Session 1202

DESIGN-CENTERED FRESHMAN INTRODUCTION TO AEROSPACE ENGINEERING

Narayanan Komerath
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta GA30332-0150

ABSTRACT

The conceptual design of a large airliner was used to focus a 3-quarter-hour Introduction to Aerospace Engineering, taught to 39 first-quarter freshmen. Starting from high school physics, chemistry and mathematics, the students completed several engineering assignments, and 2-person team designs of their aircraft to mission specifications. The course went on to introduce space flight issues, and a perspective on the various fields of engineering. Student performance, and assessments of the course, showed high levels of enthusiasm and participation. Many aspects of design, usually postponed to the senior capstone course, are seen to be appropriate for introduction to first-quarter freshmen.

INTRODUCTION

The questions posed in this paper are: a) To what level can students coming fresh out of high school learn Flight Vehicle Design, in their first 8 weeks in college? and b) will they appreciate the experience? The genesis of these questions, and the process of answering them, are described below. Figure 1 summarizes the structure and philosophy of the course.

Many of our students come to college with an abstract idea of exploring the unknown, flying free into the blue sky, and reaching out into distant worlds. The rest want to create things that move fast and fly[1]. They come from a wide spectrum of backgrounds, but each has an excellent record of achievement in high school. Far too many of these students are lost to us by the sophomore year, and some of the reasons are specific to AE. Some drop out because the expectation levels are beyond anything they had encountered before, and they are unable to adjust to this early enough. Others are lost because they cannot get excited about some of the prerequisites for engineering courses, and decide that engineering is not for them. A greater fraction, being good at anything they do, find themselves following their classmates, the majority of whom are enrolled in Mechanical and Electrical Engineering. They hear too often that these disciplines are much more “general” than A.E., and that A.E. is “too hard”. These superstitions are general, both worldwide and through the decades. In the mid-90s, attrition rates climbed as bad news kept pouring in from the traditional employers of A.Es.

Getting into Trouble

The Introduction to Aerospace Engineering course has existed for a long time, intermittently. Its advocates pointed to the perspective and motivation it provided; its detractors called it an “easy-A” waste of a good 3 credit hours on PR movies and picnics, which delayed the weeding-out of those who would not survive the “real” courses. A few years ago the course was re-worked and taught by several senior faculty, using different approaches. In 1996-'97, the course was moved into the Freshman 3rd quarter to strengthen the motivation of the new recruits. This course had to appeal to people who had little background in calculus or mechanics. Options included ideas such as hands-on projects, lab demonstrations, multimedia, invited speakers, industry tours, and an approach which had been laughed off in the past: teach Aircraft Conceptual Design.

This was initially suggested out of frustration with the fact that few of the technical capabilities learned in senior-level aerodynamics or propulsion courses (or Structures, Materials or Controls, for that matter) were used in Capstone Design. From Ref. 2 it appears that this has been observed about Capstone Design by others across the nation. As the weeks passed, the author observed unusual anticipation among colleagues for the impending experiment in AE2350: some of it had to be for the same reason why people watch Asteroid-impact movies. This focused the thinking and preparation for the Fall '97 plunge into the Design-Centered Freshman Introduction course.

Problem Statement

Introducing Aerospace Engineering to *first-quarter freshmen* poses a few obvious problems. They have not studied calculus, nor the concepts of equilibrium, resultant force, and moment, let alone moment of inertia, thermodynamics, and most of chemistry. Graphics is still in the future, so the term "3-view" makes no sense. Computing is in the future, and so is the training on expressing and interpreting graphical data, and writing technical reports. These students lack the discipline, the trait of rigorous reasoning, the technical and emotional maturity, the work ethic and the in-depth knowledge inculcated by the 10 quarters leading up to Capstone Design.

Lessons from Prior Work

Several approaches have been used to engage the interest of engineering freshmen[3-14]. These can be roughly classified as follows, with many combining several ideas:

a) provide a visual introduction to the discipline, supplemented by tours of industrial facilities talks by experts from industry, and freshman seminars by faculty experts.
b) provide basic equations in the various disciplines, then let the students solve problems related to each discipline, building some confidence.
c) use hands-on construction (or disassembly) projects.
d) use competitions to motivate creativity and logical decision-making.

Several students in our School are motivated by "real aerospace engineering". A Wind Tunnel Tour, and a 15-minute presentation, usually produced recruits to the research team in experimental aerodynamics. Visits to nearby Lockheed-Martin or Delta Airlines facilities still bring the Ultimate Endorsement (**"Cool!"**). The instructors observed, however, that many students were not paying attention, or not showing up at all in class. Performance on tests in the second half of the quarter had been below desired levels.

Ambrose and Amon[7] have laid out systematic learning objectives at the freshman level, and list "seven principles for good practice in undergraduate education". Briefly these are: encourage communication, cooperation and active learning, emphasize time on task, communicate high expectations, respect diverse talents and learning methods, and give prompt feedback. These were all merged into the strategies and tactics described below. Detailed review of the notes and texts used by previous instructors, and detailed discussion, produced some common guidance:

1. Absenteeism was a major *cause* for student demoralization. Depending on their sense of responsibility was insufficient: they had to be told that as part of an engineering organization, they were expected to show up on time, every day. Enforcing this was still a problem.
2. Introduce more visuals, classroom demonstrations of technology, and ndustry contact to the class: this motivated many students.
3. Assignments based on pre-developed spreadsheets to calculate performance of an aircraft, motivated many students. These, however, were sophomores, not 1st quarter freshmen.

The DCI course used all these, as seen below. The previous approaches, except perhaps Ref. 15, cautiously assumed that the entire course had to be based on the new students' assumed ignorance of engineering *at the beginning of the course*. This is linear and incremental. *Could nonlinear gains be achieved by (a) building rapidly on the student's rate of learning* <u>*during*</u> *the course, and (b) providing an iterative learning mechanism , where students had to deal with the same new concept several times ?* Such a concept had been tried out successfully here [16, 17].

APPROACH

How do you get Freshmen to design aircraft? *You build the runway straight across the canyons of advanced knowledge. At each such chasm, you guide them to the right "bridge": plot data on current aircraft, and see where your mission fits. Or provide an empirical formula and keep on accelerating. The benefit of completing the process far outweighs concern about depth and rigor: that's what advanced courses are for. After all, this is roughly what industry does, except that the thumb-rules are huge programs. Recognizing that the designers are 17-year-old high school superstars who like to sleep late, you also convey unpredictability about the consequences of absence and tardiness. Let them see for themselves that the numbers they get are "in the right ballpark", and that they can correct their answers by iteration if they start early enough.*

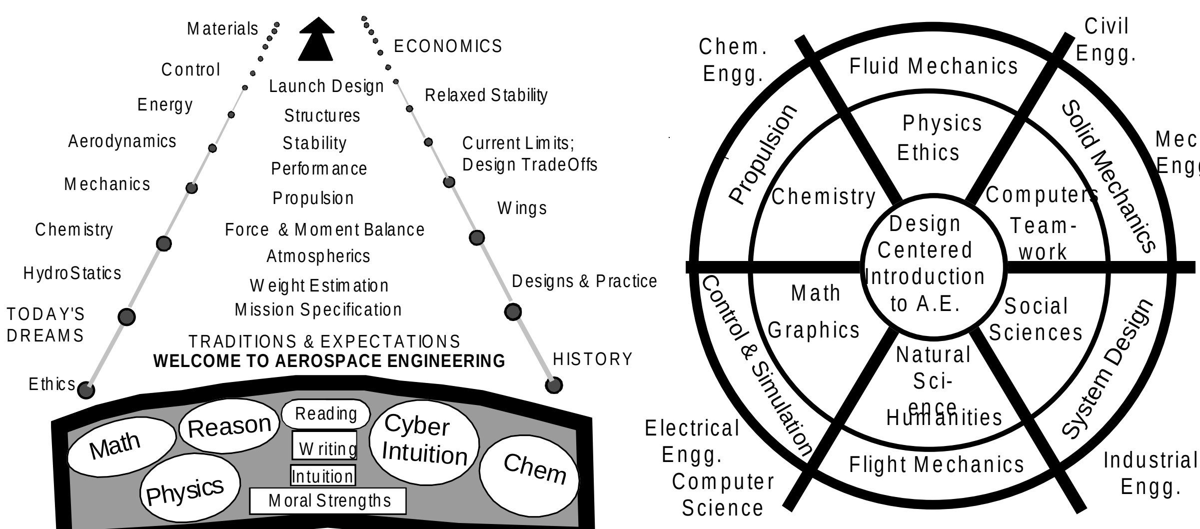

Figure 1(a) Conceptual layout of the Design-Centered Introduction (DCI) Course. The student starts with high school memories and knowledge, and accelerates in 8 weeks along a direct path to a vehicle design. (b) The immediate environment of the freshman consists of first-year courses and concepts, linked through the DCI course to the advanced disciplines.

This approach banked on the following principles:

1. Being new to college, freshmen can be taught good habits before they learn “realities”.
2. Freshmen are unaware of what they do not know, and there is time before others convince them that engineering is difficult, and lock their creativity in straitjackets. The confidence of solving problems can be used iteratively to build rigorous understanding in later courses.
3. Discipline is essential, to tide the students over the difficult periods of the Midterm-Test Season. Freshmen might believe, for a few weeks, claims regarding the high standards of upper-level engineering students, long enough to get over this period.
4. Tantalizing glimpses of the visual attractions of aerospace engineering would be provided, *but not until the required work had been done*. Students should not feel that they are doing the School a favor by staying interested, or that the instructor has to “perform” for them.
5. The course would stay in “shallow waters” where the instructor could appear knowledgeable. His “lifeline” was a Spring 1997 Senior Design report on a long-range military airlift vehicle, kindly donated by his friends from the Class of ‘97[18].

IMPLEMENTATION

In the Spring, the textbook by Shevell [19] was approved by the curriculum committee. Over the Summer quarter break, the calculation sequence for the conceptual design[20] of a large airliner was developed and tested, modeled after an “extended” Boeing 777. The specifications were pushed a bit beyond what the Boeing Company had as yet announced[21]. Since this was not the Capstone Design, some reliance on “advanced” materials and engines could be forgiven. Homework problems dealing with g-forces and maneuvers were usually built around fighter aircraft, where the engineers could imagine themselves in the pilot’s seat, but the actual aircraft characteristics were not needed. The airliner design was refined using a spreadsheet on a PC, and then the sequence of the notes was reorganized to smooth over the discontinuities in logic. Concepts which required “taboo” topics (e.g. derivatives and integrals) were reworked. A sequence emerged, where topics were introduced as needed for the design process. The incentive for systematic preparation received a huge boost when several senior faculty colleagues, who had taught the Introduction course to sophomores, started attending the class, sitting in the back row and conscientiously taking notes.

Day One: Get their Attention. The students received several things on the very first day of class: a course outline (Tabular form of Fig. 1), the reading assignments for the entire quarter, and a 2-page Welcome to Aerospace Engineering. Yet another sheet listed “Expectations in the School of Aerospace Engineering”. These included regular and prompt attendance, with absences to be reported promptly to the instructor. Assignment 1 was handed out the first day.

Accelerate at full throttle: The first day’s reading assignment included 47 pages on the history of flight. This was based on alumni surveys (in the research lab) which declared lectures on history to be boring, because they had heard most of it in elementary school, seen it again on TV, and read it again the day they got the textbook. Considerable time was saved, and learning achieved, by requiring students to draw the Plan, Elevation and Front views of an airplane (any airplane) and point to each of a list of 26 parts. Responses included pictures downloaded from web sites, artistic sketches with no straight lines, semi-professional-looking drawings, and a uniformly successful identification of all parts except for the APU (auxiliary power unit). This last item introduced the practice of sending e-mailed questions to the instructor, enabling focused guidance. No one had seen the relation between the plan, elevation and front views, and in many cases these were different airplanes. Some included rear views to show the APU.

Reduce anxieties by encouraging cooperation, giving a second chance: The Expectations page made it clear that there was no relative or "curve" grading, and encouraged everyone to help classmates learn. Discussions with anyone were encouraged, with the caveat that each person must do all the work submitted for a grade with their name on it. The exception would be the team assignment where division of labor was allowed. The definition of unfair practices included any effort to get ahead by holding someone back. A Web Page was created, with links to the School's Pages, the author's research group and the outside world, and a table of names and e-mail addresses posted with the consent of all students. *A second objective was to build up a support network between the AE students.* On the first assignment, suggestions were provided, but no points deducted for anyone who completed the assignment. Incomplete assignments were returned for re-submittal without penalty. This "one-time exception", based on the Iterative Learning concept[17] served to get everyone moving, and give them time to adjust to the expectations. The best were encouraged with superlatives.

Encourage day-dreaming: The second lecture was on "Today's Dreams", summarized in Table 1. This was to convey (a) the vast opportunities in the field and (b) the idea of distilling an abstract dream down to mission requirements. A Specification and typical Mission Profile were then constructed for an airliner which could take 400 passengers on a hot day from a mile-high airport, 10,000 miles non-stop. Requirements included takeoff with one engine failed, and landing with enough reserves to cruise another 500 miles. The design process was laid out (Table 2). Assignment 2 was to develop a Specification and Mission Profile for a search-and rescue vehicle to save stranded climbers from any peak or canyon in North and South America in the worst weather, and rushing them to hospital. Many students found the tallest peaks, and added "scramble time" as a criterion. A few did specify 600mph cruise plus hover at 40,000 feet.

Table 1: Today's Dreams

Dream	**Technical Requirements**
Fly like a bird	0 - 100mph; land anywhere, hover, cross mountains & rivers
Commute by air	Garage to parking lot to garage. 1 million cars per day above I-85, 300mph, all-weather, safety & traffic management
City-city, doorstep service	400mph; VTOL with mild downblast and noise
Zip across the world in ½ a day	Mach 3, approximately 1800 mph
Visit low earth orbit	18000 mph; re-usuable spaceliner; comfortable takeoff, acceleration, re-entry and landing. Cheaper than $50 /lb.
Visit nearby planets	36,000 to 500,000 mph
Visit nearby star systems	Proxima Centauri, 6 light-years: 5.7E14 km
Deep space travel	millions of light-years.
Nano-probes	10E-9 meters size. Numerous applications.

Weight estimation and benchmarking. This is perhaps the most under-emphasized concept in all of engineering (and faculty committees)*: to make something new,* ***<u>you have to start</u>*** ***<u>somewhere</u>****.* The initial synthesis must precede most analyses[22]. "Payload" was estimated from the average weight of the 400 passengers, crew, their baggage, enough water and food to last a long trip (*question: "why should airplanes carry water?"),* and 20,000 lbs of cargo. There was some debate on the average, thinking of the numbers of families with children, and athletic businessmen on an intercontinental flight. The cargo allowance was seen to provide leeway. Then came Thumb-Rule ("Empirical Formula Based on The Professor's Vast Practical Experience") #1: Payload Fraction was declared to be 17%, thereby obtaining the gross Take-Off Weight (T.O.W.) as Payload divided by 0.17.

Table 2: Simplified Design sequence

Step	**Issues**
Define the mission	What must the vehicle do?
Survey past designs	What has been shown to be possible? (don't worry about WHY yet)
Weight estimation	How much will it weigh, approximately?
Aerodynamics	Wing size, speed, altitude, drag
Propulsion and engine selection	How much thrust or power is needed? How many engines? How heavy? How much fuel will they consume?
Performance	Fuel weight, take off distance, speed/altitude boundaries
Configuration	How should it look? Designer's decisions needed!
Stability & Control	Locate & size the tail, flaps, elevators, ailerons etc. Fuel distribution.
Structure	Strength of each part, material, weight reduction, life prediction.
Manufacturing: concurrent engineering	Design each part, see how everything fits, and plan how to build and maintain the vehicle. Break this down into steps involved in manufacturing.
Life-cycle cost	Minimize cost of owning the vehicle over its entire lifetime.
Iteration	Are all the assumptions satisfied? Refine the weight and the design.
Flight Simulation	Describe the vehicle using mathematics. Check the "flight envelope".
Testing	Build models and measure their characteristics, verifying the predictions. Explore uncertain regions. Build & test first prototype.
Iteration and refinement	Keep improving, reducing cost and complexity, and extending performance, safety and reliability.

Assignment 3 conveyed the next idea*:* ***look at previous work to see if you're in the ballpark: then venture into the unknown.*** The young designers estimated the payload fraction for various airliners, from data in the text, the Web, Jane's All the World's Aircraft[23], etc. They made qualitative allowances for differences in range, and concluded that the 0.17 Payload Fraction was indeed reasonable. This produced many exclamation marks on the assignment sheets. It probably went a long way towards alleviating concerns about the professor's mental health as well. Note that this process could have been shortened by giving empirical formulae from the excellent texts for Capstone Design[24], but this way the students *derived useful numbers from data that they had hunted down by themselves*. The course had lifted off the runway, both in rate of progress, and in irreversability of the experiment. Weight fractions were "decided" for engines, fuel and structure, and engineers were assigned to represent these "groups" as the design progressed. The fuel weight fraction would decide whether the range was feasible on full pay-load. The Structure fraction required advanced materials, and the engines were probably beyond current products. Technology was projected to the 2010AD rollout date.

Force, moment and equilibrium. Now that the students were really involved in the class, a diversion into "theory" could be risked. The concepts of forces, equilibrium and moments were introduced: things that cause much grief in the sophomore Statics course. The students were breezily assured that all they needed was Newton's Laws of Motion. This appeared to go off well in class, but came to the brink of disaster. One student sat down in the instructor's office and calmly asked if she should drop out, because she knew calculus from advanced courses in high school, *but had never taken a course on physics.* A few minutes of discussion revealed that the student could easily understand velocity and acceleration when explained in terms of first and second derivatives! An hour later she left with a crash course on physics in her notebook, and an assurance that she was quite as competent as any of her classmates.

Climb, descent, and g-forces in coordinated turns. With the experience of drawing their own airplanes and naming the parts, the class had no trouble grasping the functions of various control surfaces in changing attitudes and forces of the aircraft[25]. The concept of "moment" was explained in a few different ways, but this would remain a shaky concept for some time. Introduced right after lift, weight, thrust and drag, the concept of a coordinated turn was absorbed as a natural extension of Newton's Laws with the help of a $3 styrofoam aircraft (used in teaching aerodynamics[17] in 1994). Several assignments and questions over the entire quarter reiterated these principles: most students had become comfortable with it by the final exam. This allowed a discussion on "g-forces", and allowed several problems related to fighter planes, combat maneuvers, missile firings (and misfirings), and flight testing without ever venturing beyond simple trigonometry, algebra and Newton's laws.

Learn-as-needed: Tour of aerospace engineering. With the weight known, and an estimate for Wing Loading[26] similarly conveyed (empirical results had credibility now), the wing area was known. To go further, we had to know more about air, and that introduced three lectures on Earth's atmosphere[27]. The calculus-infested concept of pressure variation with altitude was crossed without losing the attention of the class by imagining the instructor holding up the entire weight of 150 miles of air on his head. Assignment 3, which asked about expected landing field conditions on the Planet CZX356 (called something else by the college students there) where the gas composition was very different from Earth's, caused no difficulty. Neither did the question on the propagation time of a flight attendant's warning shout (speed of sound), to decide if an errant passenger had time to grab a seat belt before the plane made a diving turn to avoid a tornado. Next came the aerodynamics of airfoils and wings, (lift vs. angle of attack; lift loss at the tips) and the concept of aspect ratio, lift-induced drag and lift-independent drag[28]. Aspect ratio (square of span divided by wing planform area) was decided by limiting wing span to 200 feet, consistent with present aircraft, explained by the need to park at the airport gate.

Speed for minimum drag: venture into Calculus. One big difference between a flight vehicle and other forms of transport is that a flight vehicle encounters minimum drag at a non-zero speed[26]. This was shown by logical argument, and then by derivation. It was then shown by differentiation (Week 3 of Calculus was underway by then). Ironically, some students tried using their new-found differentiation skills on the midterm test, and got lost, where they could easily have got the answer using algebra: these were graded kindly. The "speed for minimum drag" concept opened discussions of airplanes optimized for various flight regimes, and birds[26]. An article on flying saucers[29] served to illustrate diversity in design concepts and configurations.

Thrust and engine sizing. The thumbrule is that takeoff thrust should be roughly 30 to 33% of takeoff gross weight [19,26]. This leads to one of the major decisions of aircraft design: ***how many engines?*** The answer was easily provided by the class: the Boeing 777, and competing Airbus designs, all have just 2 engines each, having proven the reliability to make trans-Atlantic trips. The "1-engine-out takeoff" requirement was taken into account, and the required engine thrust values were found. Using "state-of-the-art projections" to the year 2010, an engine thrust-to-weight ratio was extrapolated, and used to ensure that engine weight was within the allotted weight fraction. These concepts were covered very fast, because the class indicated near-total, and *conscious*, agreement. ***Iterative learning at work!***

This started an ambitious 2-hour presentation on propulsion (the instructor being on safe ground here), going through the basics of a gas turbine cycle, bypass ratio, and expressions for thrust. The class saw with no prompting that the rate of mass flowing out of the nozzle had to be the sum of the intake air and fuel mass flow rates. They were <u>then</u> told that they had just used the Law of Conservation of Mass. Similarly, they saw quickly that the thrust came from reaction to the rate of change of momentum (Newton's 2nd and 3rd laws), and this could either come from a lot of mass accelerated through a small velocity increment (high bypass turbofans or propellers), or much less mass accelerated through a large increment (turbojets). This was declared to be the Law of Conservation of Momentum: pressure thrust is essentially zero for subsonic exhausts[30]. The concept of "work" was introduced, and led to the Law of Conservation of Energy. The lesson is that ***concepts are easily introduced in an intuitive context, rather than as consequences of Laws With Big Names***. This material is normally taught in senior classes, and has to be re-learned anyway.

Tighten Discipline. By the 3rd week of the quarter, many eyes in the class looked sleep-deprived and stressed. Well-informed and unsympathetic opinion in the research lab held that the demands of "HomeComing Weekend" were more to blame than the demands of the curriculum. After expressing concern for adjustment to college and the possibility that they might be homesick, the instructor gently declared that if anyone missed two classes in a row, without leave, enquiries might be made into whether they had run away from school[§] Several e-mails confessed to alarm clocks not going off, etc. One student came in to declare a chronic problem with not getting up early, and was advised to change that by going to sleep early: *apparently this worked quite well*. The horrified reader is asked to note that the class was at **9am**, not 6, and every freshman lives in campus dormitories, less than 15 minutes away.

[§] An empty threat, but with an effectiveness of 97.5%.

Specific Fuel Consumption and Range. This is the toughest part of conceptual design to convey at this level: the "Breguet Range equation" has to be introduced without scaring people who have never seen integrals. This was done by giving the result in terms of logarithms, solving an example, and then relating it to the physical meaning of integration. During the Summer, simplified empirical formulae had been developed from figures in the text[19] and tested for the thrust lapse rate and the specific fuel consumption for high-bypass turbofans, with the breakthrough being the guidance given on how to estimate fuel consumption[19] during climb.

Structures and Materials. This section was started with a rudimentary introduction by the author, and then taken forward by Prof. Erian Armanios to discuss the capabilities of advanced materials, with classroom demonstrations of tailored composites.

Iterative Design. The other major feature of Design is *iteration*: note that everything till now came from a ball-park guess of weight fractions. Twenty years ago, the author did his iterations with a slide rule and eraser, with last-minute salvation provided by a borrowed Electronic Calculator. His FORTRAN program card deck, designed in a grand labor-saving strategy with brand-new computing knowledge, but with a batch turnaround time of 1 to 2 days for each error-correction, left him alone out on a limb, (not surprisingly) failing to work until after the deadline for the first Semester of Design. Today this is easily done with a spreadsheet on a PC. The 1998 freshman class at Georgia Tech is the first to be required to own computers, so the data on freshmen using computers came from observing research assistants, who comfortably and responsibly use research systems with a little initial help[#] . The question "do you know what a spreadsheet is?" brought blank stares. The question "do you have Microsoft Office on your computer?" produced universal recognition and agreement. Using the multimedia projector and the computer in the Design Auditorium where the class was conducted, the secrets behind the success of the "thumbrules" were revealed: how formulae were placed into the spreadsheet, and how easy it was to re-do the entire set of calculations. The class watched with interest, because they would be doing this very soon. On Assignment 5 they were asked to set up their own calculations, and reproduce (or come close to) the results obtained by the instructor. This again was only graded as "completed" because several students merely typed in many of the results as constants into their spreadsheets, rather than calculate them using formulae. The use of spreadsheets for engineering calculations is not expected to be mastered at the first try: they got the idea all right as they struggled with their own designs.

Detailed Design: Teams had to size the fuselage so that they could accommodate the 400 passengers in the comfort needed for a 17-hour flight (lesson in engineering ethics). *This was the first time that decisions were needed on the actual configuration of the aircraft.* In this first iteration of the course, the instructor, in the interests of self-preservation, only hinted at unconventional configurations: no one took up this challenge. Fuselage length for most airliners is not much more than the wing span. Seats in the uni-class cabin were based on luxury car front seat size. Business-and first-class passengers in 2010AD are expected to take the much-faster but more expensive High Speed Civil Transport. The cabin floor height had to be reachable by current airport Bridges (limits found by asking Co-Ops who worked at the airport), and the aft fuselage had to be boat-tailed to allow landing and take off at specified angles without the tail

[#] One is known to have called her Mom and declared that she was now allowed to use a "$20,000 computer" hitting the runway at maximum compression of the landing gear (a major exercise in trigonometry at this level). This aspect burned up the e-mail wires, and brought several ideas.

Flying Out into Space:. As the design assignment produced questions over the e-mail system, the lectures went forward. *(Q: "Its so easy when you explain it. Am I being really stupid for not having figured it out myself"? A: "If you were a 3rd quarter junior, I* ***might*** *expect you to figure out things a bit more. Right now you are doing great: my explanation was easy only because you have already done a lot of good thinking about it.')* The differences in high speed flight were presented, with the Prandtl-Glauert correction included in the design. The drag divergence Mach number was presented, and enabled determination of a boundary of the flight envelope[$]. This was extended to discuss swept wings and supersonic flight. Shocks and atmospheric re-entry were discussed, along with the effect of meteors coming close to the surface, breaking up due to extreme pressures and temperatures [31], the effect of the shock pattern on the trees[32] below a meteor trajectory, and why supersonic flight is not allowed at low altitudes. This logically extended to the issues of space flight. One lecture discussed the law of gravitation, and various kinds of orbits: there was acceptance of the concept that the instructor was really a satellite, temporarily confined to shallow, low-energy elliptic orbits that intersected the earth's surface. Concepts such as specific impulse, the difficulty of single-stage-to-orbit, and the need for energy to transfer from one orbit to another, were all conveyed through examples, and tested on the Final exam, though it is certain that few will have retained these with sufficient gravity to obviate the need for reiteration in advanced courses. These were followed by the usual Wind Tunnel Tour, conducted by PhD candidates Leigh Ann Darden and Catherine Matos. The final lecture periods were used to present movies and animations on the Space Shuttle, the X-33, microgravity flight experiments, and futuristic concepts for space launchers [33]. The Final was a traditional 3 hour exam, which most students finished early.

Don't waste time on TQM: This instructor, being an old-fashioned Ivory Tower resident, declined to ask first-quarter students to think about engineering's goals as being "Cost Cutting", "Do it Right the First Time", "Zero Defects", "Total Quality Management", Chart-Flipping, or being "Lean and Mean" and maximizing executive compensation and stock prices. It was hoped that students would view engineering as still having room for grand dreams, daring to experiment, tolerating hard-fought failures, and putting customer comfort (seat pitch and spacing on international flights, economy class) before stock price rate of increase. They have plenty of time, and other sources, to learn the realities.

RESULTS

Assignments 5 and 6 presented the Design Assignment, in two installments. The detailed specification sheets were given with a hope and a prayer: the results were far beyond anything that the instructor dared hope. Students were allowed to work in pairs, with the instructor helping to match up the few who did not find partners themselves, through an e-mail exchange. Some preferred to work alone, though they were told that the grading would not recognize that fact.

[$] One of the students mentioned here did not have the formula for this on her "2-page Security Blanket"sheets in the Final Exam. This did not faze her: she sketched the remembered Drag Divergence graph, and the fact that the expression was a model, and invented her own exponential drag rise expression to solve the problem.

1. All but 1 out of 39 turned in a Design Report. One was so late that the final grades had already been assigned, but his grade was changed to reflect his persistence.
2. More than half met <u>all</u> the specifications, and most met the one about lettering size on graphs. By comparison, we spend more time convincing graduate students of the need for large lettering.
3. The drawings were still widely non-uniform in technical quality, ranging from full AutoCAD drawings to color freehand sketches, but they were also dazzlingly original.
4. Many designers had names and interesting sales-pitches for their "companies" and aircraft.
5. The Design Reports were neat, remarkably well-organized, and succinct.
6. The vast majority got perfect answers to spacecraft problems on the final exam. In fact, the performance on the final exam was quite remarkable.

The Bad News. Forty-five students signed up for the class (10 over the initial size limit). One 3rd-quarter student was asked to drop the course (all other tactics having failed; see footnote, p.8) at the end of the 4th week, not having really started attending classes or doing assignments. He left engineering at the end of the quarter. One lost his Scholarship due to poor grades in previous quarters, and dropped out of school. One decided that engineering was not for her. Two dropped, citing midterm disasters in Chemistry / Math (sadly, for they were doing quite well in this class). One just dropped. Of the 39 who stayed, one (a 3rd quarter student) has to repeat the course: he had not started on his design assignment (and did poorly on the Final). The rest did remarkably well. Apparently, experience in engineering school (number of quarters prior to taking this course) correlated inversely with performance: the fresh entrants did better, by far.

Student Reactions. Free-form comments on the Course Evaluation were extremely positive, with the following memorable example (comments about instructor deleted): "*…learned a lot compared to knowing very little at the beginning of the quarter. Course work was very challenging, but possible to understand."* Considering that the statement "Assignments were challenging" brought an agreement strength of 4.9/5.0, this was a surprisingly positive reaction to their first encounter with aerospace engineering, and a great relief in view of their reputation (overheard in the lab) for tearing instructors to pieces. The statement "The course has been valuable to me" brought an agreement strength of 5.0/5.0. The lowest scores were on "Explained complex material clearly" (4.1) and "Exams were fair" (4.2). Several students commented on the instructor's role in making the course "laid back" and "fun", and they were quite wrong: it was the instructor who was having the fun, while they worked harder than anyone believed possible. What they learned may be glimpsed from these quotes (Nathaniel Owen, Ref. 34):
"In this Design Report I am trying to show how from a few simple values you can design the rest of an aircraft. All the values found in this report are either in Metric (on the spreadsheet) or in English (on the remaining calculations). So, a mixture of units is involved. Starting by taking an estimate of Take-Off Weight and approximating Payload, Fuel Weight, Engine Weight, and the remaining Structure Weight Percentages. Next, a decision was made…..(3 paragraphs of valid detail deleted here). …*"Making sure that the plane can fit into the bridge between the Gates in the airport, and the airplane, is important to the success of the plane…."*
"….The next page shows you a picture of the inside of the plane, showing how comfortably 400 passengers can sit in this plane. Also, it shows the number of kitchens, bathrooms, and elevators to the below decks inside the plane. The final picture is the 3-view sketch of the plane itself, giving basic dimensions of the exterior of the plane."

The Introduction is very short: "*This is a conceptual design for a 400 passenger aircraft capable of flying anywhere around the globe at an efficiency of no less than 0.99* (??? Probable reference to the Spanwise Efficiency Factor used in computing wing lift coefficient). "*This aircraft should be able to lift passengers in style in this airplane built with only 1st class seating. It should be able to fly into any and all international airports. So, I now bring you the newest bird of the sky in the Buzz Air Fleet, Wreck1990-NGO:*"

So is Capstone Design Obsolete? Absolutely not. Conceptual Design, however, can be introduced at a very elementary level. The basic ideas of how a design takes shape are so simple and wonderful that students learn it eagerly: this is why they come to Aerospace Engineering! The design has to be grand in the imagination, universal in curiosity and interest, but straightforward to describe at a superficial level. A huge airliner fits this bill ideally, but extending this to other systems must be done with great care: a fighter design, for example, may get negative reactions for surprising reasons. Note that even in the Capstone Design, much time is spent (perhaps 6 of the total 20 weeks) getting to this level of understanding. This time can be saved by introducing Conceptual Design at the freshman level. The engineering science courses can build on this remarkable knowledge, and the Capstone Design can go ***much further in risk level*** than it now does. Refs (35-42) present some recent thoughts on Design in the curriculum. Finally, it is pointed out that all errors in the teaching of design described here should be attributed to the author's lack of "Practical Industry Design Experience". It is hoped that expert Design teachers, given this summary of experience, will feel encouraged to try out adventurous new ideas and greatly increase the value of the undergraduate learning experience. The aim here, of course, was only to introduce AE without wasting time or scaring too many students away.

CONCLUSIONS

1. Freshmen come with good skills in computing, report-formatting and graph-plotting.
2.The capabilities of 1st quarter Freshmen engineering students, for creativity, innovation, and thoughtful engineering, are vastly underrated by the traditional curriculum.
3. These capabilities may be atrophied through disuse in the first few quarters, resulting in an observed inversion in the correlation between experience and performance.
4. Much of what was traditionally covered in the first quarter of Capstone Design can be effectively absorbed and used by first-quarter freshmen in a 3-credit course.
5. In the context of design, freshmen are able to appreciate *and use* concepts such as drag divergence, speed for minimum drag, induced drag, and compressibility corrections.
6. Many aspects of <u>detailed design</u> are also appropriate for new freshmen.
7. The physics needed for this does not go beyond Newton's laws of motion and gravitation.
8. Only high school mathematics and chemistry are essential, with calculus used as needed.
9. To make such a course successful, the confidence-building involvement of the instructor is essential: no part of this course could have been automated or left to non-empowered assistants.
10. Firm discipline is essential to keep students from falling behind and dropping out.
11. Despite an early start and constant attention efforts to achieve zero attrition failed.
12. At this level, the instructor does not need to be an industry veteran to have credibility.
13. *An integrated course strategy, based on learning through iteration, is seen to succeed, yet again, in achieving remarkably high levels of student performance, simultaneously with a large increase in course content and depth.*

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BIOGRAPHICAL SKETCH

NARAYANAN M. KOMERATH is a professor of aerospace engineering. He has taught 17 different courses in computer applications, aerodynamics, high temperature gas dynamics, combustion, propulsion, flow diagnostics and flow control. He is the director of the John J. Harper Wind Tunnel, and conducts research programs related to vortex-dominated flows. He has guided over 70 undergraduates in research projects.