriculum revisions in hand, as well as results of the Military Aircraft Division engineering workforce survey, the committee developed the elements of a Request-for-Proposal (RFP) released by Northrop Grumman management to Los Angeles area universities in the winter and spring of 1984.

Program selection

Four Los Angeles area universities expressed an interest in the Northrop Grumman RFP. Three of these universities submitted proposals for a fully developed on-site External Master's Degree program. All three proposals were generally acceptable, but the CSPUP proposal offered the most advantages. On June 13, 1984, CSPUP was notified that its proposal had been accepted by Northrop Grumman for the presentation of an on-site Aeronautical Master's Degree program.

CAL POLY, POMONA—MASTER OF ENGINEERING DEGREE

The Cal Poly, Pomona, College of Engineering, graduate program is interdisciplinary. The interdisciplinary graduate program leads to a Master of Engineering degree with an emphasis in some specific area such as Aerospace Engineering. One strength of the program is that it is sufficiently flexible for the graduate student, together with a faculty advisor, to create a course of study specifically tailored to the individual student's talents, interests and professional goals. A minimum of 45 quarter units was and is required for the degree, twenty-four of these units must be taken at the 500 or 600 course level (i.e., 5th or 6th year). A maximum of 21 units may be taken at the 400 (senior) level.

Course Distribution

Within the 45 quarter-unit program, a minimum of 15 (was 16) quarter units must be selected to meet breadth (e.g., mathematics, science or capstone design) requirements. Additionally, a minimum of 15 (was 12) quarter units must be selected by the student to emphasize a specific technical area. The remaining units are elective but are required to be consistent with the student's overall professional goals.

Upon completion of the required coursework, the student must complete a thesis (4–9 quarter units) or pass a comprehensive examination. A graduate writing examination must also be completed in a satisfactory manner by the student.

The CSPUP graduate engineering program is administered by the Director, Graduate Studies with the support of the College of Engineering Graduate Studies Committee. Each engineering department within the College of Engineering has a representative on the Graduate Studies Committee.

External degree

An external degree has been defined as one that is awarded to an individual on the basis of some program of preparation (devised either by the student or by an educational institution) which is not centered on traditional patterns of residential collegiate or university study [1]. The response of Cal Poly, Pomona to the Northrop Grumman RFP had to be within the framework of the Master of Engineering degree program on-campus in order to be in compliance with California State University guidelines and procedures. However, because the Master's degree program developed for the Northrop Grumman Corporation is off-campus, contains some courses specifically addressing aircraft industry needs, and utilizes some part-time instructors from industry, it is defined as an external degree program.

At Cal Poly, Pomona, external degree programs are administered through the Office of Continuing Education by the Dean of Continuing Education. The diplomas awarded for satisfactorily completing the Master of Engineering degree requirements are the same regardless of whether those requirements are completed via the on-campus program or via an external degree program. Students in both types of programs must meet equivalent graduation requirements and standards.

INITIAL CSPUP/NORTHROP GRUMMAN EXTERNAL DEGREE PROGRAM

Within the academic environment, the CSPUP/Northrop Grumman External Master's Degree Program required sequential approval at both the College and University levels as well as by the Chancellor's Office. It should be noted that the Northrop Grumman program was the third external Master's degree program developed by the

CSPUP College of Engineering. The first such program (interdisciplinary) was developed for Norton Air Force Base personnel; the second (mechanical engineering) for the Fluor Corporation.

In accordance with the provisions of Chapter III, Section 6, subdivision K of the Standing Orders of the California State University Board of Trustees, the Chancellor's Office fixed the various fees associated with the external degree program. The initial (1984) and current fee structure is contrasted in Table 1. The change in the fee structure represents the change in program costs over the last twelve years. Classes were first offered during the Fall quarter of 1984.

The external Master of Engineering degree program with emphasis in Aeronautical Engineering that was developed with and for the Northrop Grumman Corporation required a minimum of forty-five quarter units of coursework. All courses were four quarter units in size, except for the Comprehensive Examination, ARO 697, which was one quarter unit in size. Thus, the program, then as now, required eleven subject matter courses plus a comprehensive examination.

The Northrop Grumman Committee and management considered that their engineers were sufficiently involved in research, design and proposal preparation on a daily basis that the completion of either a thesis or a project would not represent the educational experience for their employees that it would for the traditional graduate student. Thus, with few exceptions (e.g., those students who might transfer to the on-campus program), all students in the CSPUP/Northrop Grumman program must pass the comprehensive examination. In addition, without exception, they must all receive acceptable marks on the Graduate Writing Examination (GWT).

Where possible, it was considered desirable to use existing courses from the on-campus program in the CSPUP/Northrop Grumman program. However, the specific nature of the CSPUP/Northrop Grumman program required that most of the external degree program courses be newly developed. It should be noted that the senior author developed the original CSPUP proposal response to the Northrop Grumman RFP and then served as both the academic coordinator and an occasional instructor and faculty advisor for the program for the period 1984–88. The second author has served as the faculty advisor, an occasional instructor and as the academic coordinator from 1988 to the present.

Table 1. CSPUP/Northrop Grumman external degree program fees

Fee	1984	1992	1995
Course fees per Quarter Unit	$95.00	$155.00	$233.00
Application for Admission	35.00	55.00	35.00
Application for Graduation (Diploma Fee)	10.00	18.00	18.00
Graduate Writing Test	15.00	12.00	18.00

The original CSPUP/Northrop Grumman program consisted of a group of specified breadth courses totaling twenty-four quarter units and elective courses totaling twenty quarter units. The elective courses originally could have been taken in a single specialty area or distributed in some fashion over two or more specialty areas.

Expected student background

The CSPUP/Northrop Grumman external degree program was primarily developed for students whose baccalaureate degree was in aeronautical/astronautical/aerospace, mechanical or some related engineering discipline. However, the program emphasis is on aeronautical engineering. Students without suitable preparation for this graduate program are expected to obtain that background from one of the several universities (including CSPUP) in the greater Los Angeles area or from a limited number of supplemental preparatory courses offered in the CSPUP/Northrop Grumman external degree program.

Graduate credit was originally allowed for most but not all of these preparatory courses. For example, Gas Dynamics (ARO 311) is a junior level course in compressible flow. It continues to be offered on a per need basis for those students who have not had an equivalent course in their undergraduate studies. No graduate credit was or is allowed for ARO 311.

Other preparatory courses listed in Table 2 were all senior level courses and as such were initially offered for graduate credit, if similar courses had not been taken by the student as an undergraduate. As an example of program tailoring, ARO 470 (Aerodynamics and Performance) was developed as an accelerated course in subsonic and supersonic aerodynamics/airplane performance for those students who had not had an equivalent course as an undergraduate but who had industrial aircraft experience.

Breadth

The breadth component of the initial program consisted of six specific courses (twenty-four units), regardless of specialty area. In contrast, the on-campus program initially required a minimum of sixteen quarter units with considerable choice of coursework (currently, a minimum of fifteen quarter units are required).

The initial CSPUP/Northrop Grumman breadth requirements are shown in Table 3(a). They

Table 2. Preparatory coursework

ARO 311 Gas Dynamics (4)
ARO 405 Aerospace Vehicle Stabilityand Control (4)
ARO 406 Dynamics of Aerospace Systems (4)
ARO 408 Finite Element Analysis of Structures I (4)
ARO 470 Aerodynamics and Performance (4)
ARO 482 Feedback Control Systems (4)

Note: Preparatory courses are scheduled only when requested by eight or more students.

Table 3. Breadth (required) courses for the external master's degree in aeronautical engineering

(a) Initial Program

ARO 501 Matrix Algebra, Vector Analysis, Complex Variables (4)
ARO 502 Statistics, Probability and Partial Differential Equations (4)
ARO 504 Mechanics of Composites (4)
ARO 510 Airbreathing Propulsion Systems (4)
ARO 515 Aerodynamics for Engineers (4)
ARO 578 Aircraft Stability (4)

Note: These six courses were required of all students.
Note: The numbers in brackets at the end of the course titles indicate the quarter units allocated to the course, i.e., all courses are four quarter units in size.

(b) Current Program

ARO 501 Methods of Engineering Analysis (4)
ARO 502 Differential Equations and Transforms (4)
ARO 506 Aircraft Structures (4)
ARO 510 Airbreathing Propulsion Systems (4)
ARO 515 Advanced Aerodynamics (4)
ARO 578 Aircraft Stability (4)

Note: Depending upon the student's area of specialization, five of the above courses, totaling 20 quarter units, are required to satisfy the breadth requirements for this program.

included two courses in advanced mathematics and single courses in structures, propulsion, aerodynamics and stability and control. The breadth requirements for the initial program were chosen to enhance the general analytical capability of the individual student and to expose the student to at least a brief glimpse of most of the major fields of effort required in aircraft analysis and design.

The current CSPUP/Northrop Grumman breadth requirements are shown in Table 3(b). The current requirements represent the maturity of the program.

Electives

A complete list of elective courses, both initial and current, is given in Table 4. Originally the student had several options in the selection of electives. One such option was to select elective courses in a variety of technical areas for additional breadth. A second option was to select the elective courses to provide an in-depth emphasis in a specific area. The number of elective courses was such that strong emphasis areas could be developed in flight controls, structures, airbreathing propulsion and aerodynamics.

Table 5 illustrates at least one way in which these emphasis areas could be defined in the initial program. Other, somewhat different, arrangements could also be defined. A maximum of twenty-one units of 400-level electives could be applied toward the degree in the initial program. It should be noted that students need(ed) to pay strict attention to prerequisites, when developing their elective course patterns. The current program permits only three elective areas as shown in Table 5.

ACADEMIC REGULATIONS

Students in a Cal Poly, Pomona external engineering degree program are subject to the same academic regulations that govern students in on-campus graduate engineering degree programs. These academic requirements can be summarized as follows:

1. At least 32 quarter units of upper division and/or graduate level coursework must be completed in residence at Cal Poly, Pomona. Cal Poly, Pomona considers that courses offered in this program at Northrop Grumman facilities meet this requirement.

Table 4. Elective courses for the external master's degree in aeronautical engineering

(a) Initial Program	*(b) Current Program*
ARO 402 Numerical Methods (4)	ARO 503 Numerical Analysis for Engineers (4)
ARO 405 Aerospace Vehicle Stability and Control (4)	ARO 504 Mechanics of Composites (4)
ARO 406 Dynamics of Aerospace Systems (4)	ARO 506 Aircraft Structures (4)
ARO 408 Introductory Finite Element Structures (4)	ARO 508 Finite Element Analysis of Structures II (4)
ARO 431 Intermediate Finite Element Structures (4)	ARO 512 Airframe-Propulsion System Integration (4)
ARO 470 Aerodynamics and Performance (4)	ARO 515 Advanced Aerodynamics (4)
ARO 476 Manufacturing Processes (4)	ARO 516 Aerodynamics of Wings and Bodies (4)
ARO 482 Feedback Control Systems (4)	ARO 517 Unsteady Aerodynamics (4)
ARO 503 Numerical Analysis for Engineers (4)	ARO 518 Computational Fluid Dynamics (4)
ARO 506 Aircraft Structures (4)	ARO 521 Structural Dynamics (4)
ARO 507 Continuum Mechanics (4)	ARO 522 Fatigue and Damage Tolerance Analysis (4)
ARO 509 Computer Aided Design of Structures (4)	ARO 524 Advanced Aircraft Structures (4)
ARO 512 Airframe-Propulsion Systems (4)	ARO 525 Aeroelasticity (4)
ARO 516 Wing-Body Aerodynamics (4)	ARO 535 Modern Control Theory (4)
ARO 518 Computational Fluid Dynamics (4)	ARO 538 Advanced Topics in Flight Controls (4)
ARO 525 Aeroelasticity (4)	ARO 545 Aircraft Flying Qualities (4)
ARO 535 Modern Control Theory (4)	ARO 578 Aircraft Stability (4)
ARO 537 Concepts in Integrated Control (4)	ARO 595 Boundary Layer Theory (4)
ARO 545 Aircraft Flying Qualities (4)	ARO 598 Flight Sciences (4)
ARO 691 Directed Study (1)	ARO 697 Comprehensive Examination (1)

Note: The numbers in brackets at the end of the course titles indicate the quarter units allocated to the course.

Table 5. Elective emphasis areas

(a) Initial Program	*(b) Current Program*
Flight Controls	*Flight Controls*
ARO 482 Feedback Control Systems (4)	ARO 503 Numerical Analysis for Engineers (4)
ARO 516 Wing-Body Aerodynamics (4)	ARO 535 Modern Control Theory (4)
ARO 535 Modern Control Theory (4)	ARO 538 Advanced Topics in Flight Controls (4)
ARO 537 Concepts in Integrated Control (4)	ARO 545 Aircraft Flying Qualities (4)
ARO 545 Aircraft Flying Qualities (4)	ARO 578 Aircraft Stability (4)
	ARO 598 Flight Sciences (4)
Structures	*Structures*
ARO 408 Introductory Finite Element Structures (4)	ARO 503 Numerical Analysis for Engineers (4)
ARO 506 Aircraft Structures (4)	ARO 504 Mechanics of Composites (4)
ARO 509 Computer Aided Design of Structures (4)	ARO 506 Aircraft Structures (4)
ARO 516 Wing-Body Aerodynamics (4)	ARO 508 Finite Element Analysis of Structures II (4)
ARO 525 Aeroelasticity (4)	ARO 521 Structural Dynamics (4)
	ARO 598 Flight Sciences (4)
Airbreathing Propulsion	*Aerodynamics and Propulsion*
ARO 512 Airframe-Propulsion Systems (4)	ARO 503 Numerical Analysis for Engineers (4)
ARO 516 Wing-Body Aerodynamics (4)	ARO 515 Advanced Aerodynamics (4)
ARO 518 Computational Fluid Dynamics (4)	ARO 516 Aerodynamics of Wings and Bodies (4)
ARO 525 Aeroelasticity (4)	ARO 517 Unsteady Aerodynamics (4)
ARO 535 Modern Control Theory (4)	ARO 518 Computational Fluid Dynamics (4)
	ARO 598 Flight Sciences (4)
Aerodynamics	
ARO 503 Numerical Analysis for Engineers (4)	
ARO 516 Wing-Body Aerodynamics (4)	
ARO 518 Computational Fluid Dynamics (4)	
ARO 525 Aeroelasticity (4)	
ARO 545 Aircraft Flying Qualities (4)	

2. Candidates for the external Master's degree must earn at least a 3.0 (B) grade point average (GPA) in all graduate coursework taken in Cal Poly, Pomona programs. No grade lower than a 'C' may be applied toward fulfillment of degree requirements.
3. Dropping a graduate course after the 15th day of instruction will only be approved for serious and compelling reasons that must be completely documented.
4. The external graduate degree program must be completed within seven years of the start date for the first course considered applicable to the degree.
5. Those students with a GPA below 3.0 (B) are subject to disqualification and, in fact, may be disqualified from the program upon the recommendation of the College of Engineering Graduate Studies Director.
6. Students are required to meet all of the academic regulations of the University as set forth in the Catalog of California State Polytechnic University, Pomona.

Transfer credit

Transfer credit may be obtained for prior graduate coursework completed by the student at other accredited colleges and universities, provided such courses are acceptable as substitutes for either required or elective courses in the CSPUP/ Northrop Grumman program. Not more than thirteen quarter units may be transferred to the student's CSPUP/Northrop Grumman program from other institutions.

Instructional staff

The instructional staff of the CSPUP/ Northrop Grumman external degree program is comprised of full-time faculty members from California State Polytechnic University, Pomona, primarily from the Aerospace Engineering Department, and from qualified industry-based engineers who teach primarily in their particular field of expertise. A number of these industry-based instructors have had teaching experience in other university graduate programs. All of the industry-based instructors must meet the requirements for teaching graduate level courses offered by the Cal Poly, Pomona Aerospace Engineering Department.

Scheduling

Initially, from one to three classes were scheduled each quarter. Academic quarters at CSPUP typically have ten weeks of classroom work with an additional week for final examinations. Such a ten-week quarter has forty academic hours (fifty minutes to the academic hour) of instruction. A four-unit class will usually meet four days a week for one hour (fifty minutes) at each meeting or twice a week for two consecutive fifty-minute periods (with a ten-minute break between periods). However, neither of these course modules appealed to the external degree students or faculty.

With student and faculty consensus, it was decided that each class would meet once a week for three consecutive fifty-minute periods with a ten-minute break between each period. This weekly class module required a thirteen-week 'quarter' (for a total of 39 academic hours of instruction) with an additional week for final examinations. This somewhat unusual 'quarter' seemed to be adequate during the formative years of the CSPUP/Northrop Grumman program but allowed only three such 'quarters' each academic year, rather than the usual four eleven-week quarters.

It should also be noted that a few courses were scheduled for two meetings per week with two consecutive academic hours of instruction at each meeting. Typically the students did not like to meet twice a week, and since campus instructors had to drive to the Northrop Grumman facilities twice a week, they also were not particularly fond of this schedule. The CSPUP/Northrop Grumman schedule was eventually matched to the CSPUP campus calendar.

Registration

Registration takes place during the first meeting of each course. Typically, the Cal Poly, Pomona Dean of Continuing Education will bring the necessary registration materials, as well as the textbooks, to this first class meeting. If the course instructor is a full-time Cal Poly, Pomona faculty member, the instructor may occasionally be asked to bring the course textbooks and registration materials to the first class and, in addition, perform the registration function and the necessary student advising. In any event, a Cal Poly, Pomona graduate student faculty advisor was and is always available to students during the registration process and, by appointment, at selected other times during the year.

Recruitment

At Northrop Grumman, course offerings are always announced in the 'After-Hours, Continuing Education Programs', bulletin published quarterly by Northrop Grumman [2]. The Cal Poly, Pomona Office of Continuing Education also advertises the program and individual course offerings in the monthly newsletter of the Los Angeles Section of the American Institute of Aeronautics and Astronautics (AIAA) [3]. Continuing students also receive scheduling information by mail (from Northrop Grumman) and are asked to return a form to Northrop Grumman indicating their intent to enroll in specific courses before each quarter.

An appropriately designed one-page brochure describing the program in general as well as the specific course offerings was prepared and distributed to its employees by Northrop Grumman [4]. The admission criteria, overall curriculum, scheduling information and telephone numbers to call for additional program information were included in the brochure.

A more complete multipage brochure was prepared and released in July of 1986 by the Cal Poly, Pomona Office of Continuing Education. This brochure contained the external degree curriculum, admission criteria, academic regulations, complete course descriptions and telephone numbers, both at Northrop Grumman and at Cal Poly, Pomona, that students or prospective students could call for additional information. This brochure is updated aperiodically to reflect the changes and improvements to this dynamic program [5].

Some employees from firms near Northrop Grumman have already taken advantage of the CSPUP/Northrop Grumman external Master's degree program. To date, employees from some ten companies in the Los Angeles area have participated in the program.

Program evaluation infrastructure

At a meeting near the end of each course, the instructor distributes course evaluation forms which the students complete and return, in a sealed envelope, to the instructor at the end of the class meeting. This evaluation considers both the student's perception of the instructor's effectiveness and an assessment of their own expectations for the course. The evaluation forms are sent to the Office of Continuing Education for analysis by the Dean of Continuing Education and his/her staff, with copies to the Faculty Advisor, instructor and Northrop Grumman administrator for review and follow-up, if required.

Periodically, representatives of both the Northrop Grumman Engineering and Training Departments meet with the students enrolled in the external degree program to discuss their perceptions of the overall program. Discussion at these meetings is focused on effective course organization and teaching methods, use of computer facilities, instructor effectiveness, use of appropriate textbooks, use of available technical literature and program administrative effectiveness.

The original Northrop Grumman Committee, recommending the establishment of the external degree program, was made a permanent corporate Committee responsible for providing oversight reports to Northrop Grumman management. This Committee, which has experienced some change in personnel over the years, meets periodically with a similar oversight committee from Cal Poly, Pomona. This Joint Advisory Committee reviews progress and, as needed, determines policy changes to meet both Northrop Grumman and CSPUP goals. The Cal Poly, Pomona Committee includes representatives from the Office of Continuing Education, the College of Engineering and the Aerospace Engineering Department.

Thus, course and program evaluation is conducted at several management levels to ensure that student and program needs are being met, high academic standards are being maintained and a relevant service is being offered to the aerospace community.

EVOLUTION AND MATURATION OF THE PROGRAM

The above narrative summarizes the initial development of the CSPUP/Northrop Grumman external Master's degree program with some indication of its present format. Newberry and Hunt [6] provide a complete discussion, including all initial course descriptions, of the original program. The following narrative describes the changes that have occurred in the program, its present status and its possible future direction.

There have been some evolutionary and maturing changes in the external degree program since its inception in 1984. Some course titles were changed to reflect course content more accurately. Some of the courses were deleted and others were added to the curriculum. Course descriptions for the current program are provided in the Appendix. In some instances, course content was revised to improve coverage of essential course topics. It must be remembered that most of the courses proposed for this curriculum were new and had not been validated by the rigors of the classroom. It is often necessary to teach a course two or three times to determine the amount of time required to properly cover a given sequence of topics. Thus, some time has been required for course and curriculum 'shake down'. Time has also been required for a realistic assessment of the extent of student interest in specific areas and to develop a schedule of course offerings to meet the fiscal 'breakeven' enrollment minimum of eight students per course. Student enrollment planning has also been facilitated by the annual publication of the schedule of on-site classes to be offered.

Preparatory coursework

Initially, a maximum of twenty-one 400-level courses could be counted in the individual student's graduate program, in keeping with Cal Poly, Pomona's on-campus graduate school policy. However, Northrop Grumman wanted a more stringent program, one which would provide the student with more coursework at the 500 and 600-level. The flexibility of the on-campus program permitted this increase in 500- and 600-level courses.

The current CSPUP/Northrop Grumman external degree program does not give the student external degree credit for preparatory course work. The required preparatory courses are listed in Table 2. All of these courses are available in the instructional program for this external degree, if each course is requested by a sufficiently large enough (i.e., eight or more) group of students. If additional preparatory coursework is required, the student must use their own initiative to seek such coursework elsewhere at any of the Los Angeles area universities.

Required courses

ARO 501, Methods of Engineering Analysis, and ARO 502, Differential Equations and Transforms, have been revised in both title and content to better satisfy program goals. ARO 504, Mechanics of Composites, was replaced by ARO 506, Aircraft Structures, to provide a more fundamental breadth background in structures. A change was made in the title of ARO 515, Advanced Aerodynamics, to reflect slight changes in course content. Coverage of the thrust equations, ramjets and overall propulsion system performance topics has been added to ARO 510, Airbreathing Propulsion Systems. The Aircraft Stability course, ARO 578, has remained unchanged in terms of title and course content.

Electives

Table 4 illustrates the course title comparison in the elective course offerings. A total of eight classes have been added whereas three courses were deleted. Overall, the current program has more elective freedom than the original program.

The additional electives have been added, in part, to provide more complete course selection in the specialization areas. The current program requires that the student select one of three areas for specialization:

1. Aerodynamics and Propulsion
2. Flight Controls
3. Structures.

While this represents less flexibility than the initial program, it better utilizes available resources and thereby provides more certainty as to when courses will be offered.

Some possible initial elective and current required course specialization groupings are illustrated in Table 5. It should be noted that the actual course groupings are at the individual student's election. There is considerable flexibility available to the student when selecting specific courses in any given emphasis area. Care must, however, be exercised to make sure that prerequisites are observed. To this end, flow charts have been prepared for each of the three emphasis areas currently allowed.

Figure 1 illustrates the ramifications and obfuscations associated with elective selections in the Structures Emphasis Area. Similar flow charts are available for the Flight Controls Emphasis Area and the Aerodynamics and Propulsion Emphasis Area. Figure 2 illustrates the Program of Study Approval Form that must be completed for each student. It should be noted that Fig. 2 was developed for the Structures Emphasis Area. Similar forms are available for the other two emphasis areas.

Current program logistics

Initially the program was offered only at the Military Aircraft Division training facility in Hawthorne. Shortly thereafter, sufficient interest was generated at the B-2 Division in Pico Rivera to warrant classes being offered there as well. Northrop Grumman engineering staffing requirements have recently been such that all classes are now being offered at the Military Aircraft Division training facilities in El Segundo. It should also be noted that a number of qualified Northrop Grumman employees have served as instructors

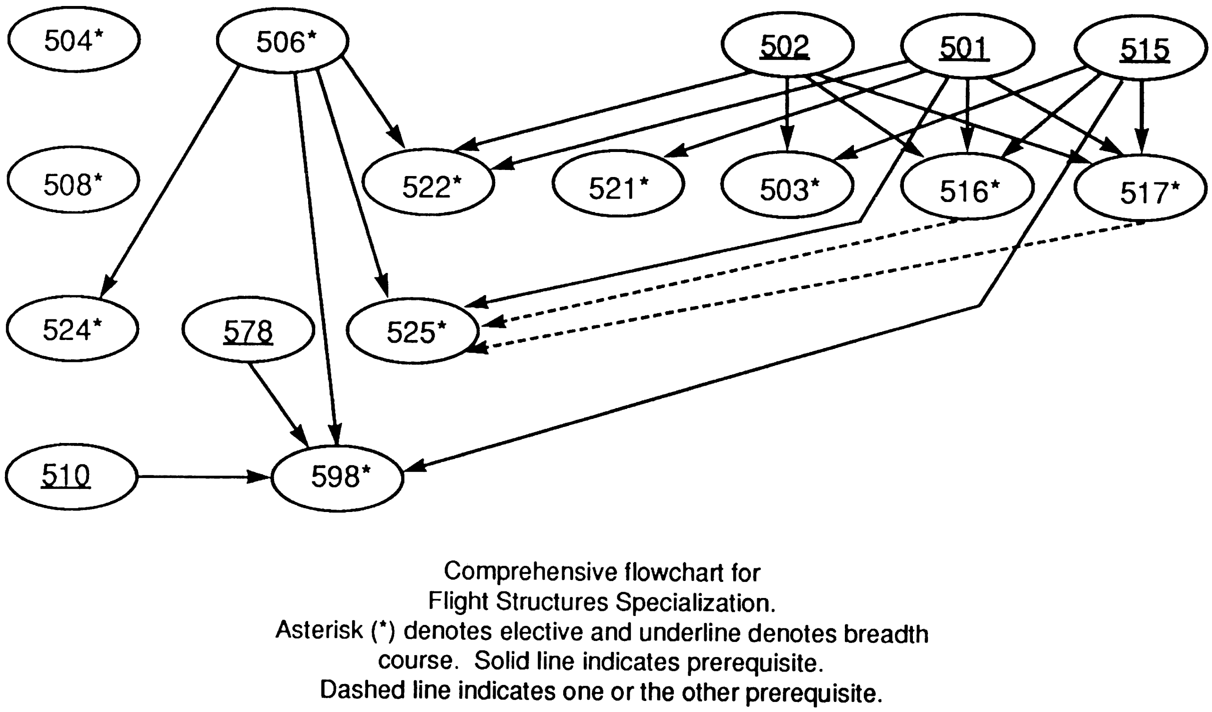

Fig. 1. Structures emphasis area flow chart.

in this program, although most of the instruction is supplied by Cal Poly, Pomona professors.

During 1991, some fifty or more students were registered in some phase of the external degree program. This enrollment easily supported three class offerings per quarter. However, enrollment has now dropped to roughly 35–40 students. This level of enrollment will adequately support only two classes per quarter. Table 6 indicates the recent past and current course offerings by quarter. The Appendix presents the current course descriptions of all courses offered in the external degree program.

The once-a-week, extended (14-week) quarter format for classes that appeared to be appropriate early in the development of the program has proven to be an untenable format. Classes now meet for four hours (four consecutive fifty-minute periods separated by ten-minute breaks) once a week. The length of the quarter is now eleven weeks, including the final examination week, and is consistent with the Cal Poly, Pomona on-campus program. Although the four-hour session can be tiring, it enables students to more easily enroll in two classes each quarter, if they so desire. Furthermore, the shorter quarter enables students to take classes during all four quarters of the year. A majority of both students and faculty members prefer the new class format over the old format. Courses are now scheduled for four quarters throughout the academic year. This markedly shortens the total calendar time for graduation.

Site facilities

The principal site for program course offerings is dependent upon where the greatest number of Northrop Grumman students are located. Thus, the initial courses were offered at the Northrop Grumman Hawthorne plant. Eventually, (around 1989) instruction also evolved to the Pico Rivera B-2 Division. Currently, all classes are held at the Military Aircraft Division plant in El Segundo. It should be noted that regardless of the Northrop Grumman location for course offerings, students (engineers) from most Northrop Grumman plant locations and from other local aerospace firms will be found in attendance.

Very comfortable Northrop Grumman classroom facilities exist at the Hawthorne, Pico Rivera and El Segundo plant locations. All three sites have a number of centrally located classrooms of varying sizes equipped with adequate whiteboard space, overhead projectors and, if required, video equipment. Depending upon the particular classroom, from 12 to 35 students can be nicely accommodated in seating provided by typical university classroom furniture. Northrop Grumman/CSPUP students have access to PC terminals. Northrop Grumman employees also have access, through company procedures, to company mainframe computer facilities, as needed. Non-Northrop Grumman employees in the program are expected to arrange for PC and mainframe computer access at their particular companies, as required.

Reimbursement policy

It should be noted that Northrop Grumman employees also have access to a significant fee reimbursement program. Currently, upon the successful completion of each course (B grade or better), each Northrop Grumman employed

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA

PROGRAM FOR THE MASTER OF ENGINEERING DEGREE

NORTHROP CORPORATION EXTERNAL DEGREE PROGRAM

TYPE in triplicate. Submit all copies to the Graduate Office College of Engineering.

NAME ________________ PIN ________ SOC. SEC. NO. ________
(Last) (First) (M.I.)
ADDRESS ________________ CITY ________ ZIP ________ RES. PHONE ________
INSTITUTION OF UNDERGRADUATE STUDY ________________ BUS. PHONE ________
BACCALAUREATE DEGREE IN ________________

GWT [ ]

GRADUATE OFFICE USE ONLY

First Program course taken

____
Quarter Year

Completion required by end of

____
Quarter Year

Comprehensive Exam passed

____
Date

By Date
Program Received ________
Notification Sent ________
Degree Granted ________

Units Gr Pts GPA
Program ____ ____ ____

CONCENTRATION: STRUCTURES

REQUIRED COURSES:

(All students are expected to have completed and passed ARO 311, Gas Dynamics, or its equivalent.)

			*Q/Yr	Units	*Grade
ARO	501	METH. ENGINEERING ANALYSIS		4	
ARO	502	DIFF. EQNS. & TRANSFORMS		4	
ARO	510	AIRBREATHING PROPULSION SYS.		4	
ARO	515	ADV. AERODYNAMICS		4	
ARO	578	AIRCRAFT STABILITY		4	

ELECTIVES
Minimum 24 Units

ARO	697	**Comp. Exam		1	

*Fill in only for courses completed
**One unit only

Total ( )

(Min. 45):

Student's Signature: ________________ Date: ________
Advisor's Signature: ________________ Date: ________
Graduate Analyst's Signature: ________________ Date: ________
Director's Signature: ________________ Date: ________

Original: Graduate Studies Yellow: Engineering Graduate Office Pink: Student Goldenrod: Continuing Education

F-1998-00

Fig. 2. Structures emphasis area approval form.

student is reimbursed 100% of all fees (including textbook charges) for that course. Reimbursement for CSPUP/Northrop Grumman students, who are not Northrop Grumman employees, is in accordance with the policies of the companies for which the students work.

LEAN INSTRUCTION

The downsizing of the US aerospace industry has had an adverse impact on aerospace engineering employment in the Los Angeles area in general and on the Northrop Grumman/CSPUP graduate

Table 6. External degree program course schedule

	1990–91		
Fall 1990	*Winter 1991*	*Spring 1991*	*Summer 1991*
ARO 501	ARO 502	ARO 506	ARO 504
ARO 504	ARO 512	ARO 538	ARO 515
ARO 510	ARO 535		
	1991/92		
Fall 1991	*Winter 1992*	*Spring 1992*	*Summer 1992*
ARO 501	ARO 502	ARO 503	ARO 506
ARO 510	ARO 508	ARO 598	
ARO 578			
	1992/93		
Fall 1992	*Winter 1993*	*Spring 1993*	*Summer 1993*
ARO 501	ARO 510	ARO 504	ARO 518
ARO 578	ARO 521	ARO 515	ARO 535
	1993/94		
Fall 1993	*Winter 1994*	*Spring 1994*	*Summer 1994*
ARO 502	ARO 503	ARO 578	ARO 545
ARO 516	ARO 506	ARO 598	
	1994/95		
Fall 1994	*Winter 1995*	*Spring 1995*	*Summer 1995*
ARO 501	ARO 502	ARO 578	ARO 503
ARO 515	ARO 510	ARO 521	
	1995/96		
Fall 1995	*Winter 1996*	*Spring 1996*	*Summer 1996*
ARO 501	ARO 502	ARO 516	ARO 510
ARO 515	ARO 506	ARO 535	
	1996/97		
Fall 1996	*Winter 1997*	*Spring 1997*	*Summer 1997*
ARO 578	ARO 598	ARO 614	ARO 504
ARO 518	ARO 545	ARO 508	

aeronautical engineering program in particular. This impact is observed in the values of average class size per quarter, number of seats occupied per academic year, number of courses per academic year and number of graduates per year as illustrated in Figs. 3 through 6, respectively. Accordingly, both Northrop Grumman and Cal Poly, Pomona have sought to find a way to maintain program viability with small student enrollments. The resulting program format might be called lean instruction.

The current program has been slightly restructured to accommodate small enrollments without significant reductions in the overall number of course offerings. The restructured program is achieved with a total of sixteen graduate courses, exclusive of the comprehensive examination. The list of the sixteen courses is identified in Table 7, which also indicates the number of times each course has been offered since the inception of the program, as well as the average class size. These sixteen courses were selected on the basis of their fundamental value, usefulness and popularity (in roughly that order).

The three areas of specialization are retained: aerodynamics and propulsion, flight controls, and structures. The modified specialization tracks or options are identified in Table 8. For each specialization track or option there are five breadth courses, four specialization courses and two 'free' electives, exclusive of the comprehensive examination. The electives are 'free' in the sense that the student can choose to enroll in any two of the remaining seven courses (of the sixteen total).

This restructured program was implemented during the 1992–93) academic year (AY). The success of the program is illustrated by the acceptable class size, seats occupied, course offering and graduation data presented in Figs 3 through 6, respectively.

The restructured program was achieved by essentially deactivating seven courses in the 1992 AY program. These seven courses will be reactivated and others added when student enrollments increase sufficiently. In the meantime, the overall program remains viable and popular with aerospace engineers in the Los Angeles area.

EVALUATION

The individual course evaluation process, Cal Poly, Pomona assessment, and Northrop Grumman

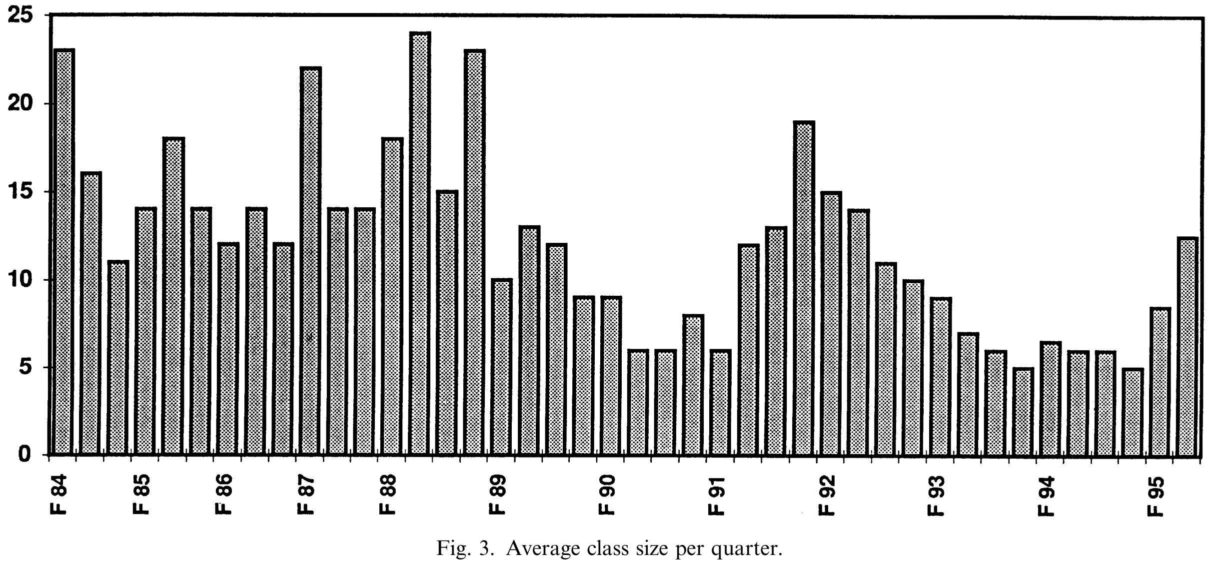

Fig. 3. Average class size per quarter.

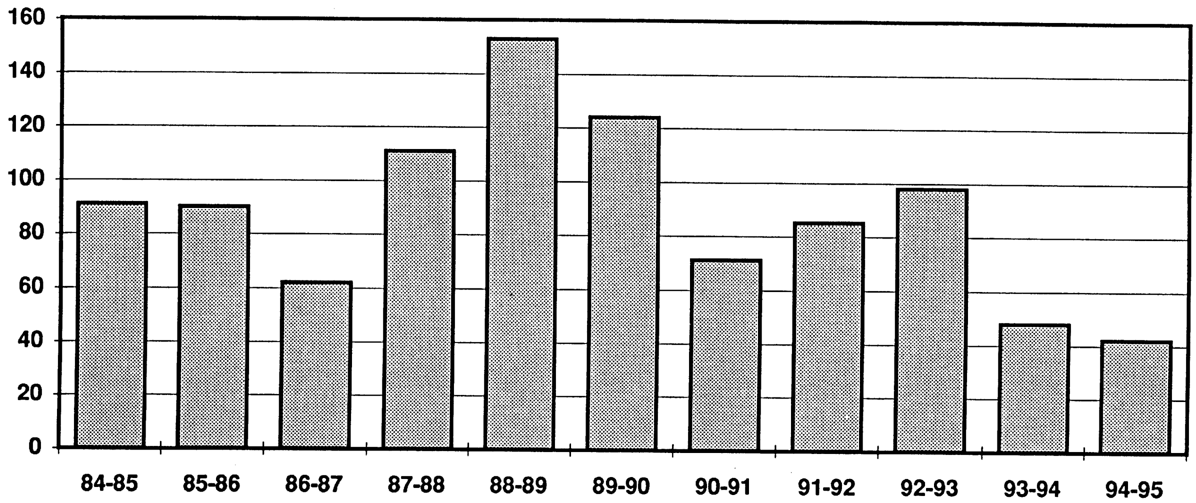

Fig. 4. Number of seats occupied per academic year.

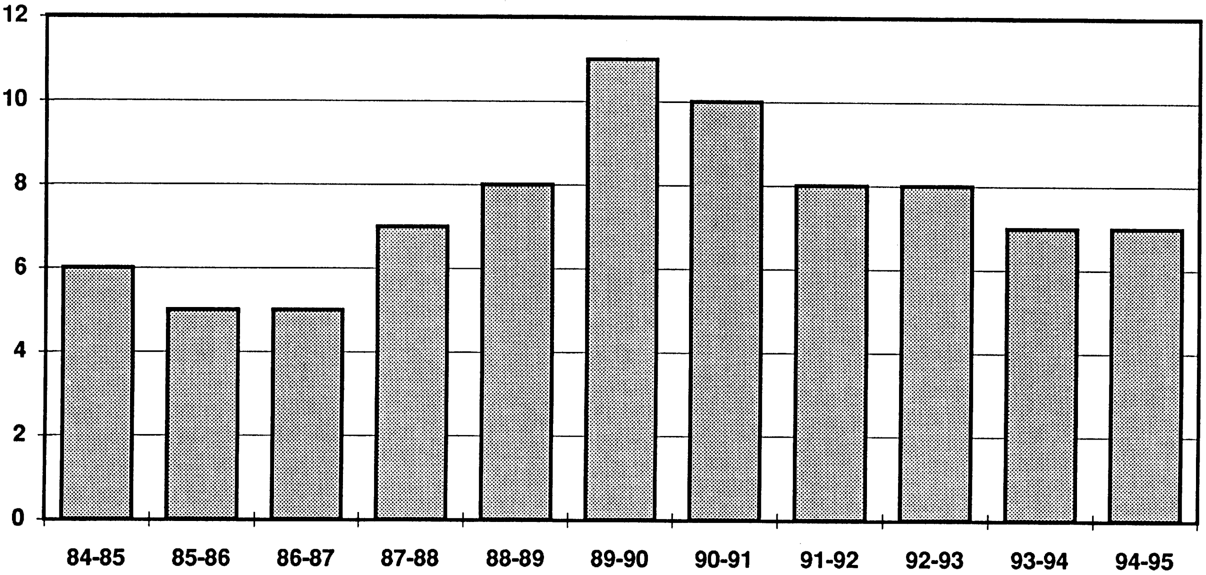

Fig. 5. Number of courses per academic year.

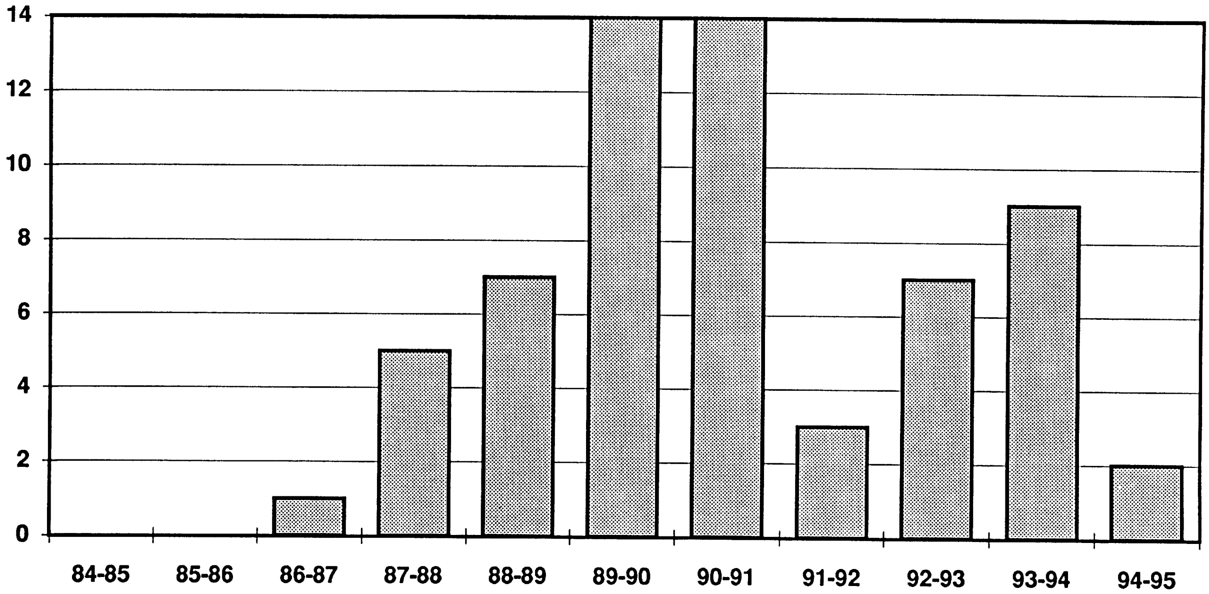

Fig. 6. Number of graduates per academic year.

Table 7. Course class size and frequency

Course	Avge. class size	No. of times offered
ARO 501	15	9
ARO 502	12	9
ARO 503	10	7
ARO 504	12	6
ARO 506	12	8
ARO 508	6	2
ARO 510	14	7
ARO 515	13	8
ARO 516	14	4
ARO 518	11	2
ARO 521	9	3
ARO 535	9	5
ARO 545	10	3
ARO 578	11	9
ARO 598	11	3
ARO 614	n/a	–

Corporation assessment infrastructure described above has been ongoing for nearly twelve years. Student comments on all aspects of the program are actively sought, through the distribution of an annual Northrop Grumman survey used to gather both planning and program evaluation data.

A statistical evaluation that clarifies some of the assessment issues has been made of the CSPUP/ Northrop Grumman external degree program. Class size, classroom seats occupied per academic year, number of total courses offered per academic year and the number of graduates per year permit a reasonable assessment of the effectiveness of and interest in the overall program.

Class size

The average class size distribution is shown in Fig. 3. It can be seen that the average class size is approximately twelve students. Since all students are required to complete the breadth courses, enrollment in these courses is typically higher than in the more specialized courses. It will be noted that a class size minimum occurred during the 1990 academic year, increased during the 1991 academic year, only to decrease to a new minimum of five students during the summer quarter of 1993 (and again during the summer quarter of the 1994 AY). Class size increased somewhat during the fall quarter of the 1995 academic year. Continued program operation is feasible at the current average class size.

Table 8. Lean instruction specialization options

	Aerodynamics and Propulsion	Flight Control	Structures
Five breadth courses:	ARO 501	ARO 501	ARO 501
	ARO 502	ARO 502	ARO 502
	ARO 510	ARO 510	ARO 510
	ARO 506	ARO 506	ARO 515
	ARO 578	ARO 515	ARO 578
Four emphasis courses:	ARO 515	ARO 578	ARO 504
	ARO 516	ARO 535	ARO 506
	ARO 518	ARO 545	ARO 521
	ARO 598	ARO 598	ARO 598
Two electives:	ARO 521	ARO 516	ARO 508
	ARO 503	ARO 503	ARO 503
	ARO 615	ARO 614	ARO 614
	Or any other emphasis or elective course		
Comprehensive examination:	ARO 697	ARO 697	ARO 697

Although as many as 75 students have enrolled in one or more classes during the 1995 AY, only 25 students are estimated to be seeking a Master's degree. The current reduced enrollment levels (compared to enrollments during the late 1980s) are probably indicative of current aerospace work-force employment levels in the Los Angeles area in particular and the US aerospace industry in general.

It should be noted that a minimum of five students are typically required to conduct any given class. A class with fewer than five students will be conducted only in extraordinary circumstances. As noted above, a minimum of eight students per course is required for a fiscal breakeven enrollment.

Seats

Figure 4 indicates the number of classroom seats occupied per academic year. A low value of 42 seats occupied per academic year was reached in 1994–95 and the high value was 153 in 1988–89. Figure 4 appears to suggest that the CSPUP/ Northrop Grumman external degree program has achieved a measure of stability during the current downsizing of the aerospace industry in the Los Angeles area.

Courses

According to Fig. 5, at least five courses have been offered each year, while a maximum of eleven courses was offered in 1989–90. Since then, there has been a slight reduction in the number of courses offered per academic year. However, even with the current reduced enrollments seven courses have been offered in each of the last two academic years. It appears that seven course offerings per year may be the steady-state number for sometime into the future (see Table 6 also).

The number of courses offered per academic year is dependent upon overall external degree program enrollment. If overall enrollment increases, the number of courses offered per academic year seems likely to increase, based upon the historical data shown in Fig. 5.

Graduates

Figure 6 represents one significant measure of success of the external degree program. More than 60 students have completed the program. Most have been Northrop Grumman employees although some, including the very first graduate, were employees of aerospace firms near Northrop Grumman's Hawthorne and Pico Rivera facilities.

It will be noted that the annual number of graduates increased to a maximum of fourteen during the 1989 and 1990 academic years. The decrease to three graduates during the 1991 academic year and two graduates during the 1994 academic year is thought to be due to student enrollment phasing and to Los Angeles aerospace engineering employment levels.

MEASURES OF SUCCESS

The overall success of the CSPUP/ Northrop Grumman external degree in aeronautical engineering is illustrated in Fig. 6. Over a period of twelve years, some 200 students have participated in this program; in excess of 60 students have graduated from the program. In excess of 100 courses have been offered.

As noted above, the program currently involves some sixteen graduate courses. Although some 75 students enrolled for one or more courses during the 1995 AY, only twenty-five are estimated to be seeking a graduate degree in aeronautical engineering. The others are simply using the program for unstructured professional development—a laudable end in itself. Finally, although the program was originally developed to meet the needs of Northrop Grumman employees, students from as many as ten other Los Angeles-based aerospace companies have participated in the program. It should be noted that the appeal of the program to non-Northrop Grumman employees was an initial goal of both Northrop Grumman and CSPUP.

Keys to program's success

There would seem to be no question that the CSPUP/Northrop Grumman external degree program has been a success. This is a tribute to combined efforts of the partnership of the Company and the University. There appear to be at least five key issues that account for this success:

- *Advisory committee.* The first key is the Northrop Grumman/ Cal Poly, Pomona Joint Advisory Committee. This group keeps a close watch on employee interest, currency of the curriculum, integration of the coursework, instructor effectiveness, advising and other program feedback.
- *Advising.* The effectiveness of individual student advising is considered to be a vital key to the success of the program. One-on-one student-faculty advising enables the student to know exactly what she/he needs to do and the timeframe in which it must be done. Such advising also permits the students to tailor the program to their own particular needs and interests within the constraints of the degree guidelines. The emphasis area flow charts and the Program of Study sheets enhance the advising process.
- *On-site location.* Company on-site course offerings provide a great convenience for students. Time is not lost in going from plant to classroom. This can easily save at least one and one-half hours of travel time per class meeting, attendant parking costs and delays, trying to find something for dinner before class and general wear and tear on the student's nervous system associated with frequent driving from the plant to the classroom at the end of a day of work. The on-site aspect of the program allows the student to be in a much better learning frame of mind than would otherwise be the case.
- *Student evaluation.* Student evaluation of each course and instructor provides (by academic standards) almost instant feedback to both program administrators and instructors. Instructional effectiveness, course content, classroom facilities and textbooks are but a few of the factors that can be addressed by such feedback.
- *Teaching Excellence.* Teaching excellence from both full-time faculty and part-time faculty from industry is highly valued. Recommendations from the Joint Advisory Committee guide the instructor selection process. First-time instructors (new to the on-site program) are extensively briefed by the faculty coordinator in order to acquaint them with the unique aspects of their assignments and to set expectations about the experience.

Cal Poly, Pomona perspective

There is some flexibility in the current program that is not immediately obvious. Courses in the external degree program that are also in the on-campus program—and there are a few of them—may be taken on-campus by the external degree program students within the same eleven-week quarter format. A maximum of 13 credit hours of such course work may be taken on-campus. Such flexibility may trade convenience of course offerings for convenience of site location. However, such a trade may enable a student to graduate earlier than would otherwise be possible and/or take a prerequisite in a more timely fashion. Northrop Grumman program students taking on-campus courses increase the enrollment of such classes and bring their industrial experience to class discussions.

Northrop Grumman perspective

That the on-site Master's course continues to be a vital program in the face of mammoth changes in the Southern California aerospace industry, is a tribute to all involved both at CSPUP and Northrop Grumman; the former for being responsive to Northrop Grumman's suggested course changes/amendments while ensuring that the resulting advanced degree is of the highest quality; and the latter for providing the necessary support, both financial and directional from the original concept proposal through lean enrollment times to the present. A major contribution to this success has been the Training Department at Northrop Grumman's Military Aircraft Division which is responsible for establishing and maintaining the excellent interface which now exists between the University, the students and the Corporation. This function was originally performed by the Training Department of the Aircraft Division in Hawthorne, then transferred to the Training Department of the B-2 Division in Pico Rivera and is now the responsibility of the Training Department of the Military Aircraft Division in El Segundo. All of these locations are within the confines of the greater Los Angeles area. These shifts in the location of Training Department responsibility have been coincident with corporate engineering responsibilities and student interest in the program.

From Northrop Grumman's point of view, the structure of the program and its administration offers many advantages that include:

- Tailoring courses to current needs of both students and the Corporation through the continuing review and recommendations of the Joint CSPUP and Northrop Grumman Advisory Committee.
- Providing qualified Northrop Grumman and other industry-based lecturers in specific areas to ensure that students are exposed to current practices as much as possible.

A good example of the latter is the area of propulsion integration—which is a dynamic technical area, particularly for modern high performance aircraft. (This has been something of a double-edged sword since the people who may have the most relevant experience and may be the right choice for the lecturer are frequently locked into heavy work commitments and can't spare the time).

Frequently students who join the Corporation after obtaining their baccalaureate degree would like to have obtained an advanced degree but a) were unsure what their specialty should be, b) could not afford to stay at college any longer, or c) decided that work experience before continuing graduate work would be useful. The ready availability of this on-site program allows them time to carefully assess their personal interest and needs and overcomes the financial hurdle. Clearly both Northrop Grumman and the students have been beneficiaries in the short and in the long term; this has been confirmed by informal, anecdotal data.

Student perspective

It is expected that the CSPUP/Northrop Grumman Master's program will continue to thrive as it adapts to the changing environment in the aerospace industry. Part of this adaptation will undoubtedly include more participating students from other companies in nearby areas to broaden the available base. While television-based instruction to satellite sites and similar techniques offer cheaper alternatives, it is our belief that the program, as offered, provides the most benefit to all involved, resulting in part from the direct student/lecturer interface. This belief and the structure/flexibility of the current program that has evolved during our twelve years of experience with the program will, in our opinion, ensure its continuing viability.

Regular annual surveys of students enrolled in the program, student advising and recent surveys of our graduates show that the overwhelming majority of our students rate the program favorably to very favorably. In particular, they appreciate:

- the convenience of on-site instruction;
- being able to interact with the instructor—in person—in a moderate-sized class;
- the ready availability of one-on-one academic advising;
- the excellence of instruction.

The students have voiced the most concern when a course they need is either not scheduled or scheduled and subsequently canceled due to inadequate enrollment. Course cancellations have been infrequent. This concern is being addressed by getting information from students via annual surveys of new academic needs, providing the students with a course planner (list of all courses planned for the academic year) and one-on-one academic advising.

FUTURE DIRECTION(S)

There are a number of factors that will influence the future direction of this program. These factors should attract new students as a consequence of several possible actions.

- *Broader base.* Although some students in the program are currently employed by firms other than Northrop Grumman, non-Northrop Grumman employees still represent a vast untapped pool of prospective students. A greater student enrollment would allow more courses to be offered each quarter and should result in a greater course selection for all students. More students should also result in an increased class size average and thereby better utilize resources expended upon the program. A broader student base should reduce course cancellations with the attendant student inconvenience.
- *Accessibility.* Ways should be pursued that will allow students without aeronautical and/or mechanical engineering backgrounds easier entry into the program, if they so desire. Finding ways to offer more preparatory courses may resolve this concern, e.g., using the Cal Net interactive television system. Ways could also be explored that would increase the present effort

to inform employees of firms near Northrop Grumman about the availability of the program.

- *Astronautics.* If there is sufficient student demand, the program could be expanded to include an external degree in astronautical engineering. Such a program could utilize a number of existing courses within the present program, e.g., ARO 501 and ARO 502 (the mathematics courses). The numerical analysis, feedback control and mechanics of composites courses might also be utilized within an astronautics program.
- *Degree designation.* Future efforts may lead to a study of the feasibility and possibility of changing the title of the degree from a Master of Engineering with emphasis in Aeronautics to a Master of Science in Aeronautical Engineering degree. Such a title change might broaden the student base of the program.
- *Short Courses.* Short courses in specialized areas may enhance the current program. Usable credit for such courses may present a potential problem area. However, such courses, e.g., Systems Engineering, Concurrent Engineering, and/or Taguchi Methods in Design, could be developed into full quarter length courses, if there was sufficient student interest.

CONCLUSIONS

1. The External Master of Engineering degree with an emphasis in Aeronautical Engineering is a successful, viable program. The sixty-plus graduates since 1984 attest to this fact.
2. Student participation is sufficient to justify at least two, and sometime three course offerings each quarter.
3. The eleven-week quarter is preferable to the extended fourteen-week quarter, allowing the scheduling of four quarters per year.
4. Both Northrop Grumman and Cal Poly, Pomona consider the external degree program to be a successful industry/university partnership venture in graduate engineering education.
5. The success of this program suggests it could form a suitable model for other aerospace or non-aerospace industry/university collaborations.

Acknowledgments—Many people have contributed to the success of this external Master of Engineering degree program. Space is simply not available to list all of their names. However, the authors particularly want to thank the following individuals for their constant sustaining contributions to the program: Kelly Wynne, and Brian L. Hunt of Northrop Grumman; Leland M. Nicolai, previously of Northrop Grumman; and Edward C. Hohmann, D. W. Williams, Wendy K. Wanderman, Carl E. Rathmann, Rodney D. Sutherland and Paul A. Lord of Cal Poly, Pomona.

APPENDIX

Course descriptions for the current External Master's Degree in Aeronautical Engineering

Key: B—Breadth
A—Aerodynamics and Propulsion specialization
C—Flight Controls specialization
S—Structures specialization
O—Open elective
ARO 3XX—Upper division undergraduate courses
ARO 4XX—Upper division undergraduate courses
ARO 5XX—Graduate courses
ARO 6XX—Advanced graduate courses

Example: ARO 525 Aeroelasticity (4, S, A). This is a 4-unit graduate elective for the Structures as well as the Aerodynamics and Propulsion area of specialization.

ARO 311 Gas Dynamics (4)
Thermodynamic processes. One-dimensional compressible flow. Area change, friction, heat addition. Normal and oblique shock waves. Nozzle and diffuser theory. Four lectures. Prerequisites: undergraduate courses in fluid mechanics and thermodynamics.

ARO 405 Aerospace Vehicle Stability and Control (4)
Static longitudinal stability and control; stick-fixed, stickfree. Maneuvering flight, V-n diagram, stick force, c.g. travel. Directional stability; rudder fixed, rudder free, rudder power. Lateral stability; dihedral effect, damping. Dynamic stability; longitudinal, lateral, directional. Transfer functions. Four lectures. Prerequisites: undergraduate courses in subsonic aerodynamics, supersonic aerodynamics and performance (ARO 470, or equivalent).

ARO 406 Dynamics of Aerospace Systems (4)
Generalizations of vector derivatives. Multiple reference frame kinematics. Euler transformation and rate equations. Particle system dynamics: Newtonian, Lagrangian, Euler-Newtonian, Euler-Lagrangian. Rigid body system dynamics: Newtonian, Lagrangian, Euler-Newtonian, Euler-Lagrangian. Four lectures. Prerequisites: undergraduate course in engineering mechanics (dynamics), undergraduate course in vector analysis or ARO 501.

ARO 408 Finite Element Analysis of Structures I (4)
An introduction to finite element methods. Matrix operations. Discretization of the domain. Interpolation polynomials. Boundary value problem formulation. Torsion of noncircular sections. Time dependent field problems. Computer implementation of finite element methodology. Four lectures. Prerequisite: an undergraduate course in structural mechanics.

ARO 470 Aerodynamics and Performance (4)
The atmosphere. Fluid mechanics: incompressible, compressible. Potential theory. Forces and moments on aircraft. Thin airfoil theory. Finite wing theory. Supersonic aerodynamics. Propellers

and propulsion. Aircraft performance in steady flight; straight and level, climbing, energy techniques. Aircraft performance in accelerated flight; takeoff, landing, climb, range and endurance. Standardized performance. Four lectures. Prerequisites: undergraduate courses in fluid mechanics and gas dynamics as required in an ABET accredited curriculum.

ARO 482 Feedback Control Systems (4)
Mathematical models of systems. Feedback control systems: characteristics, performance, stability. Root locus method. Frequency response methods. Stability in the frequency domain. Time domain analysis. Design and compensation of feedback control systems. Four lectures. Prerequisites: undergraduate courses in dynamics and differential equations.

ARO 501 Methods of Engineering Analysis (4, B)
Matrix algebra; determinants, matrix operations, systems of linear equations, eigenvalues, eigenvectors. Complex variables; complex numbers, functions of a complex variable, infinite series in the complex plane. Statistics. Probability. Statistical inference. Four lectures. Prerequisite: mathematics equivalent to an ABET accredited curriculum.

ARO 502 Differential Equations and Transforms (4, B)
Partial differential equations: elliptic, hyperbolic, parabolic. Solutions of partial differential equations: separation of variables, wave equation, Laplace's equation, Bessel's equation, Legendre's equation. Asymptotic expansions. Calculus of variations. Four lectures. Prerequisite: mathematics equivalent to an ABET accredited curriculum.

ARO 503 Numerical Analysis For Engineers (4, O)
Advanced interpolation and approximation methods. Advanced numerical integration concepts. Numerical solutions of ordinary differential equations; systems of ordinary differential equations. Numerical solutions of partial differential equations; systems of partial differential equations. Four lectures. Prerequisites: ARO 502 and an undergraduate course in numerical methods or equivalent.

ARO 504 Mechanics of Composites (4, S)
Design and analysis of composite aerospace vehicle materials. Fatigue properties. Fracture characteristics. Joints. Cutouts. High temperature composites. Analysis of anisotropic and viscoelastic composite materials. Producibility and optimum design techniques. Four lectures. Prerequisites: undergraduate courses in strength of materials and structural mechanics.

ARO 506 Aircraft Structures (4, B, S)
Aircraft structural design procedures. Analysis of wing and fuselage sections under flight imposed loads. Design and sizing of aircraft structural components. Semimonocoque structures: load distribution, shear flow, multicell box structures. Structural design: flexural and torsional stiffness, skins, longerons, spars, stringers. Buckling characteristics. Margins of safety. Virtual work, Rayleigh-Ritz procedures and introduction to finite elements. Four lectures. Prerequisites: undergraduate engineering mechanics, strength of materials, and structural mechanics courses.

ARO 508 Finite Element Analysis of Structures II (4, S)
Structural dynamics, structural stability and advance elements in the finite element method. Elasticity. Higher order triangular, tetrahedral and quadrilateral elements. Use of Galerkin's method. Development of computer methodology. Use of commercial finite element programs. Four lectures. Prerequisite: ARO 408 or equivalent introduction to finite element or matrix computer methods.

ARO 510 Airbreathing Propulsion Systems (4, B, A)
Thermodynamic cycle analysis of ideal and real engines. Design and performance of inlets, combustors and nozzles. Analysis of compressors and turbines. Engine component matching and prediction of performance. Thrust equations. Ramjets. Overall propulsion system performance. Four lectures. Prerequisites: upper division undergraduate courses in thermodynamics and compressible fluid dynamics.

ARO 512 Airframe Propulsion System Integration (4, A)
Air induction systems: subsonic and supersonic. Exhaust systems: converging nozzle, converging/diverging nozzle, thrust reversing and thrust vectoring. Method of characteristics. Airframe propulsion system integration. Integrated flight/propulsion control systems. Installed performance estimates. Computer simulation of engine systems. Ram drag, spillage drag, afterbody drag. Inlet-engine matching. Case studies. Four lectures. Prerequisite: ARO 510 or equivalent.

ARO 515 Advanced Aerodynamics (4, B, A)
Aerodynamic field equations. Pressure distributions; forces, moments. Potential flow theory. Complex mappings. Chordwise pressure distributions: Kutta Joukowski transformation, thin airfoil theory, thick airfoil theory, transonic approximations, supersonic approximations. Finite wing theory; symmetric and asymmetric spanwise loading, high lift devices. Incompressible displacement and momentum thicknesses. Four lectures. Prerequisites: ARO 470 or equivalent

and mathematics equivalent to an ABET accredited curriculum.

ARO 516 Aerodynamics of Wings and Bodies (4, O)
Incompressible flow: small disturbances, wings and thin airfoils in steady motion, oscillating thin airfoils. Compressible flow: wings and airfoils in steady subsonic, supersonic motion; oscillating airfoils in subsonic, supersonic flow; indicial airfoil motions in supersonic flow. Wing-body combinations: sweep effects, low aspect ratio wings, area rule, wave drag. Slender body theory. Four lectures. Prerequisites: ARO 501, ARO 502, and ARO 515.

ARO 517 Unsteady Aerodynamics (4, O)
Aerodynamics of fixed airfoils and wings in unsteady potential flow and oscillating airfoils and wings in uniform flow. Methods for predicting the pressure distribution and aerodynamic loads on airfoils and wings. Some discussion of reduced frequency, 3-D and compressibility effects. Experimental results. Applications of unsteady aerodynamics. Four lectures. Prerequisites: ARO 501, ARO 502 and ARO 515.

ARO 518 Computational Fluid Dynamics (4, A)
Current computer methods used in the field of fluid mechanics. Fundamental theoretical and numerical approaches. Panel methods. Method of Characteristics. Computational techniques and their application to aeronautical problems. Small scale computational fluid dynamics (CFD) problems will be coded. Four lectures. Prerequisites: ARO 503 and ARO 515.

ARO 521 Structural Dynamics (4, S)
Concepts of the dynamics of elastic bodies. Longitudinal, transverse and torsional vibrations of structural elements. Vibrations of plates and shells. Approximate methods in dynamics of structures. Four lectures. Prerequisites: undergraduate courses in structural analysis, dynamics and vibrations, and ARO 501.

ARO 522 Fatigue and Damage Tolerance Analysis (4, S)
Fundamentals of linear elastic fracture mechanics for static and fatigue loadings. Topics covered include: stress intensity factors, strain energy release rates, crack growth resistance, J-integral crack growth analysis, fatigue life improvement techniques and introduction to fatigue and fracture of composites. Four lectures. Prerequisites: ARO 501, ARO 502 and ARO 506.

ARO 524 Advanced Aircraft Structures (4, S)
Fundamentals of 2-D and 3-D theory of elasticity and continuum mechanics, theory of plates and shells and elastic stability including buckling of columns and plates. Additional topics may include structural optimization and applications of commercial finite element codes. Four lectures. Prerequisites: ARO 408 and ARO 506 or equivalent knowledge of finite elements.

ARO 525 Aeroelasticity (4, S, A)
Introduction; historical background. Deformations of airplane structures under static loads. Deformations of airplane structures under dynamic loads. Approximate methods of computing natural mode shapes and frequencies. Static aeroelastic phenomena. Flutter. Dynamic response phenomena. Aeroelastic model theory. Model design and construction. Testing techniques. Four lectures. Prerequisites: ARO 506 and ARO 516 (or ARO 517).

ARO 535 Modern Control Theory (4, C)
Mathematical models of physical systems. Basic automatic control with applications to aerospace problems. Frequency response analysis. State space representation, matrix analysis, controllability, and observability. Stability analysis including nonlinear and discrete time systems. Introduction to optimal control and introduction to system identification. Four lectures. Prerequisite: ARO 482 or equivalent course in linear control systems, or consent of the instructor.

ARO 538 Advanced Topics in Flight Control (4, C)
State-space representation of dynamic systems, principles of structured and unstructured uncertainty, optimal controller and observers, random process, Kalman filter, singular value decomposition, robust control basics, analysis and synthesis, model reduction for robust control, PC-based case studies. Prerequisites: ARO 535 and ARO 598.

ARO 545 Aircraft Flying Qualities (4, C)
Aircraft classification. Flight phase categories. Requirements: general, longitudinal, lateral, directional, miscellaneous, primary control system, secondary control systems, atmospheric disturbances. Handling qualities. Pilot workload assessment. Piloted simulation. Four lectures. Prerequisite: ARO 578.

ARO 578 Aircraft Stability (4, B, C)
General equations of unsteady motion. Stability derivatives. Stability of uncontrolled motion; longitudinal, lateral. Response of the vehicle to actuation of the controls. Flight in turbulent air. Automatic stability and control. Specialization to missiles. Simulation. Transfer functions. Four lectures. Prerequisites: ARO 405 and ARO 470 or equivalent courses.

ARO 595 Boundary Layer Theory (4, A)
Treatment of Newtonian and non-Newtonian fluids in the laminar and turbulent regimes. Positive and negative pressure gradients. Development of the thermal boundary layer. Some exact and

inexact solutions. Wedge flow. Four lectures. Prerequisite: ARO 470 or consent of the instructor.

ARO 598 Flight Sciences (4, O)

Basic subsonic and supersonic aerodynamics of airfoils/wings and bodies-of-revolution. Basic propulsion-design and integration (inlet, engine, nozzle). Structural requirements and aeroelastic interactions. Principles of stability and control and basic flying qualities. Basic aircraft sizing (empennage and wing). Elements of aircraft performance. Four lectures. Prerequisites: ARO 506, ARO 510, ARO 515 and ARO 578.

ARO 614 Aircraft Design (4, O)

Design requirements development. Requirements flow down to functions including structures, flight controls, propulsion, aerodynamics, materials, avionics, vehicle management system, and subsystems. Develop physical configuration with manufacturing plan and support systems. Trade studies using competing concepts. Design iterations and development of preferred configuration. Four lectures. Prequisites: Completion of graduate breadth classes.

ARO 697 Comprehensive Examination (1)

An examination of the subject areas of the student's breadth and technical specialty coursework listed on the Program of Study. May be repeated once. Students must register through the Engineering Graduate Studies Office. Offered during Winter and Spring quarters only. Advancement to Candidacy required.

REFERENCES

1. Cyril O. Houle, *The External Degree*, Jossey Bass Publishers, San Francisco, 1974, pp. 14–15.
2. ——, *After Hours, Continuing Education Programs,* Northrop Corporation, Aircraft Division, Winter, 1986.
3. ——, 'An Expanded External Degree Program in: Master of Engineering, Offering Curriculum Emphasis in: Aeronautical Engineering'; AIAA Los Angeles Section Newsletter, volume 16, number 7, July/August 1985, p. 3.
4. ——, 'An Expanded External Degree Program, Master of Engineering, Offering Curriculum Emphasis in: Aeronautical Engineering', After Hours Program, Northrop Corporation, Aircraft Division, Fall 1985.
5. ——, *Graduate Study in Aeronautical Engineering,* California State Polytechnic University, Pomona, Office of Continuing Education, July, 1986 (this brochure is reissued periodically).
6. ——, C. F. Newberry and B. L. Hunt, *An External Masters Degree Program in Aeronautical Engineering That Meets the Requirements of Both Industry and Academia*, Preprint AIAA-86-2753, AIAA/AHS/ ASEE Aircraft Systems, Design and Technology Meeting, Dayton, Ohio, October 20–22, 1986.

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Van H. Garner's tenure as Dean of Continuing Education at California State Polytechnic University, Pomona, has seen the growth of the College of the Extended University from a full-time staff of five to thirty-one. The College of the Extended University now offers degree programs. From 1991, Dr Garner has served as an elected member of the Commission on the Extended University, the policy body for extended education in the California State University System. As a member, he has served on various task forces and committees dealing with system-wide issues such as international education, the uses of technology and education equity. Dr Garner holds a PhD in history from U.C. Santa Barbara, and has produced many publications in the area of Native American land rights and in the areas of continuing education and distance education.

Alice A. LeBel gained her AB (Political Science) in 1951, MA (Political Science) 1967, PhD (Education, Higher Education Administration) 1981, at University of California, Los Angeles. Approximately 11 years with University of California Extension and 11 years with Northrop Grumman Corporation with assignments in continuing, legal and technical education. Recipient of the Award for Innovation Programming 'Attorney Assistant Training', presented by the National University Extension Association (1973). Participated in the development of a variety of educational and training programs for Northrop Grumman Corporation, including the on-site Cal Poly, Pomona/Northrop Grumman External Master's Degree Program in Aeronautical Engineering. Northrop Grumman Continuing Education Specialist (ret).

David J. McNally commenced his career in the aircraft industry with a five-year apprenticeship at Hunting Percival Aircraft (later absorbed by British Aerospace) in Luton, England. During this time he acquired a Higher National Certificate (BS equivalent) in Aeronautical Engineering and was awarded the Hunting Scholarship for two years advanced study at the College of Aeronautics, Cranfield, which resulted in the award of the college's Diploma (MS equivalent) in Aerodynamics. He returned to the Hunting Group, working for both the Aircraft and Engineering divisions as an aerodynamicist for a number of years. In 1966 he was recruited by Northrop Aircraft of Hawthorne, California, as a senior aerodynamicist involved in the F-5 program. This was followed by a period in the advance design organization with involvement in the YF-17 and F-18 aircraft programs. During this time he was appointed manager of the F-18 aerodynamics organization. His next assignment was as manager of the Aerosciences Technology organization, during which time he became involved with the Cal Poly/Northrop on-site graduate program. This involvement continued through his final assignment as manager of Advanced Design Engineering (ret).