

Freshman/Senior Design Education*

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This paper describes experience with a change in the aircraft design course at Virginia Tech. In the past this course was the so-called 'capstone' design course for seniors. In the spring semester of 1993 freshmen were included on the design teams. There were several purposes for the change. First, as part of Virginia Tech's participation in the NSF-sponsored SUCCEED coalition, we wanted to increase freshmen enthusiasm for engineering, and thus improve retention rate. We also wanted freshmen to understand the need to take all the engineering science courses required in the sophomore and junior years. Finally, we wanted to prepare students for the senior-level design course, which students were finding difficult because the orientation was so different from the engineering science courses. The results of this experience have been completely positive. Both the freshmen and senior members of the design teams want to see this approach continued. Finally, it appears that the quality of course did not suffer. Design teams with freshmen members placed first and third in the AIAA/General Dynamics Undergraduate Team Aircraft Design competition.

INTRODUCTION

FOR THE past twenty or more years the AIAA, through its Student Activities and Academic Affairs Committees, has promoted design education as an important part of an engineering curriculum. In the 1970s the Student Activities Committee started the Bendix Design Competition to promote advances in aerospace design education. The success of this program is evident in the number of technical society sponsored student design competitions in existence today. The AIAA still leads in this area with ten competitions.

The importance of design in engineering education has been emphasized recently. The situation has been the subject of studies and papers by government [1], industry [2, 3], and practicing engineers [4, 5]. NASA is addressing the problem through their support of the USRA advanced Design Program [6]. The importance of design to United States competitiveness in the global economy is finally being recognized. Some educators have also discussed the problem [7, 8]. The ASEE magazine, *Engineering Education*, devoted an entire issue to the subject of design in education [9].

Most design competition entries are submitted by engineering seniors taking their schools' 'capstone' design course. Other students are interested in design but they seldom have the time or background needed for any extra curricular involvement in state-of-the-art, total system design projects such as those used by the AIAA.

Pre-capstone design experience in the curriculum is usually claimed to exist in portions of other curricular offerings and is often the subject of considerable contention when the ABET team

comes to visit. Sometimes we seek to supplement our ABET design 'count' by introducing specific 'design' courses or projects at the freshman or sophomore level. These often add a little fun to the curriculum and may stimulate some of the student's 'design juices', but often both educators and students long for something more challenging than another toothpick bridge or egg drop package or variable angle golf club or front wheel drive bicycle design project.

Recent attempts at innovation in the curriculum have spawned intriguing but somewhat vaguely defined terms like 'vertically integrated design' or 'horizontally integrated design' or 'design throughout the curriculum'. Vertically integrated design usually refers to an attempt to have students start as freshmen or sophomores on a design project which they take with them through many of the courses in their curriculum, using the project as the example to which course concepts and theories are applied. This concept is interesting but requires more coordination among courses than most faculty want to tolerate. It also requires a complete reworking of every project-related class each year as each new class brings its project with it. Furthermore, students are likely to get bored after working for a couple of years on the same topic.

Horizontally integrated design usually refers to the participation of several different majors in a single design course or project. There is much to be said in support of the concept of a multi-major or college-wide capstone design course, but it is hard to get faculty to agree on what such a course should entail. Each engineering department seems to have a slightly (and sometimes radically) different idea about what should constitute a design course. Often these different approaches mirror those of the academic community within their field's technical society and thus, in their ABET visitor's interpretation of design. One curriculum

* Accepted 5 May 1997.
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uses only individual design projects, another only team designs. One always designs a complete system such as a car, while another is content to do an extensive analysis of the car's wheel bearings.

CURRENT OPTION FOR DESIGN TRAINING

'Design throughout the curriculum' seems to be a movement now in favor at the NSF and among those with training in educational esoterica. The entire engineering curriculum becomes one big design project, somehow covering virtually everything of value normally found in a college education, including subjects such as history, sociology and political science imported on a just-in-time basis. This approach includes visions of engineering students asking their 'design facilitator' (faculty advisor) to call in the psychology 'consultant' (professor) to give a semester's worth of lectures which would normally constitute Psyc 101 to help them better understand the relationship between seat pitch and claustrophobia. With TQM and multicultural sensitivity training, you've got a complete modern day college curriculum in a single course. This approach illustrates the problem facing the design instructor in a more traditional curriculum. The design course is supposed to cover the entire breadth of engineering ignored in the engineering-science courses. Since the engineering sciences are a relatively small, although crucially important, component of engineering practice, the design teacher faces a near overwhelming task. In particular, the business aspects of engineering are essentially ignored everywhere else in the typical Aerospace Engineering curriculum.

All of these concepts, from the simple to the sublime, were proposed for inclusion among the collection of experiments to be included in the SUCCEED (Southeastern University & College Coalition for Engineering Education) coalition's NSF-sponsored program to develop what the consortium calls curriculum 21. SUCCEED unites eight very different engineering colleges who hope to find programs which will work at all eight schools, and hence, should work anywhere. This paper describes one of the projects studied: a look at the integration of freshmen into the senior, capstone design course. The goals of this program were to increase retention of engineering students, motivate interest in the engineering science courses, and better prepare students for the senior design course, and hence the practice of engineering.

Freshmen with seniors?

As mentioned above, the usual concept of vertically integrated design education is to have students pursue a single, expanding, design problem throughout their journey through the curriculum. Our proposal was, instead, to have freshmen

and seniors work *together* on the conventional capstone design project.

The proposed merits of this approach were as follows:

1. Freshmen would, at a very early stage of their education, see where their curriculum would lead and why all those courses along the way were valuable.
2. Freshmen would be excited about working on a real 'senior' level design project and would take this excitement with them in later years.
3. Freshmen, in their naivety, would ask some of the questions that seniors are too sophisticated to ask (will the plane fit through the hanger door?), thus contributing to the design process.
4. Freshmen would be excited about doing some of the work that seniors consider drudge work.
5. Seniors, in attempting to explain the project essentials to the freshmen, would learn much more than they would on their own.

Among the questions to be answered were:

- Would the inclusion of freshmen in senior design teams disrupt the often delicate group dynamics?
- Would the degree of freshmen participation consist mostly of 'busy' work, make-work jobs created just to give them something to do?
- Would the quality of the final design project reports and presentations suffer because of the inclusion of freshmen?

In the end of the first year of the experiment all of the proposed merits have proved real and none of the possible problems evolved.

PROJECT STRUCTURE

The freshman/senior integrated design program placed selected freshmen into already established 'capstone' design course groups from two engineering departments, Mechanical Engineering and Aerospace & Ocean Engineering, in January, 1993. Participants were selected from a group of over 100 freshmen, all planning to major in either AE or ME, who were enrolled in Virginia Tech's Engineering Fundamentals program, a common first-year curriculum for first-year engineering students. (Students do not enter their desired engineering major until completion of all first year requirements). Twenty-nine project participants were selected from this group, 20 joining design groups in ME and 9 joining AE design teams. Control groups were also selected and all of these will be followed in the next few years to gauge both the short and long term implications of this experiment.

The freshmen participating in the program used their work on the design project to satisfy a project requirement in their second semester Introduction to Engineering course. This project is normally a

Table 2.9 AIAA Cargo Mix

	M-1 Tanks	AH-1G Helicopters	463L Palettes	Troops	Totals	Percent Of Cargo Bay Weight (Max 800,000 lb)	Percent Of Cargo Bay Area (210 ft x 32 ft)	Fits In Cargo Bay?
Weight Empty (lb)	104,000	7,598	10,000					
Weight Full (lb)	120,272	10,000	10,000	250				
Length (ft)	32.0	53.0	9.0					
Width (ft)	12.9	11.0	7.3					
Area (ft ²)	459.9	645.4	66.0					
Number	6	3	20	200				
Total Empty Weight (lb)	624,000	22,794	200,000	50,000	896,794	112.1%		NO
Total Full Weight (lb)	721,632	30,000	200,000	50,000	1,001,632	125.2%		NO
Total Area (ft ²)	2,759.5	1,936.1	1,319		6,015		96.5%	YES

Fig. 1. Cargo bay with AIAA Cargo Mix (Ref. 10).

CAD problem and it was suggested that the CAD experience of the freshmen would prove useful to the design groups in developing their final reports. The ability of the freshmen to do sophisticated CAD work on their own computers was seen as a plus for this experiment.

In the Mechanical Engineering Department, seniors work on a variety of design projects with a wide range of technical complexity. Favorites are ongoing efforts related to the SAE Formula Race Car and Mini Baja Car competitions as well as the GM Solar Car competition. Twelve students participated in these popular programs and eight joined other projects dealing with topics on bio-conversion, solar energy conversion, robot design and loudspeaker design.

In the Aerospace & Ocean Engineering Department the freshmen joined four aircraft design teams working on either the AIAA/General Dynamics Undergraduate Team Aircraft Design Competition or the NASA/USRA Advanced Design Program Project. Three of the teams were each joined by two freshmen and the fourth team accommodated three freshmen. In 1992-93 the AIAA competition was for a global range transport and the NASA/USRA project was a vehicle to replenish the ozone layer. Three teams worked on the AIAA aircraft design and the participating freshmen all joined the AIAA and were full members of the design effort, officially listed as part of the design teams on the report to the AIAA.

AEROSPACE DESIGN EXPERIENCE

This paper concentrates primarily on the results of this design experiment in the Aerospace Engineering program. However, the ME department reported somewhat similar results.

The Aerospace & Ocean Engineering Department

is enthused about the results of this experiment and about continuing the program in the future. Participation has been expanded to the department's space and ocean engineering design groups.

The freshmen who participated in the program were very enthusiastic about the opportunity and strongly recommended that the program be continued. Contrary to what some had feared, **the freshmen were able to make significant contributions to their design team's work.**

The freshmen helped the seniors assess and refine their design efforts by continually asking questions about their technical reasoning and about design requirements. They also had the latest version of the complete professional package of CADKEY* for use with their personal computers and were able to use this powerful tool to its full extent in the design process and in helping prepare the final report. They worked on a variety of assignments, including the layout of cargo and passenger compartments, the landing gear design and crew station design for both the AIAA's Global Range Transport and the USRA ozone replenisher aircraft.

They became heavily involved in the layout of the cargo bay of the global range transport to hold the required mix of payload in the minimum space. Figure 1 from the Juggernaut team [10] shows the

* At Virginia Tech all engineering students are required to own personal computers which they purchase upon entry to the engineering program. Freshmen make extensive use of their PCs in the first-year Introduction to Engineering course sequence using FORTRAN to study engineering problem solving methods and using CADKEY or AUTOCAD as a tool for engineering design and graphics. Since the students get their PCs as freshmen, the first year students have the latest version of the CAD program and computers which are superior to those purchased by the seniors a few years earlier. All students also have access to CAD software, design programs such as ACSYNT, and workstations in both departmental and college design labs.

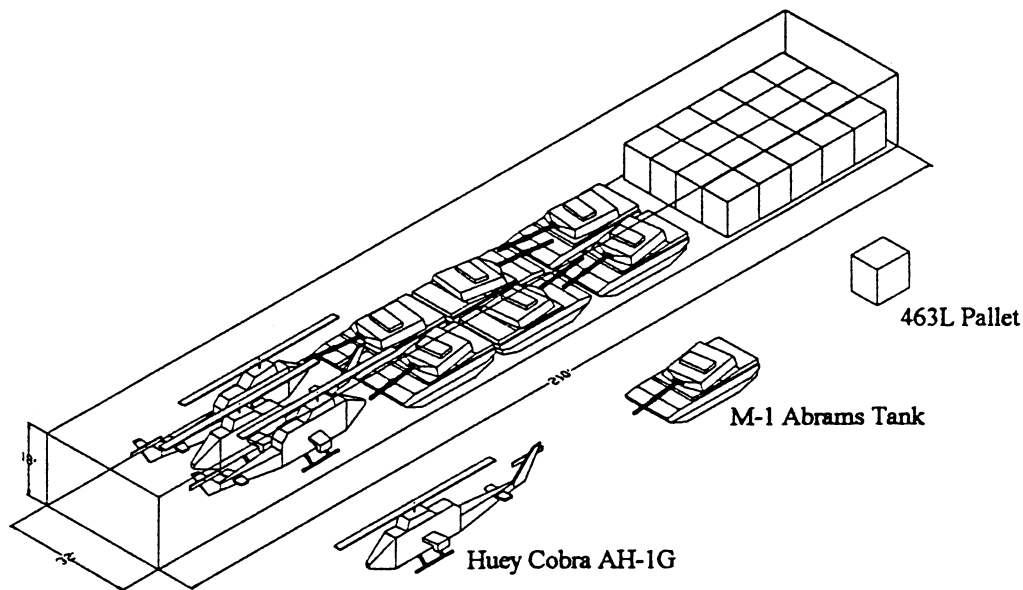


Fig. 2. AIAA Cargo mix layout (Ref. 10).

table used to assess the weight and volumetric requirements of the AIAA cargo. Figure 2 shows the use of CADKEY to actually layout the cargo bay [10]. They determined the payload dimensions and cargo bay layout as well as the weight and center of gravity location for a variety of loading conditions. Volumetric packaging, mass properties and cg determination were well within their capability.

Figure 3 shows a drawing of an entire aircraft by a freshman [11]. He actually took the lead role in the configuration layout. Examples from the Condor design team [12] include design of the cockpit layout shown in Fig. 4, while Fig. 5 illustrates the cross-section of the design for the troop cabin. The corresponding seat and emergency exit layout are given in Fig. 6. Finally, the landing gear layout is shown in Fig. 7a and 7b. These figures illustrate the many aspects of design which do not necessarily rely heavily on engineering science. The freshmen were able to proceed with consultation from team members that had taken more advanced courses.

In the ozone (USRA project) group, one freshman designed the attachment system to connect a large propane tank to the airframe [13]. He said that, compared to his assignments in his engineering static's class (being taken the same semester), this work was much more meaningful to him in learning the value of mechanics.

RESULTS

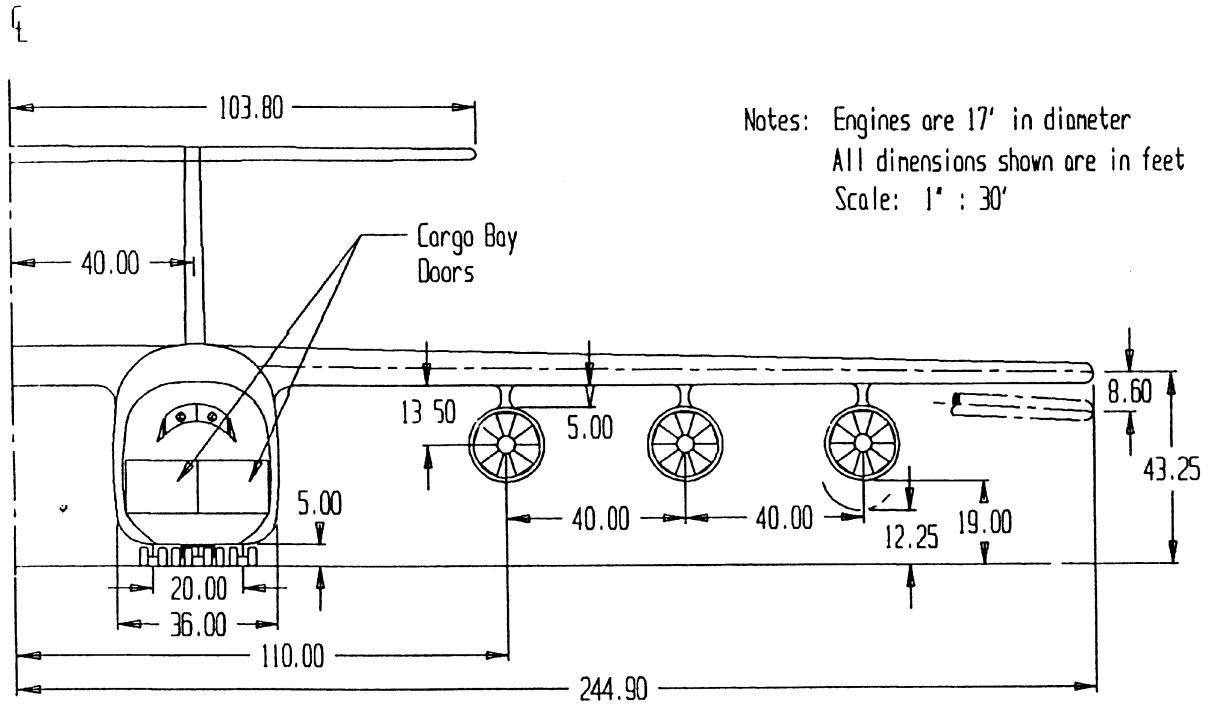
The results of this experiment were virtually all positive. Perhaps the best evidence of this is the fact that aircraft design competition teams with freshmen participants won first and third place in this national design contest. Three of the ten members of the third place team were freshmen

and two of the ten members of the first place team were freshmen. This should dispel student or faculty fears that participation of freshmen in these, normally senior only, design programs will reduce a team's or a department's chances of success in the competition.

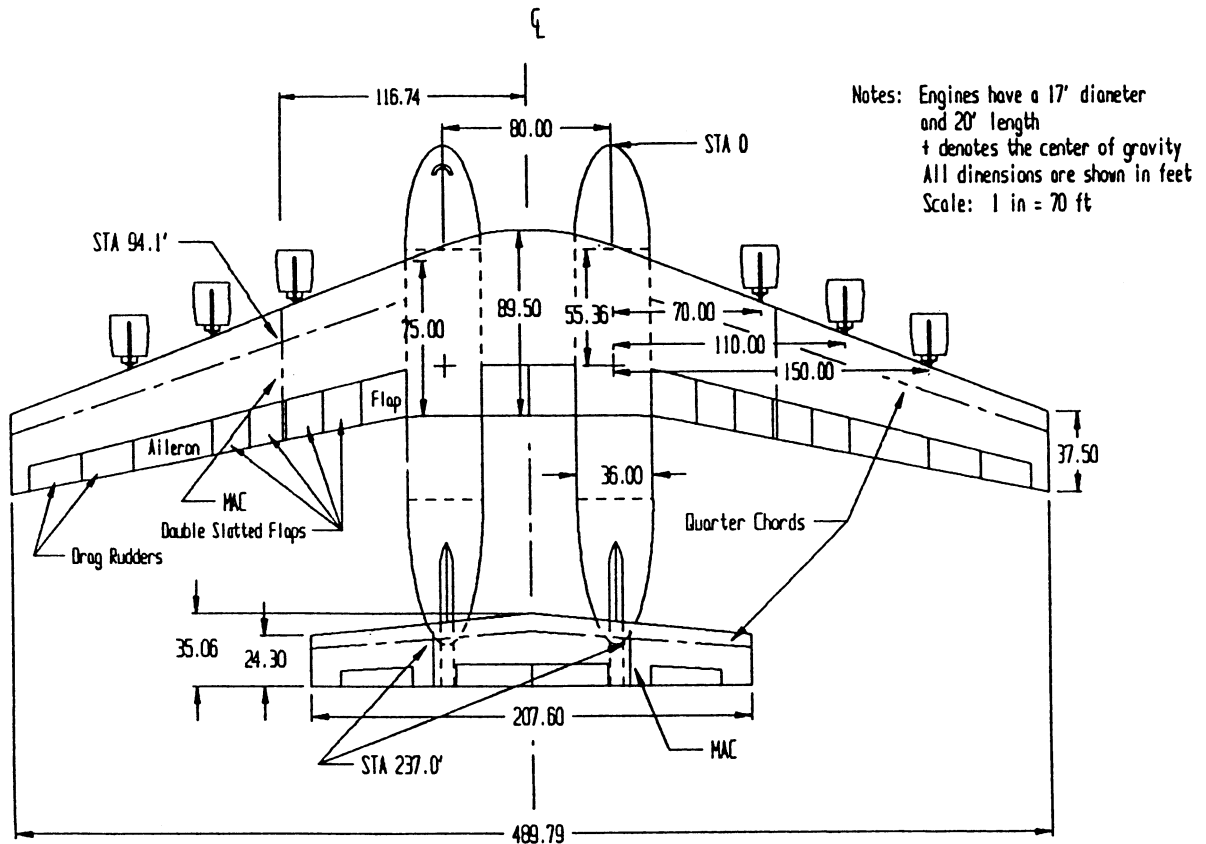
The USRA design program is not a competition, so evidence of the experiment's success is not as explicit. However, the experience there paralleled that in the AIAA-directed groups. Using funds from the NSF/SUCCEED budget, freshmen participating in the USRA group were able to attend the NASA/USRA Advanced Design Program Summer Conference in Houston along with the participating seniors. One drawback to the NASA/USRA ADP program is that the conference occurs after most of the students normally participating have graduated, meaning that the conference participants do not take the interest and enthusiasm generated by this conference back to their schools, where it can feed future programs. By including freshmen in the subsequent conferences we hope to be able to build on both the experience and the student's enthusiasm for several years to come.

At the end of the semester all the students evaluated each other's performance. They were also asked about the inclusion of freshmen in the design course. The response was entirely positive. All students responded that the freshmen should continue to be included. They also felt that the lack of engineering science background was not a major handicap.

One of the long-term goals of this experiment is to develop a program which will enhance the retention of Engineering students, particularly of women and minorities. It is, of course, too early to tell what these results will be; however, it seems successful thus far. There were some minimum criteria set for student participation in the program. Since the students were to use their work in



(a) GRT Front View (Ref. 11)



(b) GRT Top View (Ref. 11)

Fig. 3. Freshman drawing of a Global Range Transport.

Scale: 1 inch = 36 feet

Note: All dimensions shown in feet

Other Dimensions:

Wheels are 50" in diameter with 4 wheels per bogie and 9 stuts per fuselage

Engines are 20' long 17' in diameter and 5' below the wing

Tip Chord of Vertical Wing is 32 feet

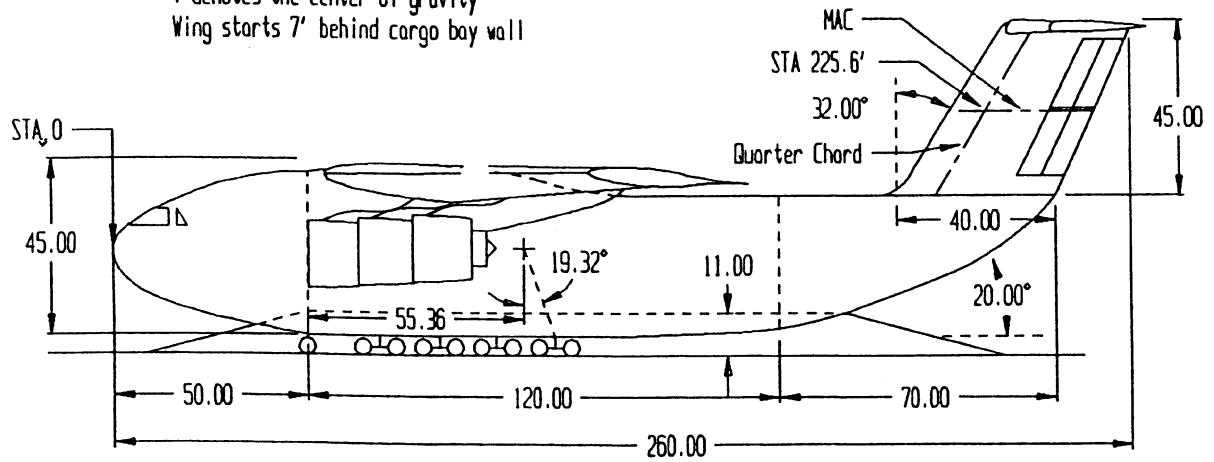
Both Loading Ramps are at 15° angles and 42.5' long

Fuselage is 5' above ground

Main Wing has a 5° incidence

† denotes the center of gravity

Wing starts 7' behind cargo bay wall



(c) GRT Side View (Ref. 11)

Fig. 3. (Continued)

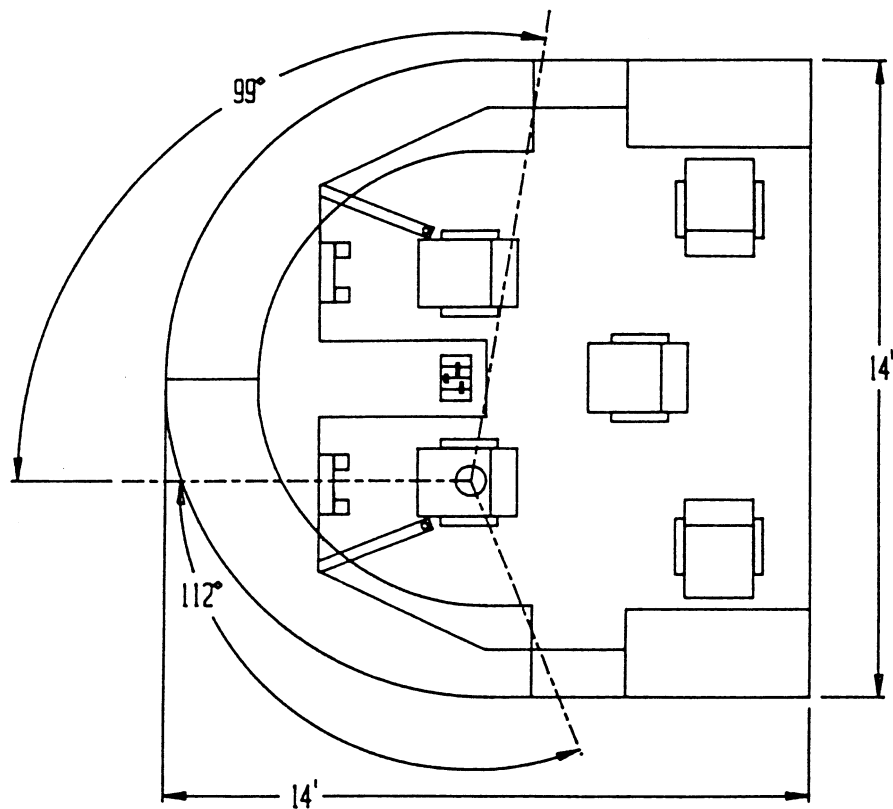
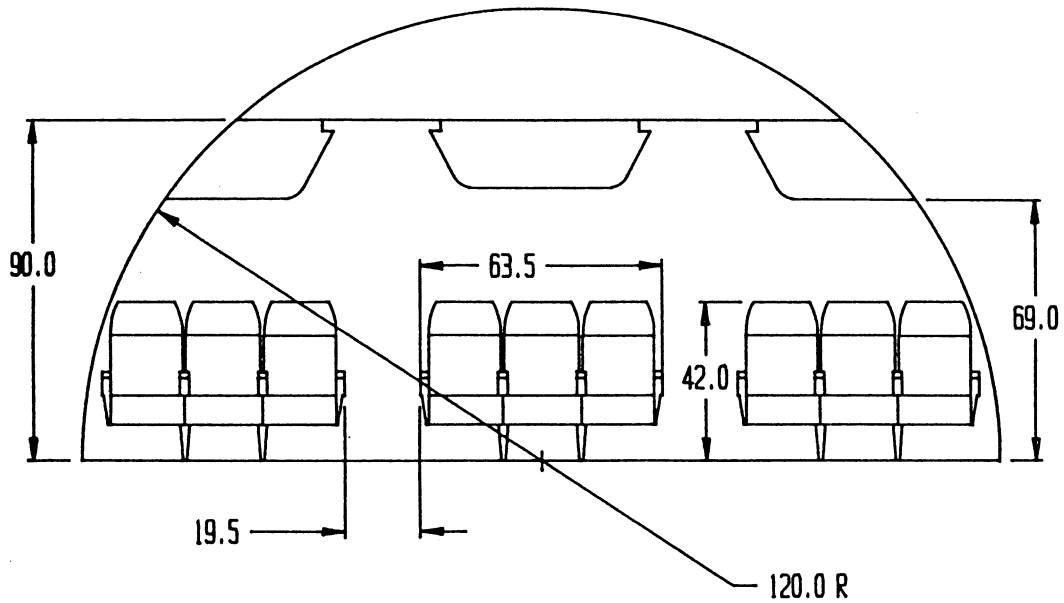


Fig. 4. Cockpit layout (Ref. 12).



FUSELAGE STATION 268 - ALL DIMENSIONS IN INCHES

Fig. 5. Cross-section of troop cabin (Ref. 12).

this program for their project in the second semester Introduction to Engineering course it was imperative that they be registered for that course. This requirement and an additional one for a minimum grade of C on the preceding course, in effect, ruled out participation by students who

were already in serious academic trouble by the end of their first term of enrollment and precluded any determination of the benefits of this type of program for this most endangered species of student. Students with passes but not with outstanding grades were eligible and the later

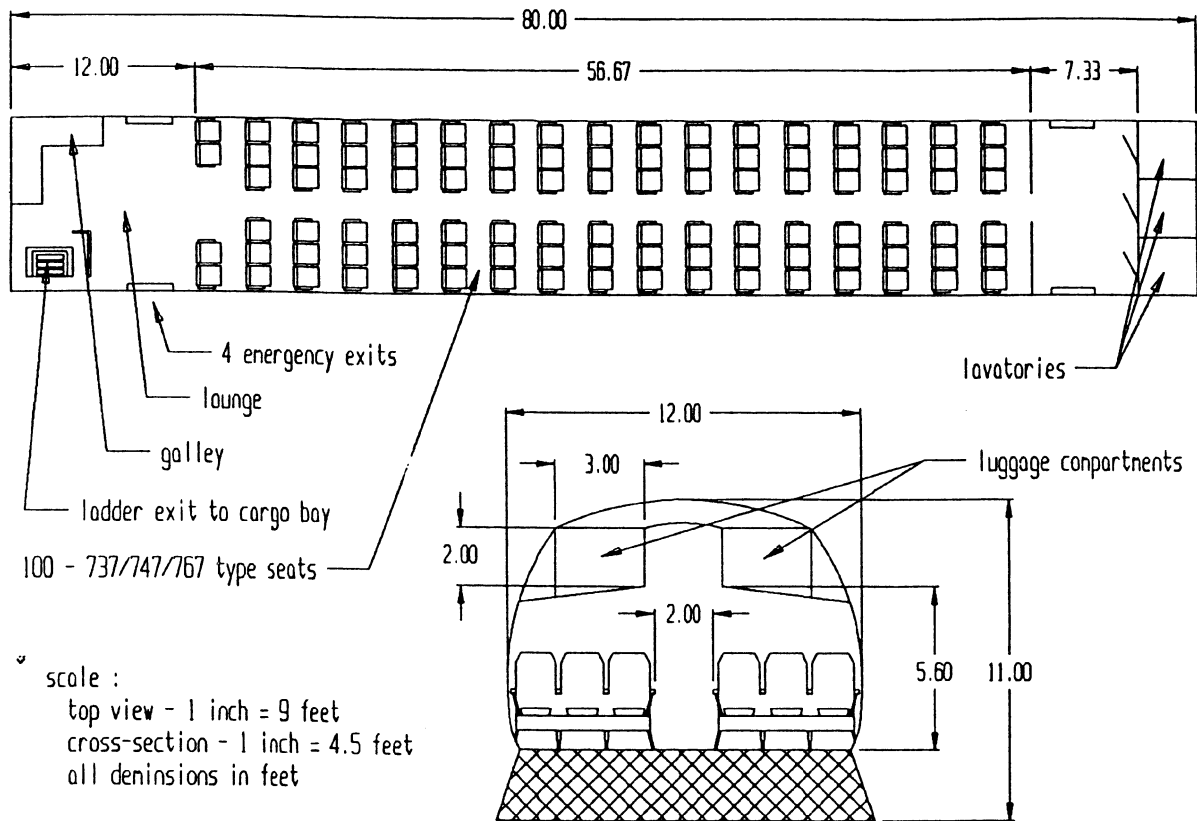
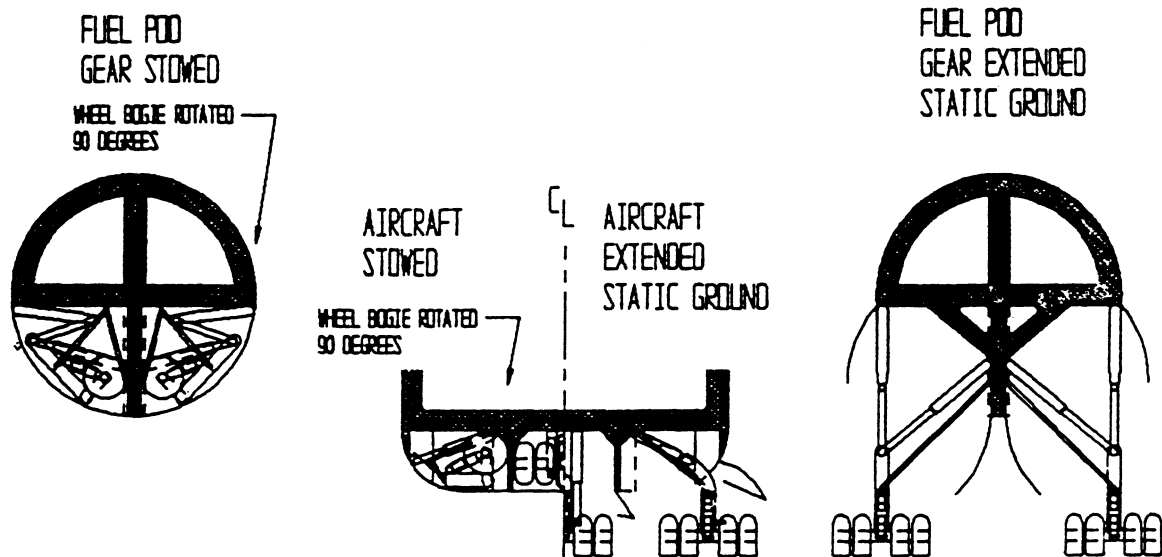
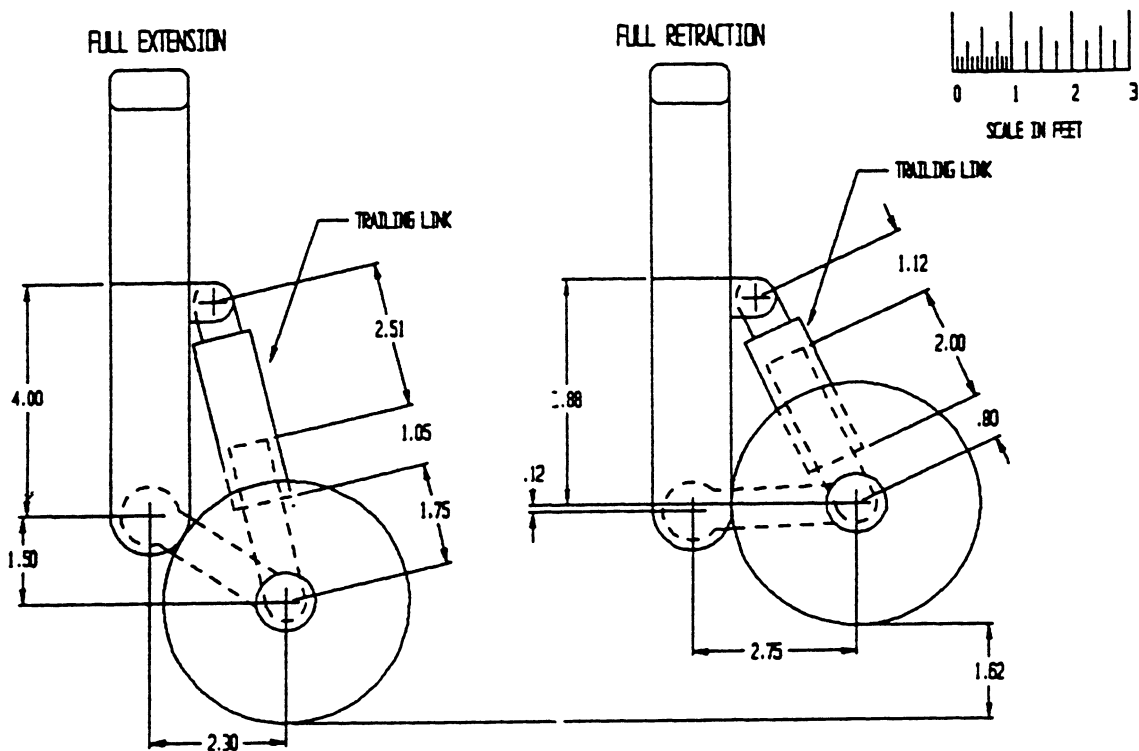


Fig. 6. Troop seat and emergency exit layout (Ref. 11).



(a) Landing gear integration in design (Ref. 12)



(b) Landing gear mechanism (Ref. 12)

Fig. 7. Freshman landing gear design for the Global Range Transport.

records of these students will be compared with a control group with similar demographics in our continued study.

At present, all 29 of the students who participated remain in engineering. Twenty-six of these were eligible to transfer into an engineering major on schedule at the end of their second semester. The remaining three had postponed taking at least one required course and had to wait until that course was completed to enter their major. By the end of the fall 1993 semester all entered a major.

The 1993 program included one African-American student and four women. As of the following fall term all made satisfactory progress in engineering; however, it is too early to tell from control group comparisons whether or not the experiment has had any impact on minority retention.

There was some thought that participation in this program would encourage the participants to enter the major in which they had been part of the design program. This, however, was not a goal of

the program. When selected all participants had indicated a preference for either ME or AE. Of the twenty students who participated in the ME design course thirteen selected ME as their major. Three of the nine who were part of AE design teams selected majors other than AE (one of these three chose Ocean Engineering, the sister program to AE in the same department). It is, at this point, difficult to tell whether the program could be said to be successful in keeping students on track toward a specific major. It is possible that some of the participants indicated an original preference for ME or AE simply to be able to join the experiment. It is possible that their experience caused some of the 10 students who supposedly changed direction to make that change, although the enthusiasm of the participants during the program would not support that conclusion.

IMPACT ON THE CURRICULUM

The major effect of this experiment has been to cause the Aerospace & Ocean Engineering Program to consider some immediate changes in the AE curriculum. The seniors involved in the participating design teams were so enthusiastic about the program that they recommended not only the continuation of the initial experiment but have also recommended an extension of the program or the creation of a similar concept that can include sophomores and juniors. The freshmen in the experiment are asking what they can do to continue to be involved in design and this year's freshmen are asking if we will repeat the experiment. Some of this year's seniors have also asked how many freshmen they can have joining their design teams in the spring semester. We do plan to continue the program, expanding it to include the AIAA space design project and a SNAME sponsored ship design project for the Ocean Engineering students.

It is obvious that, if a program such as this is to exist, there must be some way for the students who have been 'turned on' by participation as freshmen to continue with some type of design participation. The sophomore year is well known as a discouraging year for engineering students, a year in which most of their courses are generic in nature and the excitement of the 'college experience' has turned to a ho-hum routine. To enhance the 'high' of the freshman year without providing a way to continue that high makes a dull year even duller and probably will have a negative effect on student retention. We have seen this already in the sophomores who were in last spring's experiment and who are continually searching for ways to again find the excitement that they experienced previously.

Several possibilities present themselves as solutions to this quandary. One thing we have already decided to do is to create a one credit Introduction to Design course to be taught in the first semester

of the sophomore year. We currently have no in-major courses in this term and this program has made us realize the need for a course which will allow us to make direct, regular contact with these sophomores.

Several students have asked if they, as second semester sophomores in the spring, can again participate in this year's design class the same way that they did in their freshman year. To do this would result in the senior design teams including both freshmen and sophomores. This would begin to become a truly 'vertically integrated design' approach and, while it might be a worthy experiment, it results in a broadening of the scope of our experiment which we are not ready to undertake this year. It is, of course, possible that, after further experience with and evaluation of the present program we might decide to shift the emphasis to a sophomore/senior design experience, an approach which would be much more manageable since all the participants would be in the same academic department.

One thing is sure. This experiment, like many successful programs, has opened up a much wider range of questions and possibilities than were originally envisioned.

CONCLUSIONS

The Freshmen/Senior Vertically Integrated Design Program is, as of this writing, still far from the point where any final analysis of its scope and impact can be fully realized. The impact of this program on all associated with it has, however, been so profound that we can safely deem it a resounding success. The following statements will summarize the impact of the experiment on the engineering program at Virginia Tech:

- The experiment is invigorating the Mechanical Engineering and the Aerospace Engineering curricula at Virginia Tech and is having a profound impact on the freshman level Engineering Fundamentals program.
- The program is causing many students and faculty to reorient their approach to engineering education from one of emphasis on engineering analysis to a design oriented view focusing on the engineering process.
- The program is leading to an expanded use of electronic bulletin boards. A design bulletin board has been implemented for use in data exchange, team communication and instructor query, taking advantage of the freshmen's dorm room fiber-optic computer connections. Under a so called 'Electronic Village' experiment, the entire community will soon have this connectivity.
- The project has had an affect on both freshman and senior courses in terms of their use of CAD technology. Not only are the design groups able to make use of the most advanced versions of

PC-Based CAD programs contained in the freshman computer package, the freshmen are able to gain experience with the advanced aircraft synthesis program ACSYNT which is

under continuous development by Virginia Tech and a consortium of all major aircraft manufacturers and is available to students in the senior design class.

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