Int. J. Engng Ed. Vol. 8, No. 2, pp. 114–125, 1992
Printed in Great Britain.

0742–0269/91 $3.00+0.00

The NASA/USRA Advanced Design Program at California State Polytechnic University, Pomona: An Infusion of Curriculum Strength and Innovation*

C. F. NEWBERRY†
Department of Aeronautics and Astronautics, AA/Ne, Naval Postgraduate School, Monterey, California 93943–5000, U.S.A.

This paper discusses the initial three-year participation of the California State Polytechnic University, Pomona (Cal Poly, Pomona) Aerospace Engineering Department in the NASA (National Aeronautics and Space Administration)/USRA (Universities Space Research Association) Advanced Design Program in Aeronautics. The roughly $35,000 per year funding available by participation in this program has provided for a design graduate assistant, student travel and a wide variety of teaching aids and supplies. These benefits have greatly enriched the aerospace design program at Cal Poly, Pomona. This enrichment has been primarily at the undergraduate level of instruction but to a degree has affected the graduate program as well. A brief description of the Cal Poly, Pomona University aerospace engineering curriculum, design program and design environment is provided as background. A more detailed description is given of the impact that the NASA/USRA Advanced Design Program has had upon the Cal Poly, Pomona design program. Overall, the aerospace design program at Cal Poly, Pomona has been markedly improved by participation in the NASA/USRA Advanced Design Program in Aeronautics.

INTRODUCTION

FOR A little more than a decade, the U.S. undergraduate engineering accreditation criteria have specified minimal design coursework requirements. The need to provide the student with an appropriate design experience within the engineering curriculum without impairing a comprehensive engineering science education, while concurrently exposing the student to a broad educational experience in the humanities and social sciences is the increasingly difficult challenge confronting the typical engineering curriculum planner. The challenge is exacerbated by a typical four-year curriculum time constraint and by a shortage of university professors with the broad practice and knowledge base required to teach design effectively.

By careful planning, regional circumstances or by accident some universities have managed to develop and maintain reasonably strong aircraft and/or spacecraft design programs. Aerospace vehicle design has been an established component of the aerospace engineering curriculum at California State Polytechnic University, Pomona (Cal Poly, Pomona) for over a quarter of a century.

A brief history of Cal Poly, Pomona, its geographical setting and institutional organization is provided to define better the environment within which the design program exists. Other universities operating in different environments might need to address different concerns to achieve the design program quality they desire.

CAL POLY, POMONA

Cal Poly, Pomona is located about 25 miles (some 40 minutes) east of downtown Los Angeles in Southern California. The present campus lies on the eastern slope of Kellogg Hill and is bounded on the north by the San Bernardino freeway (Interstate 10). A multi-level interchange for the San Bernardino, Corona and Orange freeways is located at the northeast corner of the campus. Thus Cal, Poly, Pomona is 'freeway accessible' from communities in Los Angeles, Orange and San Bernardino counties. Nearly 90% of Cal Poly, Pomona's approximately 18,000 students commute to campus [1].

University

Cal Poly, Pomona is one of 20 campuses in the California State University system which enrols over 300,000 students. Cal Poly, Pomona recently celebrated its 50th anniversary.

In 1938, the 157-acre Voorhis Campus (formerly the Voorhis School for Boys) near San Dimas

* Paper accepted 28 September 1991.
† Professor of Aeronautics and Astronautics.

became the Southern California branch of the California State Polytechnic School of San Luis Obispo. In 1945 the San Luis Obispo school was renamed California State Polytechnic College. The 813-acre W. K. Kellogg Arabian Horse Ranch near Pomona (adjacent to San Dimas) was deeded to California in 1949 and in 1956 it became the second and primary campus of the College's southern facility [2]. In 1961 the California Master Plan for Higher Education established the California State College System (CSCS) with its own Board of Trustees. California State Polytechnic College, Pomona was established as a separate college in 1966. During 1982 the College became California State Polytechnic University, Pomona and the statewide system became the California State University [3]. Cal Poly, Pomona operates on a quarter basis (four full 10-week quarters). However, the normal academic year consists of the Fall, Winter and Spring quarters.

College of Engineering

The Cal Poly, Pomona College of Engineering enrols some 4,200 (mostly full-time) undergraduate students and approximately 250 (mostly part-time) graduate students in seven engineering disciplines. B.Sc. degrees are awarded in aerospace, chemical, civil, electrical, industrial, manufacturing and mechanical engineering. With some 4,200 engineering undergraduates, the engineering program is, arguably, the largest in California and one of the 20 largest in the U.S.A.

The College of Engineering strives to prepare its students to meet the constantly changing and evolving technical needs of the nation by stressing a balance between basic principles and their practical application. The emphasis on theoretical scientific principles is complemented by laboratory and field work. Studies in the humanities and social sciences provide each student with a broad general education and an awareness of their social responsibilities, i.e. a framework of ideas, ideals and values within which one is fully equipped to practice engineering. Upon graduation, the learn-by-doing philosophy of education espoused by Cal Poly, Pomona prepares the individual student to either successfully continue with graduate school or become an immediately productive engineer upon entry into industry or government.

The College of Engineering supports a Computer Aided Engineering Laboratory (CAE Lab) and an Automation, Robotics and Control Laboratory (ARC Lab), in addition to the individual department laboratories, to facilitate the undergraduate engineering learning experience. An Engineering Institute is in place for the purpose of building and maintaining strong cooperative relationships between the campus and the engineering community at large.

The College of Engineering strongly supports a Minority Engineering Program. Underrepresented minorities compose over 16% of the undergraduate engineering student body. According to data from the National Action Council for Minorities in Engineering (NACME), the campus ranks 17th nationally in graduating minority engineers and is first in California for Hispanic graduates. The Minority Engineering Program is strongly supported by an active Advisory Board composed of representatives from 32 major corporations and various community and educational organizations.

The College of Engineering offers an interdisciplinary graduate program of study leading to a Master of Engineering degree, which coupled with a baccalaureate degree, provides the student with comprehensive preparation for advanced work in the engineering profession. The California Legislative has not, to date, enabled the California State University system to grant independent doctoral degrees. The graduate student, with the help of his adviser, is able to pursue a course of study tailored to the student's unique talents and his or her professional goals.

Aerospace Engineering Department

The Aerospace Engineering Department is one of seven Accreditation Board for Engineering and Technology (ABET) accredited engineering degree granting programs in the Cal Poly, Pomona College of Engineering. The Department was established in 1958 and is, therefore, a relatively young one. Its graduates have done well in graduate schools across the country, as well as in industry and government technical positions. It received its first ABET (ECPD, Engineering Council for Professional Development) accreditation in 1970 and has been accredited since that time.

Instructional environment. The program provides an educational experience that is the foundation for a productive lifetime as an engineer. A fundamental methodology for solving engineering problems is emphasized in all classes throughout the program. This fundamental problem-solving approach does not change with time after graduation, even though the tools available become more numerous and more powerful. The student is prepared to expand his or her professional expertise by graduate and/or personal studies after receiving the baccalaureate degree.

This fundamental engineering approach is taught in the framework of technical subjects (aerodynamics, structures, propulsion, computers, vehicle design, etc.), defined as the realm of the aerospace engineer. The use of numerous examples enables the students to interface effectively with the industrial or graduate school situation that they enter upon graduation.

Students are encouraged to become active in the student branch of either (or both) the American Institute of Aeronautics and Astronautics or (and) the American Helicopter Society. Qualified students are invited to join the national aerospace engineering honor society, Sigma Gamma Tau, and the corresponding umbrella engineering honor society, Tau Beta Pi.

The Aerospace Engineering Department faculty consists of eight full-time and (typically) four part-time instructors. The average faculty member has roughly eight years of engineering practice in industry or government.

Enrolment. The Aerospace Engineering Department has approximately 400 undergraduate majors. Despite its youth, the Department, in terms of size, ranks approximately 16th in its field in the nation. Table 1 shows the undergraduate enrolment to vary between 350 and 410 majors over the past six academic years. The number of graduates is shown in Table 1 generally to vary between 40 and 60. As a result of limited facilities, the Aerospace Engineering Department has been under an enrolment cap (impacted program) for over 10 years.

Table 1. Aerospace engineering enrolment

Academic year	Total majors	Graduates
1989–90	410	83 (est.)
1988–89	399	53
1987–88	360	53
1986–87	368	42
1985–86	382	49
1984–85	388	65

The Aerospace Engineering Department class enrolment is shown in Table 2. Class membership is dictated by the number of overall course units the student has completed. Completion of 0–44½ units qualifies a student as a freshman, 45–89½ as a sophomore, 90–134½ as a junior and above 135 as a senior. At the present time, 202 quarter units are required for graduation.

Table 2. 1989–90 aerospace engineering undergraduate distribution

Class	Enrolment
Freshman	107
Sophomore	127
Junior	93
Senior	83
Total	410

The senior class typically consists of around 50–60 students. Each senior is required to have completed all junior level classes before entry into the senior level classes. Each senior must complete the required two-course aerospace design course sequence.

AEROSPACE DESIGN PROGRAM

ABET has two sets of criteria that must be met by university engineering programs seeking accreditation; general criteria must be met by all accredited disciplines while program criteria are discipline specific. For example, aerospace engineering programs must satisfy the general criteria applicable to all engineering disciplines as well as the specific program criteria developed for aerospace engineering curricula by the American Institute of Aeronautics and Astronautics (AIAA). With respect to design, the general criteria specify one-half year (24 quarter units) of design. The program criteria further specify that there must be at least one conceptual or preliminary design course within the 24-quarter (16-semester) unit requirement. The remaining design units can be fulfilled by those portions of other engineering science or design courses that can be designated as design [4].

Cal Poly, Pomona has a required two-course (four total units) conceptual/preliminary design course sequence. The remaining 20 units of design are distributed among the remaining courses within the aerospace engineering curriculum. The required two courses in senior projects are often used by the students to enhance their design capability.

Historical background

Aerospace vehicle design has been an integral part of the Aerospace Engineering Department curriculum since 1964. Initially, the design sequence was placed in the Spring quarter of the sophomore year. At that time the design course was preceded by a two-quarter sequence of aerodynamic and aircraft performance coursework. Student design efforts were essentially limited to aerodynamic configuration selection and analysis. Student motivation was the primary benefit of the sophomore design sequence.

As a motivating influence, the sophomore design sequence was a big success. However, curriculum development soon required that more than motivation be obtained for the two units devoted to the sophomore design effort. Accordingly, the design course was moved to the senior year during the 1968–69 academic year.

Aerospace vehicle design at Cal Poly, Pomona consisted of a single two-unit laboratory course (six contact hours per week) from the 1968–69 academic year until the 1984–85 academic year. Most faculty members considered that one two-unit laboratory capstone design course was insufficient. Therefore, a study was made to determine how a second quarter of design could be incorporated into the curriculum.

From the initial design course inception, periodic oral presentations and written final reports were required of the design students. Similar communication skills requirements existed for students in the senior seminar class. However, the senior seminar class generally required each student to make only a single class presentation. The senior seminar class was converted to a design seminar class for the 1984–85 academic year. Several presentations, by each individual, are now required in the design seminar class.

Since the 1984–85 academic year, the aerospace vehicle capstone design course sequence at Cal

Poly, Pomona has consisted of two required two-unit laboratory courses, ARO 446, Advanced Aerospace Design Project, and ARO 463, Aerospace Design Seminar, offered, respectively, during the Winter and Spring quarters of the senior year. A full year (three quarters) of required capstone design work is desirable for the students but cannot now be incorporated within the required course segment of the Cal Poly, Pomona Aerospace Engineering Department curriculum. This full-year goal has been achieved, to some degree, through the addition of an elective design course discussed below.

Design course goals

The design course sequence goals have been discussed at length in papers presented at the 1986 and 1987 AIAA/AHS/ASEE aircraft design meetings. These goals are summarized in Table 3. One of the most important goals presented in Table 3 is the desire to develop the individual's capability to solve open-ended problems. In the typical mathematics, physics, chemistry, engineering support and aerosciences courses taken by the student prior to the design course sequence, specific constrained problems with specific constrained answers are posed for the student to solve. The open-ended problems of design permit the student to consider the variability in solutions and in parameters affecting solutions.

A second very important goal is the need for the students to improve both their oral and written communicstions skills required to describe the assumptions, methods and results of analysis, synthesis and decision making associated with the many aspects of aerospace system design constrained to the requirements of a Request-for-Proposal (RFP). Each of the goals described in Table 3 contributes to the professional growth of the individual student in a form generally not experienced by the student in the typically very structured aeroscience lecture courses that constitute the bulk of almost all aerospace engineering curricula.

Design course sequence implementation

As mentioned above, the present required design course sequence consists of two consecutive two-unit laboratory courses offered in the Winter and Spring quarters of the senior year. Each course requires six contact hours per week. No formal lectures are scheduled. Mini-lectures are provided to specific groups of students to address particular problems, if and when the need arises. All required aerospace specific course material (excepting the one analysis course, ARO 445) is prerequisite to the required design course sequence as shown in Table 4, i.e. all required aerodynamics, stability and control, structures, propulsion and heat transfer courses are completed by the student before

Table 3. Goals for a senior level preliminary design course

1. Develop the student's creative ability to solve open-ended aerospace (aircraft, missile, engine, spacecraft, helicopter, hydrospace or terraspace) design problems constrained by a Request-for-Proposal (RFP).
2. Develop the student's ability to prepare parametric studies of aerospace systems.
3. Develop the student's ability to prepare trade-off studies of aerospace systems.
4. Develop the student's ability to define, calculate and evaluate figure-of-merit parameters for aerospace systems.
5. Develop the student's ability to prepare 'carpet plots' of significant design variables.
6. Develop the student's understanding of the interrelationships that exist between the specialty areas of aerodynamics, structures, propulsion, flight mechanics, stability and control, ground support, operations and cost in an integrated aerospace vehicle design.
7. Make students aware of the importance of lifecycle costs to the viability of any aerospace system design.
8. Make students aware of the importance of maintenance man hours per flight hour (MMH/FH) for any aerospace atmospheric flight system.
9. Require the student to make and accept the responsibility for design decisions related to an aerospace design responsive to the constraints of an RFP.
10. Develop the student's oral and written communication skills required to describe the assumptions, methods and results of engineering analysis, synthesis and decision making associated with the design of an aerospace system constrained to the requirements of an RFP.
11. Provide the student with an awareness of the importance of synergism to the design of an aerospace system constrained to the requirements of an RFP.
12. Provide the student with opportunities to develop leadership abilities during the design of an aerospace system constrained to the requirements of an RFP.
13. Provide the student with opportunities to develop his or her engineering judgement during the design of an aerospace system constrained to the requirements of an RFP.
14. Provide the student with an academic atmosphere that simulates the preliminary design environment to be found in industry.
15. Develop the student's abilities to successfully respond to the analysis, schedule and documentation requirements associated with an aerospace system design constrained by the requirements of an RFP.
16. Provide the student with a 'capstone' conceptual/preliminary aerospace design experience based upon preceding coursework provided by the curriculum.

Table 4. Required aerospace engineering courses

Fall	Winter	Spring
Freshman		
ARO 124 (2)* Fundamentals (Inviscid Fluid Flow)	ARO 125 (2) Fundamentals (Viscous Fluid Flow)	ARO 126 (2) Fundamentals (Computer)
Sophomore		
ARO 245 (2) Flight Mechanics	ARO 246 (2) Instrumentation	ARO 326 (4) Structures
Junior		
ARO 301 (4) Fluid Dynamics	ARO 311 (3) Gas Dynamics	ARO 312 (4) Propulsion
ARO 327 (3) Structures	ARO 351 (1) Gas Dynamics Lab	ARO 401 (4) Heat Transfer
ARO 357 (1) Structures Lab	ARO 305 (4) Subsonic Aero	ARO 404 (4) Supersonic Aero
		ARO 322 (4) Control Theory
Senior		
ARO 405 (4) Stability & Control	ARO 445 (3) Analysis	ARO 463 (2) Design Seminar
ARO 406 (4) Advanced Dynamics	ARP 446 (2) Vehicle Design	
ARO 444 (3) Analysis	ARO 462 (2) Senior Project	
ARO 461 (2) Senior Project		

* The numbers in parentheses refer to the quarter units allocated to the course.

taking the required design course sequence. Course content rather than exact titles are given in Table 4.

Request-for-Proposal. Each design activity or project is created to respond to some specific RFP. The RFP may be generated by a faculty member to address some particular interest or perceived need. Such RFPs may result from articles appearing in *Aviation Week and Space Technology*, *Aerospace America*, *Vertiflite*, news magazines such as *Newsweek* or *Time*, or local newspapers. They may also result from discussions, for example, at professional aerospace conferences. In recent years, the RFPs used have generally been issued by one of the professional engineering societies for national student competitions or generated through participation in the NASA/USRA ADP.

Some care must be exercised in the selection of an RFP. Student design projects modelled on current industry efforts may result in the student design team being strongly influenced by public perception of industry decisions, with the result that the students do not fully utilize their own initiative and creative abilities. Furthermore, if a design specification seems too unrealistic, it may have an adverse impact on design creativity.

ARO 446, Advanced Aerospace Design Project. The first course in the required design course sequence is, as noted above, ARO 446, Advanced Aerospace Design Project. This course is offered during the Winter quarter of the academic year (January to mid-March). All graduating seniors must take the course. This usually means that two sections of the course will be offered to accommodate the 50–60 students expected to enrol in the course.

A copy of the selected (or developed) RFP is distributed to all class members at the first meeting of ARO 446. The project is discussed at length in order to clarify fully the intent of the design, the methodology that might be used and the problems that may arise. Although this discussion often rages throughout the design effort, the initial aspects of the dialogue are for student orientation. Project engineers (team leaders) are elected and design teams are selected. The project engineer then makes the initial assignments.

A preliminary configuration is expected by the end of the first week. At that time, the instructor meets with the project engineers to ascertain that each team is working on a somewhat different design solution. The project engineers are then expected to develop schedules for task assignments that typically include parametric analysis, trade studies, familiarization with existing computer software, the development of additional needed computer codes, oral presentation and final written documentation. A mission profile and a constraint diagram is expected by the end of the third week.

One-page weekly reports summarizing weekly activities are often required of the student project engineers (leaders).

ARO 463, Aerospace Design Seminar. The second course in the design course sequence is ARO 463, Aerospace Design Seminar, offered during the Spring quarter of the year. Iteration of the design to satisfy RFP specifications continues through the early portion of this course. It is expected that the basic configuration will be 'frozen' within the first three or four weeks of the quarter. This permits some detailed structural analysis to be made. Consideration is also given to automatic control systems, landing-gear design, stability and control, survivability, crashworthiness, reliability, maintainability, flying qualities and cost. It is absolutely mandatory that students create the design within the constraints of the applicable Federal Aviation Regulations (FARs) and Military Specifications (Mil Specs).

The last half of the Spring quarter is devoted to preparing the written response to the RFP, as well as preparing for the industry/government design review presentation. Some analysis is performed during the last weeks in order to clarify details of the design. A 100-page (maximum) typed final report is expected from each design team. Students are encouraged to use word-processors and the best computer graphics software available. The final three meetings of the quarter are generally used to develop the slides and transparencies to be used in their final oral presentation. The last such presentation is a formal 30-minute briefing (involving all team members, as does each oral presentation) to the invited industry/government review board.

Team size. Some trial-and-error experimentation has been performed over the years to determine the appropriate size of a senior level design team. An entire class of 20–24 students has, on occasion, functioned as a design team. There seems to be at least two pedagogical disadvantages to using an entire class as a design team. The first disadvantage is likely to be isolation. With the whole class as a design team, each student is likely to work on only one component of the design and thereby be somewhat isolated from the overall project.

A student in a design team is generally doing something at least a little different from what everyone else is doing. It is sometimes difficult to get each student to contribute equal effort and achievement to the overall design effort. The Cal Poly, Pomona experience has been that the malingering student problem (i.e. the second disadvantage) increases with increasing design team size.

An extreme alternative approach to the size problem is to let each student design their own aerospace vehicle system. This requires an incredible amount of work—much more than is suggested by four quarter units of effort—but it minimizes the malingering student problem.

The Cal Poly, Pomona experience suggests that a design team of 5–7 students is perhaps optimal. With 5–7 members on a design team, the project engineers can be expected to coordinate and direct team member efforts in a reasonable fashion. Each member of the team will likely receive several different assignments in the course of the design effort and peer pressure usually keeps the malingering student problem under control. For these reasons, ARO 446 and ARO 463 design teams usually have 5–7 members.

Role of industry. Industry and government often serve as a source of information for student design teams. Engine companies are sometimes requested to provide engine data for use in the design project. Speakers from industry and government are often invited to address the design classes during regularly scheduled class hours. One of the major roles of industry and government, however, is related to the final oral presentation by the design teams.

Each year, at the end of the Spring quarter, some 20–30 design engineers from industry and government are invited to attend the final design team presentations and serve as the Industry/Government Review Board. Typically 15–25 of the design engineers are able to accept the invitation.

Judging criteria are provided to the representatives from industry and government who comprise the Industry/Government Review Board. The Board selects a first (best), second and third place response to the RFP, though the selection does not affect student grades. Student presentations to the Board are typically 30 (sometimes 40) minutes in length with an additional 10 min allowed for questions.

Other factors. A number of other factors impact the successful implementation of the required design course sequence. Continuity (between ARO 446 and 463), the proper role of the instructor, student evaluations, textbook selection, scheduling, team leader selection, team member selection and other factors have been discussed at length by Newberry and Lord [5] and Newberry [6].

NASA/USRA PARTICIPATION

During the Fall of 1984 the National Aeronautics and Space Administration developed the Advanced Space Design Program as a pilot project initiative to foster engineering design education in the universities and to supplement NASA's in-house efforts in advanced planning for space design. This program was expanded to include aeronautical design activities in 1986. The Advanced Design Program is administered by the Universities Space Research Association under grants from NASA Headquarters. Some 43 universities are currently involved in the program [7].

Design faculty at Cal Poly, Pomona became aware of the NASA/USRA Advanced Design Program (ADP) near the time of its inception. Although not part of the program in 1986–87, Cal Poly, Pomona students were invited to present briefings of their space and aeronautics design work at the NASA/USRA ADP Third Annual Summer Conference in Washington, D.C. during June 1987. Region VI and the Los Angeles and Arrowhead Sections of the AIAA together with several Cal Poly, Pomona student groups [Cal Poly, Pomona Student Branch of the AIAA, Engineering Council and the Associated Students of California State Polytechnic University, Pomona, Incorporated (ASI)] funded four students to attend the NASA/USRA Third Annual Summer Conference. Cal Poly, Pomona was invited to join the NASA/USRA Advanced Design (pilot) Program in Aeronautics in the Fall of 1987 [8].

The NASA/USRA ADP was created to promote and enhance university undergraduate space and aeronautical related design programs. Enhancement takes on a variety of meanings depending upon the condition of the design program at each participating university and the experience, philosophy, motivation and goals of the respective design faculties. Cal Poly, Pomona was privileged to participate in the NASA/USRA pilot ADP for two years. The NASA/USRA pilot aeronautics ADP was given permanent status in 1989 when Cal Poly, Pomona was one of nine universities competitively selected for the first three-year participation in the permanent aeronautics ADP.

During the 1987–88 academic year Cal Poly, Pomona's NASA/USRA design activities were focused on high-speed civil transport (HSCT) studies. The design focus was shifted to subsonic, high-altitude, reconnaissance aircraft design during the 1988–89 academic year.

High-speed civil transport design

A number of advanced supersonic transport configuration development studies have recently been performed by independent private contractors for NASA. Therefore, when Cal Poly, Pomona was invited to join the NASA/USRA ADP in Aeronautics in August of 1987, it was suggested by the Cal Poly, Pomona design faculty that related HSCT studies be performed by their undergraduate design students participating in the NASA/USRA ADP. An individual at the NASA Ames Research Center was named the NASA point of contact for Cal Poly, Pomona's participation in the ADP. The NASA point of contact (POC) concurred with the HSCT suggestion made by the Cal Poly, Pomona design faculty.

Fall quarter. During the Fall quarter (first study phase) of the 1987–88 academic year, the students had two principle objectives. The first objective was to review the available second-generation supersonic transport design studies, supplied by NASA, just completed by the independent NASA contractors. The second objective was to obtain a copy of the design synthesis computer code known as ACSYNT from the NASA Ames Research Center (ARC), get it operational on the Cal Poly, Pomona Computer System, and have the design students become familiar with the code. A new course, ARO 499 Supersonic Transport Design, was introduced to provide the Fall quarter course framework for the NASA/USRA student design project.

The students were grouped into aerodynamics, propulsion and structures technology teams in order to identify and become familiar with the technologies required for the HSCT design effort. A single mission profile was developed. The required aircraft was to have an overall range of 6500 nautical miles (plus reserves), a design Mach number between three and six, accommodate 250 passengers and operate from existing airports. In addition, the aircraft was to have a turnaround time of 1 h, an overpressure goal of 1 p.s.f. and the cruise portion of the mission was to have minimal impact on the ozone layer. One-page weekly progress reports were required to document their design efforts.

The ARO 499, Supersonic Transport Design course was designed as a two unit, six contact hours per week, laboratory course. The course was designed to complement the required Winter and Spring quarter design courses and thus provide the participating students with a full year of design experience. Eighteen students enrolled in the Fall quarter design course. They continued their HSCT work in ARO 446 and ARO 463, the Winter and Spring design courses, respectively.

Winter quarter. All of the HSCT design students enrolled in the same section of ARO 446 (two sections were offered) where they were joined by approximately 15 additional students. A couple of the new students joined the HSCT group and the rest were formed into two additional design teams: one team elected to work on a space project and the second team elected to work on a high-altitude reconnaissance aircraft.

Four final HSCT configurations (blended wing, joined wing, oblique wing and caret wing) were selected in order to evaluate the effects of planform on aircraft performance. The initial computations of vehicle performance were then performed. All groups prepared weekly progress reports. Oral presentations were given approximately every three weeks by each design team. A special NASA/USRA Ames/Dryden mini-conference was very useful for developing the oral presentation skills of students of California universities involved in the NASA/USRA ADP.

Spring quarter. Each design team completed their design efforts during the Spring quarter. This work was performed in the ARO 463, Aerospace Design Seminar, class of which there were two sections organized in a fashion identical to ARO 446. Weekly progress reports were written and several oral presentations were given by each design team. Each design team also prepared a 100-page final report. Copies of the final reports were sent to USRA as part of the NASA/USRA grant fulfilment [9–14].

All of the Cal Poly, Pomona senior design teams present the results of their efforts at the Senior Design Review. Each design team gives a 30 minute oral summary presentation, on the last class meeting of the Spring quarter, before a review board from industry and government. Each Spring some 15–25 design engineers from industry (mostly from the Los Angeles area) volunteer to serve on the Industry/Government Review Board at the Senior Design Review. The Board provides very useful feedback to both the students and faculty.

At the fourth annual NASA/USRA Summer Conference held in Cocoa Beach, Florida (Kennedy Space Center), Cal Poly, Pomona was asked to prepare a paper describing their NASA/USRA design work for the annual AIAA aircraft design meeting held in September of 1988 in Atlanta, Georgia. The paper was prepared by the graduate assistant, Steve Cass, and one of the HSCT design team leaders, Chris Ball [15].

High-altitude reconnaissance aircraft

The four HSCT configurations as well as the long endurance reconnaissance configuration studied during the 1987–88 academic year (first year with the NASA/USRA pilot ADP) were primarily concerned with high-altitude aircraft design. The cognizant NASA personnel and Cal Poly, Pomona faculty decided to continue the high-altitude studies during the 1988–89 academic year when Cal Poly, Pomona was invited to participate for a second year in the pilot program [16]. The second-year design goals were prompted by the need for a low speed instrument bed for monitoring air pollutant concentrations at high altitude in the Earth's polar regions.

Fall quarter. As in the first year of the Cal Poly, Pomona participation in the NASA/USRA (pilot) ADP, approximately 18 students enrolled in the 1988–89 Fall quarter ARO 499, Advanced Vehicle Design course. The students were, again, organized into aerodynamics, propulsion and structures groups. One-page weekly progress reports were required of each design team.

The design goal was to develop a subsonic aircraft ($M = 0.7$) capable of carrying some 3000 lb of air-quality monitoring instrumentation for a 2 h cruise at approximately 130,000 feet altitude. The freestream dynamic pressure during cruise was roughly 8 p.s.f. Consequently, the first Fall quarter objective for the design class was to review the available information on subsonic high-altitude design problems, including the effects of low Reynolds number aerodynamics. The second objective was to obtain a copy of the ACSYNT code (modified for high-altitude operation) from the NASA Ames Research Center and get it operational on the Cal Poly, Pomona computer system.

It should be noted that the graduate assistant for the design course had spent the summer at NASA Ames making the necessary modifications to ACSYNT for high-altitude operation. Simplified low Reynolds number airfoil and propeller design codes were also obtained from the Massachusetts Institute of Technology (MIT).

Winter quarter. During the second phase of the 1988–89 study (Winter quarter) the students involved in the NASA/USRA high-altitude design project enrolled in one of the two sections of the ARO 446, Advanced Aerospace Design Project, where they were joined by approximately 10 additional students. The high-altitude project design students were formed into three design teams. The new design students were formed into two additional design teams: one for the design of a solar sail vehicle to travel an Earth to Moon flight path and one for the development of a low-cost export fighter.

The high-altitude design teams developed an appropriate design mission for the proposed reconnaissance aircraft. Approximately six configurations were initially considered for the design mission. Three configurations were selected for further study, one configuration for each of the three high-altitude design teams. Studies of the impact of vehicle configuration upon vehicle size, range, power requirements, performance, stability and control, operating costs and lifecycle costs were initiated. Energy management, aerothermodynamic considerations and propulsion system integration received special consideration. One-page weekly progress reports were prepared and several oral presentations were given.

The second NASA/USRA Ames/Dryden mini-conference was particularly useful for the development of student skills related to oral presentations. At the fifth annual NASA/USRA ADP winter meeting held in Santa Clara, California (NASA Ames), Cal Poly, Pomona was asked to describe their NASA/USRA design program in a paper to be presented at the 1989 AIAA aircraft design meeting being held in Seattle, Washington on 31 July–2 August 1989. The paper was prepared by the graduate assistant, David Poladian, and one of the high-altitude project group leaders, David Reinhard [17].

Spring quarter. Each design team completed their analysis efforts and documented their work during Spring quarter. This work was performed in the ARO 463, Aerospace Design Seminar, class of which there were two sections (similar to ARO 446). One-page weekly progress reports were again prepared and several oral presentations were given. These oral presentations included the Senior Design Review and the fifth annual NASA/USRA Summer Conference.

A 100-page final report was prepared by each design team. Copies of these reports were sent to USRA as part of the NASA/USRA grant fulfilment [18–22].

1989–90. The high-altitude reconnaissance aircraft design effort was continued during the 1989–90 academic year. Using the required (of all Cal Poly, Pomona engineering students) Senior Project classes, several non-aerospace engineering students were able to participate as members of the high-altitude aircraft design teams (working on aerospace design problems related to their particular engineering disciplines). This multidisciplinary effort required close coordination and cooperation between faculty members in the affected engineering departments.

Benefits of the NASA/USRA ADP

The aerospace engineering design program at Cal Poly, Pomona has been enhanced in a variety of ways by its three-year participation in the NASA/USRA ADP in aeronautics. This enhancement includes the availability of a graduate assistant who has spent the summer at a NASA center preparing to lead the design effort, additional (elective) coursework for student design development, wider access to technical information, greater capability to utilize computer software, more computer software, interaction with students at other universities, interaction with NASA personnel and a greater appreciation for the role of the NASA research centers in the continuing development of aeronautical engineering and science in the U.S.A. This program of enhancement is expected to increase throughout Cal Poly, Pomona's participation in the first three-year implementation of the permanent NASA/USRA ADP in aeronautics.

New courses

In August 1987 the Aerospace Engineering Department at Cal Poly, Pomona was notified that it was invited to participate in the NASA/USRA ADP pilot program in aeronautics [8]. Discussions with our NASA Ames Research Center point of contact (POC) led to a decision that Cal Poly, Pomona would primarily consider the design of a hypersonic commercial aircraft capable of flying 6500 nautical miles at speeds in the $M = 3$–6 range at altitudes in excess of 100,000 ft.

Undergraduate. Consequently, a new two unit elective design course, ARO 499, Supersonic Transport Design, was offered during the Fall quarter of 1987 with an enrolment of 18 students. The hypersonic vehicle work started in this class was continued and completed by these 18 students (aided by two additional students at the beginning of the Winter quarter) in the required ARO 446 and ARO 463 design classes in the Winter and Spring quarters, respectively, and was presented at the NASA/USRA ADP Summer Conference in Cocoa Beach, Florida in June 1988 [9–12]. This effort was summarized by Cass and Ball [15].

In the Summer of 1988, discussions with our NASA/Ames POC led to a decision to shift the Cal Poly, Pomona student design focus to consideration of a subsonic, $M = 0.7$, high-altitude (in excess of 100,000 ft) reconnaissance aircraft capable of carrying an instrumentation payload of 500–3000 lb. This initial high-altitude, low-speed effort was described at the 1989 NASA/USRA Summer Conference held in Huntsville, Alabama. The 1988 Fall quarter vehicle design work was performed in ARO 499, Aerospace Vehicle Design. The course was renamed to account for the shift in design emphasis and expanded to four quarter credit hours. The ARO 499 design class is now in place and can be used for either aircraft or spacecraft related design.

The introduction of the ARO 499 design class into the Fall quarter of the senior year permits a smooth integration of the NASA/USRA design effort into the established required design program at Cal Poly, Pomona. The design teams working on the NASA/USRA design project work side by side with design teams working on the other aerospace design projects. This integrated design effort has had a synergistic effect which improves the design experience for all students.

Graduate. The success of the undergraduate design program has led to the development of a two-course sequence in aerospace vehicle design at the graduate level. EGR 524, Advanced Aerospace Design, and EGR 624, Advanced Aerospace Design, were scheduled to be offered during the 1989–90 academic year. The courses are multidisciplinary design efforts involving aerospace, mechanical, civil, manufacturing, electrical, chemical and industrial engineering graduate students. This design experience is expected to simulate the truly multidisciplinary design work of industry and government. The EGR 524 and EGR 624 course descriptions are expected to first appear in the 1990–91 university bulletin. It is expected that, to some degree, the graduate design students will serve as consultants to the undergraduate design class, though the graduate and undergraduate design projects are expected to be different.

Computer software

Participation in the NASA/USRA ADP in aeronautics has resulted in access to a greater increase in aircraft design computer software capability than would have otherwise been possible. The NASA Ames Research Center POC has, for example, made the design synthesis programs ACSYNT and GASP available to Cal Poly, Pomona. The Harris wave drag program and several PC programs were provided by personnel at the NASA Langley Research Center. A low Reynolds number airfoil design program was obtained from MIT. These examples represent only a small fraction of the computer software that has been obtained as a result of Cal Poly, Pomona participation in the program. This software has greatly enhanced the aeronautics design program at Cal Poly, Pomona.

Personnel interaction

One of the great experiences derived from Cal Poly, Pomona participation in the NASA/USRA ADP has been the technical and social interaction between faculty, students and NASA personnel at the Winter and Summer conferences. The opportunity for students, faculty, NASA and USRA personnel to share experiences at these conferences has resulted in improved information transfer, improved instructional methodology, greater student interaction in design and an expanded design database that has markedly improved design instruction at Cal Poly, Pomona.

California mini-conference

In 1988, personnel at NASA Ames/Dryden, serving as the point of contact for the University of California, Los Angeles (UCLA) NASA/USRA Aeronautics design project, thought it would be useful to sponsor a mini-conference for California students involved in the NASA/USRA Aeronautics program. Accordingly they held such a conference during the Winter quarter of the 1987–88 academic year. California Polytechnic State University, San Luis Obispo (Cal Poly, SLO), UCLA and Cal Poly, Pomona were invited to attend. The intent of the conference was to give the students some experience at oral presentations in a less familiar environment and to provide the students with a forum for exchanging ideas and information. Approximately 60 students and faculty attended the one-day conference.

The 1987–88 California mini-conference program included a tour of the Dryden facility, lunch and presentations by students from the three schools. Each presentation was approximately one hour in length. A video tape of the presentations was made so that the students could see their own presentations and improve them (if necessary) for the 1988 NASA/USRA Summer Conference held at Cocoa Beach, Florida. Everyone considered the mini-conference to be a great success.

The second annual NASA Ames/Dryden mini-conference was held in April of 1989 with results similar to those obtained for the 1988 mini-conference. Faculty and students from California State University, Northridge also attended the 1989 conference. The third such successful conference was held at NASA Ames/Dryden in the Spring of 1990.

Assistantships

The NASA/USRA ADP provides a Summer Assistantship position, with the NASA center serving as the point of contact for the university. In addition, Cal Poly, Pomona has used the graduate assistant funds to establish a Design Assistantship (graduate assistant) at the university during the academic year.

Summer Assistantship. NASA/USRA Summer Assistantship funding enables the graduate assistant to spend the summer (10 weeks) at the NASA center serving as the point of contact for the University. The Assistant is able to work directly with NASA scientists and engineers and obtain invaluable experience. During the summer the Assistant is able to develop the scope of the forthcoming undergraduate design problem. He or she is able to identify the literature, NASA personnel and computer programs that will contribute to the successful forthcoming undergraduate design task. The Assistant is able to bring this database back to the university to enrich its design program.

Design Assistant. At Cal Poly, Pomona the Summer Assistant becomes the Design Assistant (graduate assistant) upon reaching the university campus at the beginning of the Fall quarter. The Design Assistant is expected to lead the design program throughout the year. The Design Assistant supplements the efforts of the design faculty member in giving individual attention to each student in the design class.

The Design Assistant generally is the local expert on the computer programs that have been brought to the campus from the NASA Center, another university or private industry. Having been through the undergraduate design process himself/herself, the Design Assistant is in a unique position to help the undergraduate design engineers.

Through the Summer Assistant aspect of the program, the Design Assistant serves as a direct link between Cal Poly, Pomona and the NASA Ames Research Center. This link is recognized as a great asset to the university design program.

MULTIDISCIPLINARY EFFORT

Occasionally, the aeronautics design process identifies problems in the automatic controls, environmental systems, power generation, support facilities, manufacturing processes and/or material properties that fall outside the normal bounds of expertise provided by aerospace engineering students but within the field of expertise of engineering students in other engineering disciplines. The resources provided by the NASA/USRA ADP in aeronautics permit Cal Poly, Pomona to incorporate some multidisciplinary components into the undergraduate design programs. As future design requirements dictate, engineering students from electrical, chemical, manufacturing, civil and industrial engineering departments will be able to participate in the aerospace engineering design process. Synergistic improvements in the final design product can be expected from this infusion of talent from outside the aerospace engineering department.

Each Cal Poly, Pomona engineering department requires two courses in the Senior Project course sequence. A mechanical engineering student, for example, with the advice and consent of the mechanical engineering faculty, can enrol in the

Senior Project course for mechanical engineering students and complete an acceptable mechanical engineering task associated with the NASA/USRA aerospace engineering design project.

The Aerospace Engineering Program at Cal Poly, Pomona will somewhat limit non-aerospace engineering student involvement, but it is expected that 5–15 non-aerospace engineering majors will be able to contribute effectively to the NASA/USRA design effort, depending upon the particular project in question for any given year. This multidisciplinary effort was initiated during the 1989–90 academic year.

RELATED DESIGN EFFORTS

A senior class of some 60 students is usually large enough to yield some nine or ten design teams within two sections (two instructors) of the required design course sequence. The selected NASA/USRA design topic was typically used by only three or four of the design teams during each of the three years of participation in the NASA/USRA program in aeronautics. However, the benefits of the program were indirectly enjoyed by the remaining design teams.

The Cal Poly, Pomona NASA/USRA ADP statement of work in each academic year has indicated that if sufficient students were available in the design class, some students could be allowed to respond to the AIAA (for example) team competition RFPs in both aircraft and spacecraft design [23]. Each year there were sufficient students for at least two non-NASA/USRA design teams. One team each year responded to the team aircraft competition and one team responded to the team spacecraft design competition. There seemed to be a useful synergy between the several design team efforts.

PROJECT SELECTION

During Cal Poly, Pomona's participation in the NASA/USRA ADP the project selection was made during the early summer for the following academic year. Selecting the design topic at the beginning of summer permits the Summer Assistant (graduate assistant) to spend her or his time at the NASA center preparing material for the forthcoming undergraduate design effort. The project selection was jointly made, after considerable discussion, by the NASA Ames Research Center POC and the design faculty at Cal Poly, Pomona. This process has worked well for three years and should continue to be an effective design selection mechanism.

CONCLUSIONS

1. The preparation of the reports and the oral presentation required by the NASA/USRA design program over and above the design course requirements have improved the communication skills of Cal Poly, Pomona design students.
2. Many Cal Poly, Pomona students have derived 'reality checks' from the tours of NASA facilities provided by the NASA/USRA program. Such tours allow the students to see full-scale vehicles and test facilities and thereby let them establish their own physical frame of reference for these items.
3. The Cal Poly, Pomona aerospace design program has been greatly improved by the computer software obtained directly and indirectly from participation in the program.
4. The Cal Poly, Pomona graduate program directly benefits from the availability of the funded Design Assistantship provided by the NASA/USRA ADP in aeronautics.
5. The Cal Poly, Pomona students participating in the NASA/USRA program derive many intangible and invaluable benefits from the discussions they have had with the many NASA scientists and engineers they meet at the various program conferences.
6. The Cal Poly, Pomona students participating in the ADP derive a valuable intangible benefit from contacts with students from other universities attending NASA/USRA conferences. Such contacts permit the exchange of ideas and personal technical assessments that will serve the individual students throughout their professional lives.
7. University participation in the NASA/USRA ADP permits the students to work on a greater variety of aerospace design topics.
8. Three new design courses (one undergraduate and two graduate) have been added to the Cal Poly, Pomona engineering program as a result of the NASA/USRA ADP.
9. Multidisciplinary aerospace design at Cal Poly, Pomona has been enhanced by the NASA/USRA ADP.

Acknowledgements—The author hereby acknowledges the contributions to this paper by all of the students at Cal Poly, Pomona who have participated in the NASA/USRA program. Without their efforts, this paper could not have been written. Although the list of all the participants is too long to mention everyone, particular acknowledgement is given to Steven Cass, David Poiadian and Renee Yazdi who served as graduate assistants during the program. George Kidwell of NASA ARC was a constant source of encouragement and support. John Sevier, Carol Hopf and their staff at the Universities Space Research Association (USRA) provided encouragement and guidance throughout the program. It should also be noted that a brief summary of this effort appeared in the proceedings of the 1989 Annual Meeting of the American Society for Engineering Education (ASEE) [24].

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