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Aerospace Engineering Education: An Industry View from a Preliminary Design Perspective*

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By involving all affected disciplines early, costly design mistakes can be avoided. These concepts are now becoming the standard for the aerospace industry. Indeed, the United States Air Force Material Command has mandated Integrated Product Development on all of their new programs. This is a difficult concept for tradition-bound engineers in industry to accept, and a radical cultural change in attitudes is often necessary before the IPD concept can be implemented. What does this environment portend for future aerospace engineers, and what, if any, changes are necessary in aerospace engineering education? Two considerations come to mind—the depth and breadth of the technical curriculum and the relevance of the student's design experience. I address these issues from the perspective of a Preliminary Design Department.

INTRODUCTION

AERONAUTICAL and aerospace engineering are arguably the most consistently dynamic and exciting of all technical fields. From the beginning of powered flight in 1903, to the establishment of a large scale air transportation industry (with the DC-3), took a mere 35 years. Less than 20 years later the first artificial earth satellites were launched. Today, access to space is almost at will, long-range commercial aircraft can reach any point in the world non-stop, and military aviation may have become the dominant force on the modern battlefield. What will the next 20 years bring? Manned exploration of the planets, permanent habitats on the moon, hypersonic transports, intelligent unmanned airborne military systems are certainly reasonable goals. The degree to which these will be achieved will depend at least on two factors: advances in technology and the availability of highly trained engineers. Before turning to the specifics of aerospace engineering education, it is important to recognize the rapid changes that are taking place in the industry.

Aerospace systems may be the most highly optimized of all man-made devices. They synergistically combine the most advanced features of many technologies. The evolution of microelectronics had a lot to do with making manned space flight possible; major breakthroughs in materials science, not just aerodynamics, will, for instance, be necessary for hypersonic transports to become a reality. The ability to not only recognize the potential application of many diverse technologies, but to integrate these into advanced aerospace systems, will be the greatest challenge to future engineers. Whereas the pioneers of flight were largely self-taught, highly individualistic entrepreneurs and visionaries, designers of future aerospace systems are likely to be broadly experienced systems engineers. This is not to say that visionaries will have no role. Indeed, since the rewards in this industry tend to be more intellectual than financial, those who persevere tend to be driven by an obsessive love for aviation. Although each project may still have a 'chief-engineer', increasingly the design process will rely less on singular genius and more on collective wisdom.

The wide breadth of applicable technologies is not the only reason for this trend; economics is an even greater driver. As the cost of aerospace systems increases in concert with increasing capabilities, the number of new starts decreases. This is true in both commercial and military markets. Cost cutting is perceived as the only way for individual companies to survive the intense competition for future programs. Newly rediscovered design, manufacturing and management techniques are being applied to increase efficiency and reduce flow times. These include 'concurrent engineering', 'lean production' and 'integrated product development (IPD)'. Their focus is on a design process that enhances communication and helps break down barriers in what had become, in the recent past, serial design by functional specialists.

One of the tenets of the integrated product development concept is that not only is each member of the team technically qualified to represent his/her functional specialty, but, more importantly, the team as a whole is given total authority and responsibility for developing a complete product. Each member of the design team is empowered to represent his functional area of expertise, and each has an equal voice in decision

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making. Narrowly focused knowledge is not sufficient. The process challenges individuals to broaden their scope and view design from a higher level. 'Concurrent engineering', is an integral part of the IPD process. The term 'concurrent engineering' is, however, somewhat of a misnomer, since concurrent design implies the complete involvement of not only design engineers, but tooling, manufacturing, quality control, integrated logistics support and many other disciplines as well. The idea is to avoid problems associated with 'tossing the design over the fence' for serial development into a fielded product. It is in this environment where the IPD concept has the most immediate impact, and, secondly, preliminary design (PD) is where the fun is—an assignment that every young engineer should aspire to. First, however, some preliminaries.

PRELIMINARY DESIGN CONCEPT

The primary goal in preliminary design is to explore the feasible design space. A general requirement is usually stated for the system to be developed, together with general constraints; the latter clearly expressed in quantifiable terms (e.g., weight, cost, etc.). The design team identifies applicable near/far-term technologies and their associated risk. Design trades are then conducted within this framework. Performance parameters (e.g., speed, payload/range capability, etc.) are varied and the net effect on figures of merit (e.g., cost) established. The objective is to find the most promising, cost-effective solution to the top level design requirements. For this process to be meaningful, as many attributes as possible must be quantified with a high degree of accuracy. This implies that the modeling techniques used must be calibrated tools, based on sound engineering and physical principles. Hence, we can establish a first requirement for engineering education: graduate engineers must be adequately prepared in the fundamental engineering sciences. A corollary, based on the need, in general, to apply advanced technologies, is that these engineers must also be well versed in the newest techniques.

As the design effort proceeds from conceptual design to higher level integration, the need to balance the design becomes increasingly important. Fundamental sizing of an air vehicle is a good example. The aerodynamicist will seek to increase wing span for increased cruise efficiency, whereas weight considerations tend to favor low-aspect ratio planforms. Advanced materials may offer weight savings, but often at increased cost. Herein, then, is another requirement: each member of the design team must have a fundamental understanding of the concerns of the other technical disciplines affected by his design decisions. As the design progresses from parametric analyses to the lay-out stage, more and more constraints become evident. The integration of high-lift devices into thin wings, for example, will impact structural design. Intense iteration of the design concept will occur, and compromise solutions will be necessary. At this point, other design teams become affected, and a structured process must be employed to ensure that system level constraints are not violated. Furthermore, the design decisions of individual design teams will establish requirements for other teams. These must be collected and disseminated. This is the role of the systems engineering staff. An appreciation and working knowledge of the systems engineering process of requirements allocation must, therefore, also be part of every engineer's background and education. It is within this context that particular emphasis is afforded to cost and risk issues. The economics of design and quantitative risk measurement/mitigation are inherent to this process.

Curricula requirements

Upon assembling the above-stated implied requirements for engineering education, we can draw some general conclusions. First, within the aerospace curriculum, there must be continued emphasis on the basic sciences and mathematics, including numerical techniques and modeling/simulation of dynamic systems (including real time). It is imperative that students entering the engineering curriculum be adequately prepared to undertake college level work in the first semester (e.g., calculus). There is no time available for remedial or preparatory courses.

Secondly, basic engineering sciences also need to be introduced early, preferably within the first year of studies. Only in this way can the applied engineering fields of study, necessary to provide breadth of understanding, be adequately covered. Topics related to computer-aided engineering and manufacturing, integrated logistics support and economics should be included during the third and fourth years of a four-year curriculum. Typical aerospace engineering curricula, however, do not address these issues, primarily because of overall program credit-hour limitations. This then, leads to the inevitable question of whether the number of social science and humanities courses currently required of engineering students should be reduced in order to provide time for additional technical courses. I think not, since, as a society, we place value on educating our technologists to view their work within the ethical and moral framework of our social system. The implied educational depth and breadth requirements for graduate engineers entering industry will undoubtedly cause these engineers to pursue advanced degrees as soon as possible. Perhaps the course of undergraduate study should be lengthened, and the debate over a five-year curriculum (leading to a professional degree) should be renewed.

Design experience requirements

Perhaps the biggest challenge to aerospace engineering educators is to provide their students with an adequate design experience. First and foremost, design is a structured, disciplined process. It begins with an understanding of top-level requirements, the flowdown and allocation of requirements, and the development of derived requirements. Too often even experienced, practicing engineers fail to take these preliminary steps, jumping directly to the design itself.

The system engineering process must be the framework for the design experience offered as part of the aerospace curriculum. This is best done in a multi-year sequence of design courses. However, since other curricular demands make this impossible, most programs of study include, at best, a two semester capstone design sequence. In an attempt to provide students with additional exposure to the design process, and in order to meet ABET (Accreditation Board for Engineering and Technology, Inc.) requirements for design experience, design content is typically included in other advanced courses. Unfortunately, this is not always a successful approach. Instructors cannot necessarily structure their course material to offer legitimate design experience. Too often problems assigned to students and claimed as design related are not. If the assigned problem already has a structured solution, and only parameters need to be established to meet specified system performance, the task is analysis. As an example: a control problem wherein the feedback loops are prescribed and the student is required to only calculate proper gains, is not design, but analysis. True design involves synthesis, trades and optimization among alternatives; in the cited example, alternative feedback loops should be considered and trades performed.

In design, there is almost never a single, ‘correct’ solution. Under these circumstances, an integrated design experience can only be provided if there is extensive coordination among all the faculty involved. This problem is recognized by ABET, and the current accreditation requirements for design experience in aerospace curricula are under review. Irrespective of whether ABET requirements are changed, design problems should continue to be part of every advanced level engineering course.

Relevant engineering assignments

There is no doubt that a multi-semester capstone design course is mandatory. The emphasis should be on design process and team problem solving. Extreme care must be afforded to selecting appropriate problems. First, the problem must be tractable, i.e., the students must have the necessary background and tools to conduct trade studies and optimization. Possible solutions must be quantifiable, with measurable figures of merit. Problems where solutions are proposed in terms of qualitative rankings or assessments are next to worthless as an educational experience. They lead students to believe that ‘arm-waving’ answers are acceptable. In general, they are not. Only highly experienced professionals will attempt qualitative evaluations, and even then, with great trepidation. Qualitative evaluations suggest uncertainty and risk; these are at the heart of the *art of engineering*, a skill that only the truly great designers, alluded to earlier, dare practice. It is for this reason that I find capstone design course projects such as design of a lunar habitat preposterous assignments, pedagogically unsound and, I suspect, unsatisfying to the students as well.

For a system-level problem to be tractable, not only must it be formulated in quantitative terms, but the analysis tools must be available and realistic. An aircraft sizing problem for instance, can be made tractable. Simple sizing routines can be written, assuming that weight integration formulas are made available and engine performance characteristics can be provided. Clearly, this is a significant challenge to the instructor. Here the benefits of faculty involvement with industry are obvious. Industry experience can provide the instructor with exposure to current design practice and access to current state-of-the art design data as well.

CONCLUSION

I recognize that some of the above proposals may be hard to implement, yet it is incumbent on engineering educators to provide industry with well qualified graduate engineers. Given the inevitable contraction in the aerospace industry, there will be, at least in the near term, fewer employment opportunities for new graduates. Only the best qualified will be given a chance to enter the field of aerospace engineering—to me, the most challenging of all possible careers.

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