Vitalizing the Conceptual Aerospace Design Offering

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Abstract

Traditional aerospace capstone design courses often suffer from a lack of student skills in dealing with open-ended problems. Key to solving this shortcoming is finding the right balance when teaching students the three primary elements of design proficiency: (a) engineering sciences, (b) Computer-Aided Engineering (CAE) methods, and (c) the actual design process. Clearly, the fundamental science/engineering knowledge is covered well in the present system. Thus, the critical elements in today's design education are familiarity with modern CAE tools and their thoughtful application to the conceptual design process. The lack of these factors has been found to impede the efficient development and evaluation of various alternative aircraft/space vehicle systems in both academia and industry, resulting in a less informed final design decision.

In the School of Aerospace and Mechanical Engineering at the University of Oklahoma, this problem is being addressed on various levels: by moving the CAD course to the junior year, students will have better retention of the material; the junior-level aerospace structures course is being redesigned to include a major finite element component (using Pro/Mechanica and/or ANSYS); the junior-level aerodynamics course will utilize a vortex-lattice approach (e.g., LinAir, VORSTAB); and a state-of-the-art computer code for the conceptual and preliminary design of flight vehicles has been acquired for use in the senior capstone experience. This design tool called PrADO (**Pr**eliminary **A**ircraft **D**esign and **O**ptimization) incorporates many different modules for the multidisciplinary analysis, design, and optimization of conventional and unconventional flight vehicles. Students will initially learn about the code in the first of the two semester capstone courses, then will use the code for actual applications in the second semester. At the same time, they will be exposed to the classical aerospace design paradigms for better understanding of the computational results.

Finally, we will vertically integrate a hands-on design-build-fly experience, starting at the sophomore level and culminating in the two senior design capstone courses. Here, the students will initially build an R/C aerospace vehicle, which will be optimized in the different disciplines structures, aerodynamics, and controls over the course of their studies, using the mentioned software. All changes will be evaluated by our standard ABET assessment methods. We expect that this hands-on approach using both hardware and software will make our graduates more competitive in the job market and more interesting to industry.

Introduction

"In time, the ... public and possibly even the 'educated classes' will come to appreciate that engineering is no more applied (and therefore second rate) science, than science is theoretical engineering."[1] When defining a new aircraft or space launch vehicle, the *Advanced Projects Group* in industry or the *Capstone Design Group* in academia both have to evaluate the available design space and compare it with the design space required to accomplish the specified mission. As with any flight vehicle development process, the overall vehicle characteristics are established first at the conceptual design level, before a design proposal can be released to the follow-on design phases such as preliminary design, detail design, and finally flight test. As a rule of thumb, it can be assumed that around 80% of the flight vehicle configuration is determined during the conceptual design phase alone, which is the key phase where the initial brainstorming takes place. It is the conceptual design process that enables students to touch on all aspects of design evolution.

In academia and industry, the primary aerospace vehicle design decisions (e.g., overall configuration selection) at the conceptual design level are still made using extremely simple analyses and heuristics. A reason for this scenario is the difficulty involved in synthesizing the range of individual design-disciplines for both, classical and novel aerospace vehicle conceptual designs, in more than an ad-hoc fashion. Although the conceptual design segment is seen as the most important step in the product development phase due to its pre-defining function, it is the least well understood part of the entire flight vehicle design process due to its high level of abstraction. It is time for this to change. We are in the process of adjusting the balance between the primary engineering design elements (a) engineering sciences, (b) Computer-Aided Engineering (CAE), and (c) the actual design process in academia, leading to enhanced design proficiency critical for solving open-ended problems.

Design Education Dilemma

THE AEROSPACE CHALLENGE. Aerospace is arguably the most consistently dynamic and exciting of all technical fields some 100 years after the Wright brothers accomplished their first controlled powered flight. Design proficiency is key to such evolutionary and revolutionary advancements.

INDUSTRY CRISIS. The degree to which the nation's current and future industry needs can be satisfied will depend on at least two factors: advances in technology and the availability of highly trained engineers. Government and industry leaders are concerned that the shortage of talented scientists and engineers in the U.S. aerospace and defense complex is getting worse. Clearly, the U.S. aerospace industry is in a state of sustained pre- and post-9/11 crisis[2]. The U.S. is losing the quality race to foreign industries in key markets; see Boeing versus Airbus[3].

FOCUS ON ENGINEERING EDUCATION. The importance of engineering design education and its effect on the U.S. economy is becoming generally recognized since few engineering graduates are truly prepared for today's industrial design environment. Clearly, there is a disconnect between higher education and the workplace[4]. *"What engineers do, however, depends on what* *they know, ...”* This quote from Vincenti[5] reflects the responsibility of the academic institution and the individual educator. The proper implementation of aerospace education has been widely debated throughout the last two decades. Industry in general[6], government sources[7], and design educators[8] have begun to emphasize engineering education beyond the normal concentration on engineering sciences.

ACCREDITATION CRITERIA. The Accreditation Board for Engineering and Technology (ABET) in general requires six months of engineering design. There must be at least one conceptual or preliminary design course that integrates pertinent technical areas through the use of trade-off studies. These studies must highlight the compromises necessary to meet a stated design objective[9].

DESIGN EDUCATION PARADOX. The majority of academic engineering institutions are doing very well teaching the classical engineering sciences. However, in aerospace engineering, design is primarily taught in the senior year as a one- or two-semester capstone design course with limited or no earlier CAE and design exposure. Students usually are unprepared for the capstone design challenge where they are all of a sudden confronted with open-ended design problems that require the difficult task of correlation while being asked to utilize a range of CAE design methods and tools. Nicolai[6] puts it as *“... Our engineering schools are turning out great scientists but mediocre engineers.”* In addition, the academic community, compared to scholarly research, generally holds the design activity in low regard with all the associated implications for the design faculty member. Having said all this, industry makes money by designing, manufacturing, and selling products in the marketplace. Engineering design is the key technical ingredient in the product realization process, the means by which new products are conceived, developed, and brought to market.

Balanced Aerospace Design Education Model

There are two major components we intend to implement to improve the aerospace design experience for our students: the integration of modern CAE methods and tools into a number of our junior and senior level courses, and the vertical integration of a hands-on design-build-fly experience, which will give students the chance to build hardware such as a R/C aircraft, to be enhanced and optimized as the students become more experienced.

1. CAE Integration Objectives

Having reviewed and understood the aerospace engineering design education dilemma, it is time for this to change. We are harmonizing the balance between classical engineering sciences, CAE exposure, and design applications by exposing students early to CAE methods and tools and their thoughtful application. Clearly, the role and effective use of CAE design tools has to occupy a distinct place in education similar to the acceptance of the slide-rule and later the pocket calculator. However, there is a fine line between successful application of CAE tools in an educational environment and students using software packages as black-box systems. What needs to be avoided most are ‘designers’ relying on advanced software tools while loosing sight of the underlying processes, the ability to use imagination and creativity, and the ability to critically evaluate the results.

CAD COURSE. We are moving the CAD course from the freshmen year to the junior year so that students will have better retention of the material when they need it most, in the senior capstone design course sequence. Clearly, a designer needs to be proficient in visualizing geometry. This requires integration of our industry-standard CAD systems Pro/ENGINEER[10] and SolidWorks[11] into the CAE educational and research toolbox. In a next step, we aim to parameterize certain standard geometry models in the CAD system to allow for an automatic interface with those CAE disciplines requesting a central geometry model (e.g., structures, aerodynamics, etc.).

AEROSPACE STRUCTURES COURSE. The junior-level aerospace structures course is being redesigned to include a major finite element (FE) component and an optimization component. After a short introduction to theory, students will develop initial structural FE models, to be analyzed, then modified and re-evaluated, using Pro/MECHANICA[10] as a follow-up to Pro/ENGINEER[10] and the industry standard FE code ANSYS[12]. Students can access all of these codes under site-licenses. The semester will be capped off by a short introduction to the mathematical tools available for structural optimization and for Multidisciplinary Design Optimization (MDO). To demonstrate MDO, the code ASTROS[13] will be used. Due to time constraints, students will not create their own models, but will be given moderately complex aircraft wing models to optimize under structural and aerodynamic constraints.

AERODYNAMICS COURSE. The contributors to aerodynamic understanding can be classified to be the 'three dimensions': (a) pure experiment, (b) pure theory, and (c) computational fluid dynamics (CFD). The junior-level aerodynamics course has to concentrate on covering the basic concepts of aerodynamics. In addition, we will expose the students to the following aerodynamic CAE tools relevant to the conceptual design level: (a) analytical (lifting-line method and derivatives, e.g., Phillips[14]), (b) semi-empirical and empirical (Digital Datcom[15]), and (c) fully numerical (vortex-lattice approach: LinAir[16], VORSTAB[17]).

CAPSTONE DESIGN COURSES. A state-of-the-art computer code for the conceptual and preliminary design of flight vehicles has been acquired for use in the two-course senior capstone experience. This design tool called PrADO (**Pr**eliminary **A**ircraft **D**esign and **O**ptimization)[18] integrates many different CAE modules for the multidisciplinary analysis, design, and optimization of conventional and unconventional flight vehicles. Clearly, some strict guidelines have to be in place to utilize only those PrADO features during these courses, which accelerate repetitive calculations like parametric trade studies and design sensitivity studies to avoid using the code as a non-transparent black box.

Thus, students will learn about the individual CAE tools and methods throughout the junior year and the first senior capstone semester, then, will use the codes for actual applications in the second capstone semester, augmenting the manual conceptual design process. With this approach, we also aim to encourage students to write and apply their own small engineering application programs, a capability, which is critical in today's industry workplace.

2. Hands-On Design-Build-Fly Experience

We will utilize radio-controlled aircraft models as well as wind tunnel models throughout the curriculum. A design case study serves as a platform to encourage design variations. Central is the activity to design, construct, and flight-test a traditional versus non-traditional aircraft, requiring innovative design solutions, some of which cannot be extracted from existing applications. The model hardware needs to be flexible, so each academic year the students can start with a variation of the bare airframe, adding successively the aerodynamics (airfoil, wing size and shape), propulsion system (reciprocating, jet, rocket), control system (open-loop, closed-loop), landing gear arrangement (fixed, retractable), etc., until the model design is optimized at senior capstone level. The complexity of the design tasks will increase up to senior level, where the students finalize their respective aircraft design, utilizing all available design tools.

3. Assessment

The students' proficiency on computer-based problems and their understanding of the open-ended design process will be evaluated inside and outside of the classroom, using our standard ABET assessment methods: student course evaluations, student exit interviews, and alumni and employer surveys 2 years and 5 years out. These will inquire about the students' demonstrated knowledge of and familiarity with computer-aided engineering tools such as CAD, analysis, and design software and their overall design proficiency.

Conclusions

With our focus on design proficiency we are not aiming for a paradigm shift in engineering education, but instead propose to combine already proven elements in education and industry with selected novel educational elements and bring them into the classroom early as an integrated model. Thus, we will place our emphasis on the *understanding* of the workings and advantages of modern CAE tools rather than their blind use. At the same time, we will incorporate flying models into the design sequence so that students can see what works and what doesn't work firsthand, giving them a chance to try out innovative concepts in a non-threatening but thrilling environment. We hope this will generate engineers that are well rounded and ready to assume their roles in industry faster and more effectively.

References

1. Chaplin, C.R., *"Creativity in Engineering Design – The Educational Function",* The (U.K.) Fellowship of Engineering, November 1989, p. 41
2. Scott, W.B., *"'People' Issues are Cracks in Aero Industry Foundation, New Management Incentives are Key to Change, 'Hire and Fire' Paradigm is Obsolete, Panel Links Launch Failures to Systemic Ills, Editorial: Misguided Direction Threatens Aerospace Crown Jewel,"* Aerospace in Crisis, Aerospace Management, Aviation Week & Space Technology, 21 June 1999, http://www.aviationweek.com/aviation/aw63-66.htm

3. Anon., *"Trans-Atlantic Aircraft Sales Contest",* Tourism, January 2003, http://www.bizasia.com/tourism_/bmxrs/trans_atlantic_aircraft_sales.htm
4. Clough, W., *"The Future of Engineering Education",* Georgia Tech, Winter 2000, pp. 36-42
5. Vincenti, W.G., *"What Engineers Know and How They Know It – Analytical Studies from Aeronautical History",* Johns Hopkins Studies in the History of Technology, The Johns Hopkins University Press, First Edition, 1990
6. Nicolai, L.M., *"Viewpoint: An Industry View of Engineering Design Education",* Int. J. Engng Ed., Vol. 14, No. 1, 1998, pp. 7-13
7. Anon., *"Improving Engineering Design: Designing for Competitive Advantage",* Committee on Engineering Design Theory and Methodology, National Academy Press, 1991
8. Roskam, J., *"What is Needed to Teach Aeronautical Engineering Students How to Design Aircraft?",* AIAA Paper 90-3257, 17-19 September 1990
9. Anon., *"Criteria for Accrediting Engineering Programs",* Engineering Accreditation Commission, 1 November 2000, http://www.abet.org
10. Anon., *"Pro/ENGINEER Wildfire – Simple. Powerful. Connected."* PTC, http://www.ptc.com/index.htm
11. Anon., *"SolidWorks Success Stories",* SolidWorks Corporation, http://www.solidworks.com/index.html
12. Anon., *"ANSYS Workbench Environment",* ANSYS Inc., http://www.ansys.com
13. Johnson, E.H., and Venkayya, V.B., *"Automated Structural Optimization System (ASTROS) – Theoretical Manual", AF*WAL-TR-88-3028, Vol. 1, December 1988
14. Phillips, W.F., and Snyder, D.O., *"Modern Adaptation of Prandtl's Classic Lifting-Line Theory",* Vol. 37, No. 4, Journal of Aircraft, July-August 2000, pp. 662-669
15. Williams, J.E., and Vukelich, S.P., *"The USAF Stability and Control Digital Datcom",* Vol. 1, User's Manual, AFFDL-TR-79-3032, April 1979
16. Kroo, I., *"A Nonplanar, Multiple Lifting Surface Aerodynamics Program",* Version 3.4, Desktop Aeronautics, Inc., http://www.desktopaero.com/manuals/LAPManual/LinAirProManual.html
17. Lan, C.E., *"Methods of Analysis in the VORSTAB Code (Version 3.1)",* Department of Aerospace Engineering, The University of Kansas, May 1993
18. Hepperle, M., and Heinze, W., *"Future Global Range Transport Aircraft",* RTO Symposium on "Novel Vehicle Concepts and Emerging Technologies"; NATO Research and Technology Organization, Brussels, 7-10 April 2003

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