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Graduate Teaching Methods in Fixed-Wing Aerospace Engineering Senior Design

Joseph A. Deneke, and Felix E. Ewere
North Carolina State University

Capstone senior design courses in the field of Aerospace Engineering (AE) provide students with their first sustained opportunity to synthesize the technical knowledge and problem-solving skills they have learned over the course of their undergraduate degrees. Typically, this experience is delivered in the form of a semi complex aerospace vehicle design project. This paper highlights three years of delivery of this course in the fixed-wing aircraft section as a graduate student in the Mechanical and Aerospace Engineering (MAE) department at North Carolina State University (NCSU). The paper details the structure of the aerospace engineering senior design course by addressing the challenge of embedding key preliminary design topics into graduate teaching lecture time, which is limited. Selected teaching emphasis is placed on configuration aerodynamics, wing design, and methods of testing and validation which are not explicitly embedded in the undergraduate AE curriculum. The developed lectures provide an example of an adaptable set of material created by a graduate teaching assistant with a particular skill set. Student feedback is analyzed across multiple years in the form of statistical teaching reviews delivered by the university, demonstrating how course modifications improved both technical learning outcomes and student confidence. The paper concludes with lessons learned for future graduate instructors and recommendations for sustaining GTA-led contributions in AE senior design.

Corresponding Author: Joseph A. Deneke, jadeneke@ncsu.edu

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Introduction

Aerospace engineering senior design presents a challenging balance between course requirements and aircraft design instruction. This paper examines the lecture component of fixed-wing AE senior design from the perspective of the graduate teaching assistant (GTA). In this design synthesis phase, graduate teaching lecture delivery makes up about 50% of the face-to-face time for the fixed-wing section. Under supervision of the senior design faculty, it is the primary method to deliver section-specific information from the GTA to the teams in the fixed-wing section. These include content related to specific design methods, project life cycle techniques, and technical design analysis which are presented in these lectures[1].

For aerospace capstone design courses, it has been found that simulation-based learning helps students think more like practicing engineers, and it prepares them to move on to design-based positions after graduation[2,3]. This paper presents a push for this further enhancement of student knowledge on aerospace-specific simulation software and strategies to better prepare them for industry application. Furthermore, in this paper, a summary of the course structure is explained, and five fixed-wing-focused lectures are described which have been newly implemented over the past three iterations of the course lecture delivery. These lectures are adaptable and are catered to the strong-suits of the graduate teaching assistant, and it will be shown that the addition of these lectures has helped with retention and integration of advanced design topics into the student's projects.

However, including additional technical lecture content in capstone courses does not come without tradeoffs. Engineering education literature emphasizes that capstone courses must balance technical and administrative instruction with open-ended design work and team-based project development[3]. Therefore, the goal of this work is to evaluate the contributions of a GTA to the design process through technical lectures that can enhance the quality and fidelity of the design solution developed by the student teams in the first phase of their undergraduate capstone design experience.

NCSU Course Structure

The NCSU AE senior design program consists of a two-semester sequence taught over the course of an academic year. Students begin the course in their first senior semester and complete it in their final undergraduate semester.

The first semester consists of the analytical design phase of the project, where the mission profile is set through requirements from the customers in the first week of class. Students are split into teams of six based on their skill sets, which are determined before the fall semester begins through a series of surveys on technical skills. After mission requirements have been defined by the customers at a high level, the teams work through the aircraft design process with the following deliverables in the fall semester: Project Definition Document (PDD), Preliminary Design Review (PDR), Critical Design Review (CDR), and the Verification, Validation, and Testing Proposal (VV&T)[1].

The second semester consists mainly of the hands-on activities like prototype assembly, component fabrication, and verification testing of the manufactured vehicle. The first part of the spring semester is spent manufacturing the aircraft. Throughout the spring semester, a series of deliverables make up the majority of the students' grades: Manufacturing and Test Review (MTR), Flight Readiness Review (FRR), and a final report with a presentation on senior symposium day.

Graduate Teaching Design Topics

In the fall semester, the course structure allows for the graduate teaching assistant and course instructor to deliver approximately 8-10 lectures, mostly catered specifically to fixed-wing aircraft design. Aside from the administrative delivery of course requirements within this delivery time, the GTA has the opportunity to present additional selected topics that they think may benefit the students in the course. Lecture content is adaptable to the GTA's expertise, which varies each year. It has been shown that the integration of an instructor, especially at the course-section level (about 30 students) is essential for effective feedback and betterment of student learning within a capstone course[4,5].

The focus of this section will be on the delivery of this introductory set of select fixed-wing design topics taught in the fall semester (as teams go through the design process). These lectures primarily benefit the conceptual and preliminary design phases of the project, when the teams are in the process of designing large-scale components while analyzing their effect on vehicle performance and mission parameters. These lectures have been developed mostly over the past three iterations of this course delivery and have focused primarily on configuration aerodynamics design topics. Through teaching this course, students conveyed that they learned a wide range of topics throughout their undergraduate careers related to fixed-wing aircraft design, but they expressed a need to learn them at a more practical and applied level. The intent of integrating these lectures into the course is to bridge that gap between the knowledge learned in academia and the knowledge needed to apply what they learned to a real-world design solution. These lecture topics were selected based on recurring challenges observed in previous course iterations, particularly in the areas of configuration aerodynamics, airfoil evaluation, and design of CFD simulations. Figure 1 shows the schedule of the forthcoming lecture deliveries in the fall semester within the high-level design process.

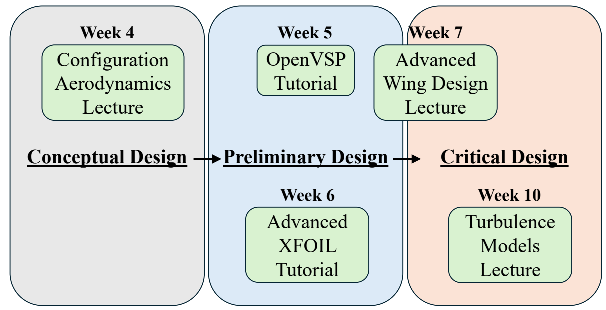

Figure 1: Integration and schedule of design lectures in the fall semester.

1. Intermediate Configuration Aerodynamics

Configuration aerodynamics is a topic in aircraft design that is crucial in the conceptual and preliminary design stages of the design process. Students are introduced to this topic in their aircraft performance class, so this selected topic is meant to be a continuation of those discussions with the addition of more practical application examples. This lecture is delivered early in the semester while teams are performing trade studies for their vehicle design. This lecture primarily discusses tail/empennage configuration as well as wing/tail configuration relative to each other. The advantages and disadvantages of different tailplane placements are discussed at a qualitative level, and real-world failure examples as well as previous senior design failures are shown to display the importance of the topic.

2. Advanced OpenVSP Tutorial

CAD has been proven to significantly increase realism in the senior design education environment, but CAD is not always completely accessible to students as it is not specifically taught or required in most engineering curriculum[6]. Often times, a group of six seniors may have never used software like Solidworks or Inventor. In such a case, it is much easier to teach a lighter-weight CAD tool such as OpenVSP, FreeCAD, or Onshape. With this, an advanced lecture on the use of OpenVSP was recently integrated into the course delivery to help students in the early design process[7]. OpenVSP is a relatively easy-to-use software that is used for conceptual and preliminary design of aircraft. The students are introduced to the software in their early undergraduate aerospace classes, so this lecture has been designed to build upon those concepts with some advanced design strategies that the software employs. The lecture dives into the multitude of wing design parameters that can be altered within the software, as well as interfacing the output of OpenVSP into other software such as VSPAero and Ansys Fluent.

Figure 2 shows part of an example delivered to students in this lecture where a wing design is altered with constraints set on AR, b, and λ. With this, OpenVSP's interactive GUI is a great tool where users can set a maximum of three constraints on geometric wing design features. Students have received the lecture well based on verbal feedback, and over the recent two deliveries of this course, OpenVSP has been utilized more for conceptual and preliminary aircraft design.

AR	b	λ
2	6.86	0.25
4	6.86	0.25
4	6.86	0.10

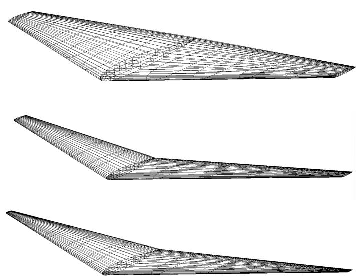

Figure 2: The effects of varying λ and AR while holding b constant in wing design.

3. Advanced Aerodynamic Design in XFOIL

XFOIL is another valuable tool used in aerodynamic design of fixed-wing air vehicles[8]. Students use the tool to determine airfoil characteristics and choose an airfoil for their wing and tail designs that would best fit the mission profile. For general airfoil design, it is common to compare airfoils across a range of angles of attack (α) with Reynolds number (Re) held constant. This is the method taught in the undergraduate curriculum, which is good for various disciplines. The focus of this lecture is to deliver information to the students on implementing 'Type 2' analysis into their preliminary design, where $Re\sqrt{C_L}$ is held to a constant value determined by the aircraft weight. This lecture demonstrates the effect of this design method, and it shows the difference in airfoil aerodynamics as an outcome of Type 2 analysis.

4. Advanced Wing Design Theory Topics

One of the fantastic aspects of senior design is that the project is very open-ended, and there are unlimited design solutions that can fulfill the same mission requirements. Design of the wing is arguably the most important physical component design for this project, and it is simple for teams to just choose a simple rectangular wing and have great success. For teams that want to go above and beyond to be more competitive among the customer ratings, wing design is usually an aspect of the project where teams can differentiate themselves from each other. To help foster this environment, two in-depth lectures consisting of a slew of wing theory topics have been developed over the past three years of teaching this course. The lectures cover a high-level summary of an introductory graduate course on Wing Theory at NCSU[9]. Students get exposed to the major elements of wing design: incidence, aspect ratio, taper, twist, sweep, and dihedral in these lectures. Quantitative pros and cons of various wing designs are shown in the form of lift coefficient and spanwise loading distributions. Students are exposed qualitatively to stall propagation and the effect of the major design parameters on stall behavior over a wing element. The outcomes of implementing these two lectures have been very noticeable. Students are more receptive to thinking outside of the box with respect to their wing designs, and students are more willing to design their wings with variance from the simple rectangular wing design. Figure 3 shows an example of an elevated wing design produced by students in this course[10]. The wing design features a forward swept wing of aspect ratio 10 with moderate taper, a wing design that is difficult to manufacture with the provided machines and resources.

Figure 3: REACHR's HERO 1 at the critical design phase.

5. Introduction to Turbulence Models in CFD

Turbulence models are an element of Reynolds-Averaged Navier-Stokes (RANS) CFD that is not fully discussed in the undergraduate curriculum but is an essential element in running a successful CFD simulation, especially for a fixed-wing aircraft. Due to computational costs associated with higher-order CFD, RANS is utilized for any CFD simulations completed in aerospace senior design. Based on graduate lecture material, the overarching equations used for a one-equation model (Spalart-Allmaras) and a two-equation model ($k - \omega$)

are introduced in this lecture. High-level derivations of the RANS closure models pertaining to eddy viscosity are also part of this lecture. The pros and cons of one-equation models versus two-equation models are discussed, and practical applications of these models are shown to the students within ANSYS Fluent. A slew of model constants are provided to the students from research papers, and example results are shown which compare the two models for a flat plate turbulent boundary layer solution. The goal of this lecture is to at least give a baseline overview of the types of modeling that can be achieved through inexpensive CFD simulations. Through surveys related to this lecture, students have expressed a better understanding of turbulence closure models and their effects on RANS-based CFD.

Student Reviews

As this course delivery has developed and changed over the past three years, surveys have been given to the students to gauge interest in the added content. For the ‘23-‘24 school year, these specific aircraft design topics were not presented, but with modifications to the lecture material, they were given in the ‘24-‘25 school year. A survey was given to the class of 31 students relating to the content and delivery of these newly added topics. In this survey, a 1-10 scale rating question was posed for both the lecture *material* and the lecture *delivery* of the presented lectures. With respect to lecture *material*, 94% of students rated above 70%. On the other hand, 90% of students rated the lecture *delivery* above 80%. It is important to note that, while these surveys provide useful feedback regarding student perception of the lecture content, they do not provide controlled baseline comparison across multiple course iterations. About 90% of student comments regarding the added technical design lectures were positive, which included notes about the pace and depth of the lectures. Only a few minor concerns were noted, including that the pace of the lectures was occasionally slightly too fast.

Conclusions

An overview of the NCSU aerospace senior design course structure has been presented, along with a description of five custom lectures focused on fixed-wing aircraft design that have been implemented recently. Through survey results and general course feedback, students have enjoyed and learned from the recent additions to lecture material. Overall, the added GTA-based lectures have aimed to build out needed competencies in the learning foundation of incoming aerospace graduates. Future work will continue to implement new intriguing lectures in this space. Many of the newly implemented lectures are very much focused on the strong suits of the graduate instructor; as different graduate students come through (with varying backgrounds), similar technical lectures in the other aircraft design disciplines can be implemented into the course structure.

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