



## Creating the Framework for Better Aerospace Engineers

### Mr. Trevor J. Bennett, Texas A&M University

Trevor Bennett is a Ph.D. student in the Department of Aerospace Engineering at Texas A&M University. His research interests include dynamics and controls of aerospace vehicles, autonomous unmanned aerial vehicle design, and astrodynamics. Bennett currently serves as the mentoring chair for the Texas A&M University chapter of Sigma Gamma Tau, the Aerospace Engineering Honor Society.

### Ms. Kristin D. Nichols

Kristin D. Nichols is completing her last semester of undergraduate study in the Department of Aerospace Engineering at Texas A&M University. Her undergraduate research has ranged from wind tunnel design to robotic interfaces and control, to her current research in simulating Solar System dynamics. She has also completed three tours at NASA's Johnson Space Center as an Engineering Co-op Student. Her graduate research will focus on asteroid dynamics and interplanetary mission design. Nichols is the recipient of the Sigma Gamma Tau Outstanding Senior Award for 2013 and has also served as the Texas A&M AIAA Vice Chair and AIAA Class Representative.

### Dr. Kristi J Shryock, Texas A&M University

Dr. Kristi J. Shryock is the assistant department head for Undergraduate Programs and Outreach in the Department of Aerospace Engineering at Texas A&M University. She is also a senior lecturer in the department. She received her Ph.D. in interdisciplinary engineering with a research focus on engineering education. She works to improve the undergraduate engineering experience through evaluating preparation in mathematics and physics, incorporating experiential education in the classroom, and introducing multidisciplinary design.

# Creating the Framework for Better Aerospace Engineers

## Abstract

This paper provides an overview of the modifications made to the freshman level Introduction to Aerospace Engineering course at Texas A&M University and details the motivation for transitioning to a more design-centered course structure from previous modifications made over the past few years. The course focuses on three multi-week design projects supplemented by other various forms of instruction, such as guest lecturing and student mentoring. The paper concludes with survey results and testimonials that demonstrate the effectiveness of engineering design education at the freshman level.

## Introduction

A successful engineer is equipped to innovate and create within the technical community and to inspire and inform the whole of society. Creating the framework for this success should be the primary goal of engineering educational institutions. An important and effective part of engineering education is the design process. Many, if not all, engineering programs require a senior design project in which the students apply their undergraduate coursework to a discipline-specific design challenge. While senior-level design is the capstone of a student's undergraduate education, the authors believe that design education should not be restricted to the final year. Instead it should be integrated throughout the curriculum and follow the development of the student. Additionally, effective implementation of design education should be unique to the current technical level of the student. At the freshman level, design education should introduce the engineering process as the foundation for all future coursework and career practices. This paper discusses an implementation of a freshman engineering design course that embodies this belief.

The Introduction to Aerospace Engineering course, AERO 101, develops the fundamental context and importance of the aerospace engineering major and profession. While it is not a required course in the curriculum, it can be completed either in the first or second semester of the students' college career and has substantial influence over the students' opinions and enthusiasm about aerospace engineering. Students enter the course with little or no engineering experience but anticipate using the information in the course to assist in making a decision on choice of major. The power that resides in this introductory course is the motivation for innovating the teaching process by the authors. The course is focused on introducing fundamental terminology, historical relevance, and breadth of aerospace engineering applications. Freshman design projects are included in the curriculum that focus more on the design process followed rather than the student-produced technical solution. Developing the student design process is an important first step in creating capable engineers whose technical competence will be developed through future coursework.

The course has evolved in two key aspects over the past three years. The first step was to make the class more student-centered by pairing freshman students with upperclassmen mentors.<sup>1,2</sup> The

most recent improvement, implemented within the past year, has restructured the traditional lecture course into a more hands-on, design-centered learning environment. The new classroom model enables students to become familiar with the engineering design process via three projects that introduce topics including Aerodynamics, Structures, Rockets, Orbital Mechanics, and Spacecraft Design.

The following section provides the fundamentals of educational psychology that support the engineering design education the authors sought to implement. Following the supporting theory section is a detailed description of the current course that accomplishes the above objectives. The effectiveness of the course structure and design projects is evaluated using student surveys in the Educational Outcomes section. The paper concludes with final comments and future work.

## Engineering Design Education

Engineering design refers to the development of innovative solutions to open-ended problems using limited resources. Defined by ABET, engineering design is “a decision-making process (often iterative) in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective”.<sup>3</sup> Merely applying mathematical equations in a specified sequence is not sufficient. Because engineering problems are generally open-ended or under-defined, several solutions are able to solve the issue, and no one answer is necessarily more correct.

Freshman-level design courses give students a more realistic and holistic perspective by introducing engineering concepts through design. This is supported by the claims of Constructivism, which holds that “learning results from a personal interpretation, is active with meaning developed on the basis of experience, is collaborative with meaning negotiated from multiple perspectives, and should be situated in realistic contexts”.<sup>3</sup> In other words, knowledge is built from experience, and the students must be actively engaged in the design process to gain such experience. The structure of the design course should construct an environment that facilitates this type of learning through the balance of individual problem solving and discovery with direct instruction and mentoring.

Experiential learning environments occur when competence grows into capability. According to Fraser and Greenhalgh, competence is what individuals know or are able to do with respect to knowledge and skills. Capability refers to the extent to which individuals “can adapt to change, generate new knowledge, and continue to improve their performance”.<sup>6</sup> Capability is not taught or passively acquired; “it is reached through a transformation process in which existing competencies are adapted and tuned to new circumstances”.<sup>6</sup> Design education should therefore provide continual opportunities for students to be “stretched by the uniqueness” of each situation, to apply knowledge in creative and novel ways beyond what is taught, and to define expertise as “the ability to access knowledge and make connections across seemingly disparate fields and life experiences”.<sup>6</sup> Thus, educators must offer an environment and teach processes that are conducive to creative thought and provide constructive feedback for student growth. In this type of learning, the instructors become facilitators of knowledge rather than providers of it.

The introductory course should not significantly develop competence. The course should develop the fundamental framework for the students to understand, appreciate, and relate the information obtained in the following years of study. The course should also promote and develop the first levels of capability.

This is consistent with a tenant in educational psychology, which states that knowledge is constructed and incremental. Therefore, students must be educated with the expectation the environment will change and new methods and technologies available. This approach is directly transferrable to the engineering profession. Design is what engineers do on a daily basis and “engages both the intellect and the imagination of the designer”.<sup>3</sup> Engineers must not only be *competent* in their technical knowledge but must more importantly be *capable* to apply this knowledge and adapt it to changing environments. Table 1 lists several qualities an effective design engineer should possess. These characteristics will be used later as a metric to measure how well students exhibit these qualities in a design environment.

Table 1. Qualities of a design engineer<sup>4</sup>.

The Engineer or Engineering Student should be able to ...
QUALITY
1. Communicate, negotiate and persuade
2. Work effectively in a team
3. Engage in self-evaluation and reflection
4. Utilize graphical and visual representations and thinking
5. Exercise creative and intuitive instincts
6. Find information and use a variety of resources (i.e., resourcefulness)
7. Identify critical technology and approaches, stay abreast of change in professional practice.
8. Use analysis in support of synthesis
9. Appropriately model the physical world with mathematics
10. Consider economic, social, and environmental aspects of a problem
11. Think with a systems orientation, considering the integration and needs of various facets of the problem
12. Define and formulate an open-ended and/or under-defined problem, including specifications
13. Generate and evaluate alternative solutions
14. Use a systematic, modern, step-by-step problem solving approach. Recognize the need for and implement iteration
15. Build up real hardware to prototype ideas
16. Trouble-shoot and test hardware

In contrast to engineering design, which focuses on the specific solution developed, engineering design education focuses on the process followed. The design process should be a tool for the student to use when approaching design problems and should provide guidance from design specifications to a final solution. While there are many design structures that could be implemented, the iterative design structure was selected for this course. This structure allows the students to complete one cycle per project within the course timeframe. See Figure 1 for the steps involved in the engineering design process.

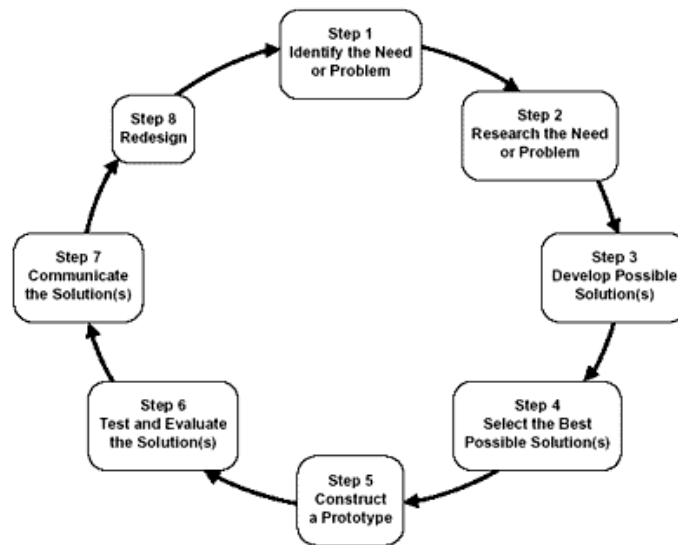


Figure 1. Steps of the engineering design process<sup>5</sup>.

Implementing design education at the freshman level requires the facilitators to be aware of the students' technical levels, expectations, and previous experiences. Developing the students' ability to understand and use the design process when tackling any engineering problems is much more important than the project-specific solution. The objective is to develop engineers capable of solving problems in a variety of situations. Students are taught to ask challenging questions expanding their understanding, to use a process encouraging creative development, and to use the resources around them to solve problems. The objective is to make the students aware of the relevant information and prepare a framework for the technical information to be fit into and expanded upon. The technical competence will come over time through continued coursework and is not within the scope of this course.

Design courses typically involve multi-week projects, such as the projects contained in AERO 101. According to Sheppard and Jenison, multi-week design projects provide freshman aerospace students with the following principles:<sup>4</sup>

- An understanding of Aerospace Engineering.
- An atmosphere conducive to developing the individual's creativity.
- Skills for team-based problem solving.
- An understanding of the importance of communication.

Selection of design project topics is made with consideration to these principles. In addition, the design problems are open-ended and their relevance apparent to students. When students understand the context of what they are doing, they become more invested in the learning and design processes. Providing projects and creating environments realistic to the field enables students to understand the type of work engineers do on a daily basis and gives students a practical idea of engineering expectations. It has also been shown that real-world design problems not only help in the learning process but “jump start the student-to professional transition”.<sup>4</sup> This means that by exposing students to realistic engineering environments, design courses can prepare students for work in the aerospace industry.

Successful engineers are also resourceful. Part of the introduction course is geared towards familiarizing students with additional opportunities outside the classroom, resources available to them in the department, and people to contact for specific needs. One such resource is additional mentoring and tutoring hours held by the department’s honor society. This will be expanded upon below.

### Course Structure

AERO 101 is designed to capture the attention and imagination of incoming students. The first and second semester of the college experience is often a time when students explore interests and passions. The primary goal of the course is to illustrate the daily work of aerospace engineers and provide opportunities to experience the engineering design process. In addition, the course characterizes the aerospace engineering major and the expected level of performance and commitment the coursework requires. The overall experience enriches any current passion or interest within aerospace engineering and supports development of new interests.

In AERO 101, students are introduced to the engineering design process through the completion of three aerospace projects. The projects provide a sample of the aerospace field through design of aircraft, rockets, and space vehicles. Each project spans three weeks and maps to the engineering design process presented previously, whereby students design-build-and-test their own creations. The three projects are discussed in detail in the subsequent section.

The course layout spans a 15 week semester, meeting for one hour of class and two hours of supplementary instruction each week. The first class of the semester is devoted to introducing the course structure, basic resources within the department, building student teams, and providing initial context of aerospace engineering concepts. The second class is devoted to pairing freshman students with mentors and facilitating their first interaction. The remaining part of the course is devoted to the three major design projects.

In addition, several classes are reserved for additional exposure. Students in the Aerospace Engineering Department at Texas A&M University (TAMU) specialize in coursework during their senior year of undergraduate study. However, undergraduate research and design opportunities exist for students at all levels. To expose freshman students to these opportunities and connect them with faculty in research, aerospace professors are invited to give a guest lectures on their field of study at the beginning of every new topic. Another class is reserved for touring senior design laboratories and hearing from student design teams. These interactions

enable freshman students to connect the coursework to a future in aerospace. Students are also taken to an off-site engineering facility or research laboratory that connects them with the opportunities available in industry. The final class period is used for students to reflect on what has been learned in the course, provide final feedback to the instructors, and celebrate achievements in design over the semester. With the current schedule, one class can be used at the discretion of the professor. Relevant activities can include tours of on-campus research laboratories, additional guest lecturers, and design project extensions. A sample semester schedule is provided below in Table 2.

Table 2. Course structure.

<b>Class Number</b>	<b>Class Activity</b>
1	Introduction
2	Mentor Q&A Aerospace Jeopardy
3	Receive Project 1 Guest Lecture on Aerodynamics
4	Project 1: Guest Lecture on Structures Airfoil Prototype, Mentor Feedback
5	Project 1: Load Test
6	Project 2: Load Test Receive Project 2 Guest Lecture on Rocket Basics
7	Report 1 submitted Project 2: Fin Prototype, Mentor Feedback Guest Lecture on Rocket Stability
8	Industry Field Trip Project 2: Fin CAD completed
9	Discuss Report 1 corrections Guest Lecture on Internships & Co-Ops Project 2 work continuation
10	Receive Project 3 Guest Lecture on Space Mission Design
11	Project 2: Launch Rockets
12	Report 2 submitted Senior Lab Tours Project 3 work continuation
13	HOLIDAY – no class
14	Project 3 Presentations
15	Present 3 Presentations Final Survey

It is critical to mentor and support students during the first year of their college experience. As part of the course, each team of freshman students is paired with a mentor who is an upper-level undergraduate student or a graduate student who attended TAMU as an undergraduate. The mentors provide insight into life as a college engineering student, characterize aerospace

engineering from a seasoned student's perspective, and answer any other personal questions that the freshmen have. In addition, the mentors provide students with feedback on designs at strategic points along the design process to help guide student progress. The mentors also provide freshmen with a professional contact during the first few years of study.

## Project Structure

All three of the design projects follow a prescribed structure modeling the formal design process presented previously in Figure 1. Each project is given three classes used for an introduction, prototype, and test phase, respectively. Establishing set design checkpoints, the students are guided through a well-structured design loop. The use of checkpoints allows the students to implement creative solutions while still receiving in-class feedback.

The projects include both individual and team design elements. Splitting the students into teams creates a comfortable and stable support structure for students. This establishes peer groups to enable the exchange of ideas, perspectives, and feedback. Fraser and Greenhalgh agree that these small design groups can achieve more than the sum of the individuals.<sup>6</sup> Fraser and Greenhalgh go further to note that the social interaction “stimulates learning, raises individuals’ confidence, and increases motivation”.<sup>6</sup>

The project introduction phase presents the formal project statement and requirements. The information is compiled in a handout with tasks corresponding to the formal design steps. The establishment of clear design objectives in the course models formal Requests for Proposals used by professional engineers. Providing projects and creating environments realistic to the field enables students to understand the engineering mindset and gives students a practical sense of engineering expectations. The introduction phase is supplemented by a guest lecture. The lecture serves to introduce students to the relevant fundamentals and the possibilities aligned with the respective specialization. This phase addresses the first step in the design process and prepares students to complete the second and third design process steps in the week before the prototype phase. The students are offered two additional hour-long sessions during the week to allow for individual instruction.

The prototype phase involves students selecting the solution felt is best and constructing a prototype design. Students bring the prototype to class and receive design critiques from student mentors and visiting professors. Inclusion of this phase creates a constructive environment for students to gather feedback on creative and unique solutions. Additional design information is provided through a supplementary guest lecture. This phase addresses steps four and five of the formal design process. The students then finalize and construct design solutions during the week between the prototype and test phases. During this week, two additional hour-long sessions are offered to allow students more individual instruction if needed.

The test phase for each project is used to evaluate the final designs and discuss overall results. Testing, or step six of the design process, is the climax of experiential learning. This is because students knit together technical theory with physical demonstrations. Students discuss observations in a comprehensive design report. The report serves as the medium for self-assessment, reflection, and future improvement. The report requires clear and concise



presentation of technical information and design process followed. This is critical in addressing the last element of capability, which is the process of continually improving the performance. Using a professional engineering format, the paper reinforces the importance of technical communication within the engineering field. This phase addresses steps seven and eight of the formal design process.

In addition, each student submits a project evaluation with the design report. The project evaluation is another form of student reflection and provides helpful feedback on projects and course structure. Feedback from these evaluations is discussed below in the Educational Outcomes section.

The course projects are intentionally designed to provide limited information. Limiting the amount of information provided to students balances problem solving with direct instruction and encourages more creativity in design. The students are expected to complete individual and/or team research on the subject to aid in satisfying the design requirements. This directly addresses the learning objectives of capability. As students, and later as professionals, adapting to new design problems and utilizing a process to develop solutions is expected. Beyond the technical knowledge gained, these projects provide students with open-ended design problems requiring the use of teamwork, creativity, technical communication, and resourcefulness.

#### *Aircraft Wing Design Project*

The first project focuses on the construction of a balsa wood aircraft wing capable of sustaining lifting loads. The wing consists of four ribs and two spars at fixed locations; however, the remaining structural design is determined by the students. The wing is covered with a plastic material called Monokote, which exhibits a heat sensitive bond that shrinks to fit the shape of the wing. To more accurately model engineering projects, design materials are limited. The wing designs were tested in an inverted g-loading rig, which simulates lifting loads by weighting the underside of the wing. The performance was evaluated on load supported, wing weight, and the presentation of the design.

The introduction lecture covers fundamental flight and aerodynamics. Introduction to flight theory enables the students to understand important design considerations when selecting an airfoil, or wing cross-section profile. Based on the design criteria and the evaluation methods, the authors found that many students researched heavy-lift and transport-type aircraft. By researching aircraft that met similar needs, students were able to extract key design aspects. This demonstrated that students began to critically analyze potential solutions. The final airfoil shape is selected from the University of Illinois Urbana-Champaign airfoil database, a database used by engineers in industry. Students then progress toward the prototyping phase.

The prototype phase lecture covers fundamental aerospace structures. This lecture provides critical information regarding the fabrication and final design elements for the internal structure of the wing. In this phase, each student is required to submit a unique rib prototype. The rib is the internal structure that shapes the wing into the desired airfoil. During class, the teams discuss the pros and cons of each member's airfoil selection and rib design. Guided by input from the professor and mentor, the student teams select one airfoil and finalize a team rib design. Teams then fabricate the wing for load testing.

The third phase is focused on testing team designs. Each team's design is tested by inverting the wing and clamping the spars into a cantilever configuration. The inverted wing simulates lifting loads by allowing gravity to act on sand bags placed on the wing. Students record and discuss the performance of the wing during the load test competition. See Figure 2 for the testing setup.

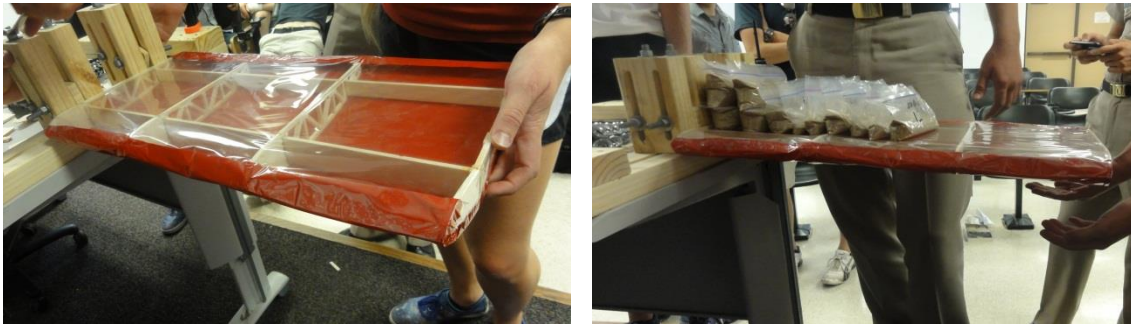


Figure 2. Load test setup for aircraft wing project.

The aircraft wing project is designed to introduce students to atmospheric vehicles and aircraft design. As part of the fourth phase, the students discuss the technical aspects of design and approach in an engineering design report. The report closes the design iteration loop by encouraging students to critically analyze the design and suggest potential improvements. This project illustrates the importance of balancing tradeoffs in aircraft wing design. The project is the first of the semester and, therefore, is designed to more thoroughly guide the students through distinct design steps from initial airfoil selection through wing fabrication and testing.

### *Rocket Fin Design Project*

The second project focuses on designing rocket fins to satisfy stability requirements for an Estes Alpha model rocket. Stability refers to the configuration in which the rocket center of pressure is aft of the rocket center of gravity. Students create unique fin solutions that satisfy the stability requirements. Students then have the opportunity to test the designs by constructing and launching an Estes model rocket. The rocket project is evaluated through design calculations and model rocket flight performance.

The introduction lecture covers the history and fundamentals of rocketry. This is important in establishing a baseline understanding of rocket design considerations. Students research fin designs on a diverse set of rockets and missiles to generate possible design solutions. The prototype phase lecture provides critical information regarding the fabrication and design of model rocket fins. Each student uses the information from the first two lectures to create a unique fin design. Fin designs are validated using hand calculations and an open source design tool called RASAero—a GUI based program that generates both a rocket visual and anticipated flight performance.<sup>7</sup> The integration of hand calculations and design software enables students to understand the influence that fin geometry has on rocket stability. Stable fin designs are laser cut for the students to affix to the model rocket.

The third phase encompasses the model rocket launch. Each student has the opportunity to launch a rocket while observing the flight of others. Figure 3 shows a student receiving feedback from a mentor on how the design affected flight just observed. Observation of various fin geometries encourages students to connect configuration choices with flight performance. Student record the technical process and understanding of rocketry in a design report.



Figure 3. Student obtaining feedback on design from mentor.

The rocket fin project is designed to introduce students to rocket design. This project connects the students' mathematics coursework to aerospace engineering and utilizes engineering software tools often used in industry. The rocket project also clearly relates design choices to vehicle performance. The addition of a new design problem strengthens the students' ability to apply the design process in a variety of settings to demonstrate capability.

### *Space Mission Project*

The third project focuses on previous and current space exploration missions. Historical relevance and technical communication skills are critical to successful engineering. To address this need, student teams are assigned one of the eleven specifically chosen missions to research and present. The missions include various destinations, mission objectives (manned and unmanned), times in history, and sponsor countries. The range of mission profiles showcases the diversity of spacecraft design considerations, methods, and solutions. Some of the available choices include: Voyager, Skylab, Mars Exploration Rover, Hubble, Venera, and Deep Impact.

The introduction lecture encompasses spacecraft considerations, design process of vehicle systems, systems engineering, and anecdotes. Student teams use the spacecraft lecture and discussion to begin research on the assigned mission. The research focuses on the objectives of the mission, design considerations, and technical solutions developed to meet mission needs. Two classes are reserved for student presentations. Each team must decide the best way to

present the information for the project. The presentations are evaluated on technical accuracy and clarity in addition to communication skills of the presenter. Immediately following any class questions, the professor and mentors provide feedback on all aspects of the presentation.

The space mission project requires students to exercise and improve communication skills in a technical setting. Students also expand the understanding and awareness of past, present, and future space endeavors. The historical context is critical in spacecraft design, as many designs build upon previous successes and failures. This project encourages students to perform research within aerospace engineering and to stay current with new developments. It also enhances the students' awareness of the technical depth incorporated into aerospace vehicles.

### Educational Outcomes

The AERO 101 course is a one hour per week seminar class held on Friday afternoons. The course has two sections of 40 students each. One section is a general section; the other is an honors section. Through the course design the honors section is challenged beyond the general requirements of the project. All of the students, with a few exceptions each semester, are first year aerospace engineering students who likely have little to no knowledge or experience within aerospace engineering. Several metrics are therefore used to assess the effectiveness of the new design-centered course structure. The metrics include student design reports, projects surveys, and an overall end of course survey. The graphs to follow were derived from the student responses on the final survey. The graph legends correspond to the bars reading from left to right with the left most bar representing Strongly Agree to the right most bar being Strongly Disagree in each of the figures. The results presented address the major objectives of the course. Figures 4 and 5 address whether the new structure better served the students. Figures 5 and 6 address whether the course provided a framework for the technical information. Figures 7 and 8 address whether the course spurred interest in aerospace engineering. The responses to the following questions are not directly compared to results received in previous semesters. This is because the surveys reflect new course objectives. This design center format changes the course objectives significantly enough that the authors felt new course surveys are not comparable to previous course surveys.

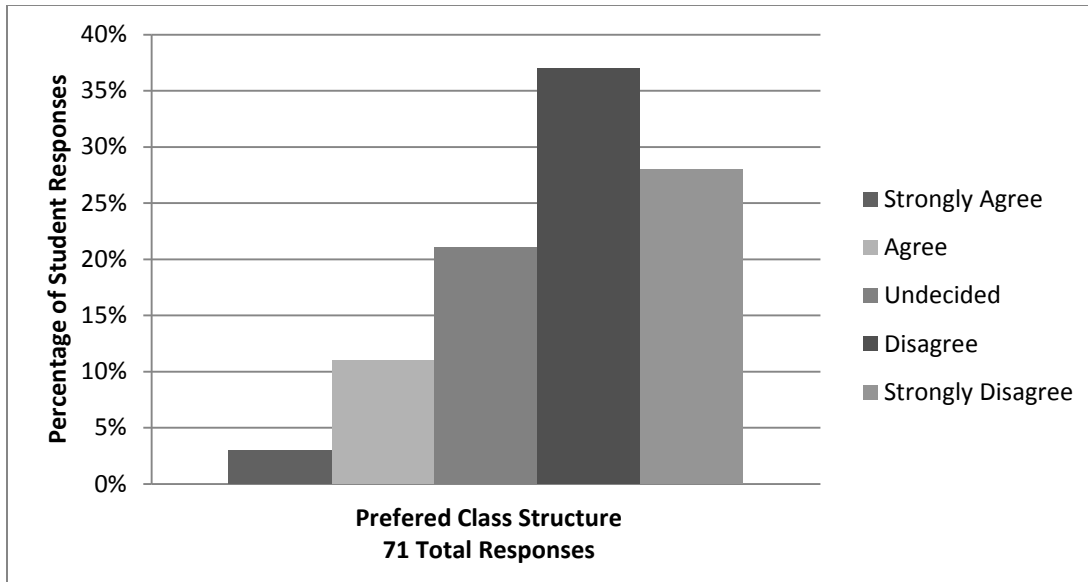


Figure 4: Student responses to “I would prefer to have straight lectures each week instead of completing design projects in AERO 101”.

Figure 4 demonstrates the overall satisfaction with transitioning to a more design-centered course structure. An overwhelming 65% of students desire design projects to be part of the course. An additional 21% of students were undecided on the question. Only 14% of students would have preferred straight lecture to the design-centered course structure. The comments that supported the straight lecture style predominantly arose from the time commitment required by the design projects. The responses in favor of the design projects strongly aligned with one student’s remark of enjoying “building the wing because [he] got see [his] drawings and sketches come to life”. The student illustrates the application of the design process from conception to fabrication.

A prime example of the development of capability within a creativity-rich environment is clearly evident in a student-developed manufacturing technique. As part of the first project, students were tasked with fabricating four ribs. The project did not explicitly dictate how to fabricate the ribs. Traditionally, wood ribs are manufactured in a jig that guides the individual assembly of pieces to ensure the proper shape. One group decided to build a unique jig, which consisted of a “negative” airfoil. The negative was a solid piece of material with the airfoil shape carved from it. The students then assembled ribs inside this negative to ensure that each rib had the proper final shape. This emergent behavior is a strong indicator of the students applying creative problem solving to a design challenge that was previously unknown. The student behavior demonstrates that creativity was strongly encouraged and capability was developed.

Students also responded to the value of the design projects. When asked to comment on “Overall, I feel I have a better understanding of aerospace engineering after completing the projects”, student responses clearly demonstrated the projects enhanced fundamental understanding of aerospace engineering principles (Figure 5).

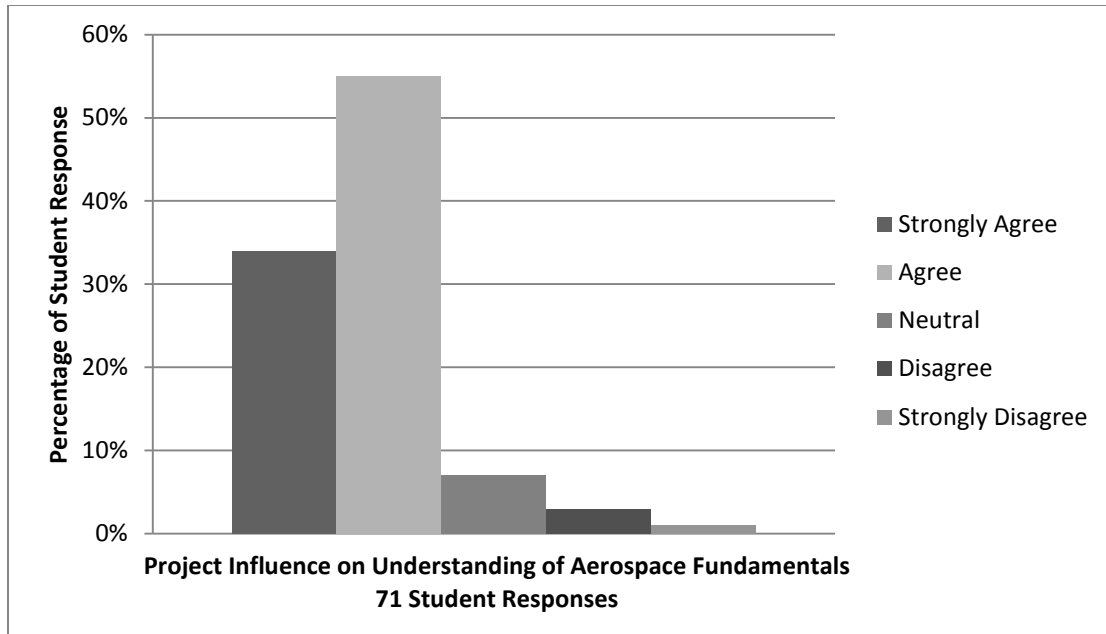


Figure 5: Student responses to “Overall, I feel I have a better understanding of aerospace engineering after completing the projects”.

The course also aimed to provide fundamental concepts for the incoming students. One student commented: “It was a very good introduction class to get students interested in the program and more knowledgeable about basic aerospace principles”. This student’s words demonstrate the overall consensus that the course provided exposure to aerospace engineering. Students were also asked how current coursework will aid them through aerospace engineering with results shown in Figure 6.

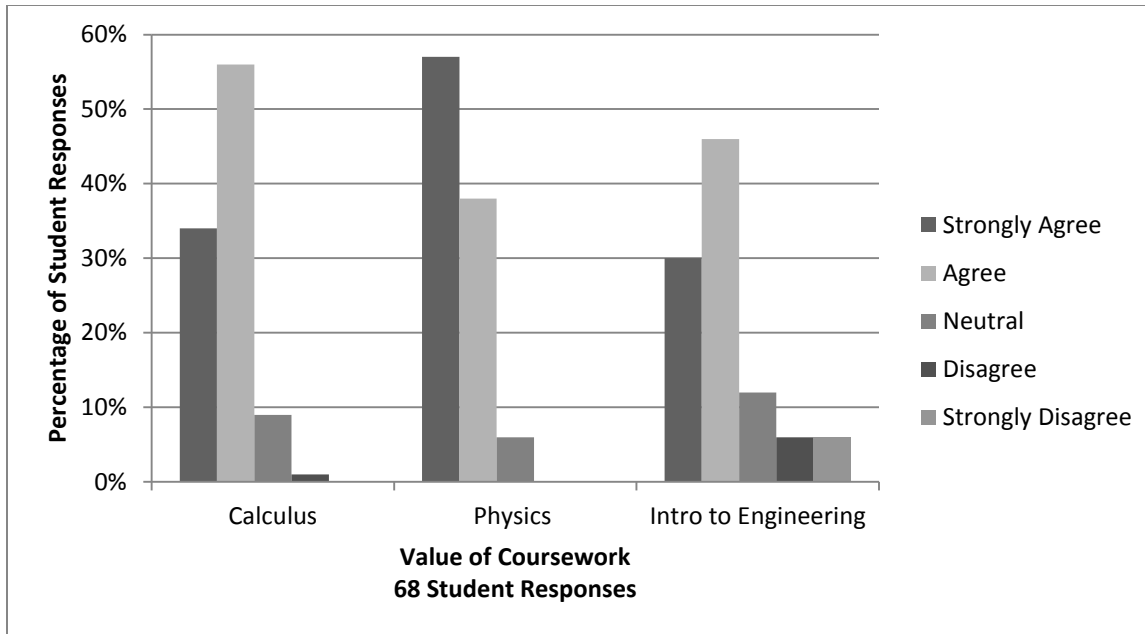


Figure 6. Student responses to “I understand how [course] will help me in my Aerospace degree”.

In support of the overall class response, several students commented on the connections made between aerospace engineering and coursework:

*“Because of the hands on projects, I was able to see and greatly appreciate the application of the calculus and physics within Aerospace Engineering.”*

*“[The project] required some calculations that made me feel like this was a valid design rather than me just piecing together parts and hoping it would work, or piecing together information and repeating it to the class.”*

The AERO 101 course strives to establish a framework that conveys the importance of follow-on coursework. The response to the coursework question and previous two quotes meet the course objective of establishing a framework for current and future courses. This educational outcome demonstrates the application of basic principles to arising design challenges. The infusion of competence in the design process is evident.

To assess the course’s influence on the student’s enthusiasm about aerospace engineering was probed in the question: “I am excited about pursuing my Aerospace degree.” The responses, shown in Figure 6, clearly demonstrate the students exit the course with excitement and enthusiasm for a future within aerospace engineering.

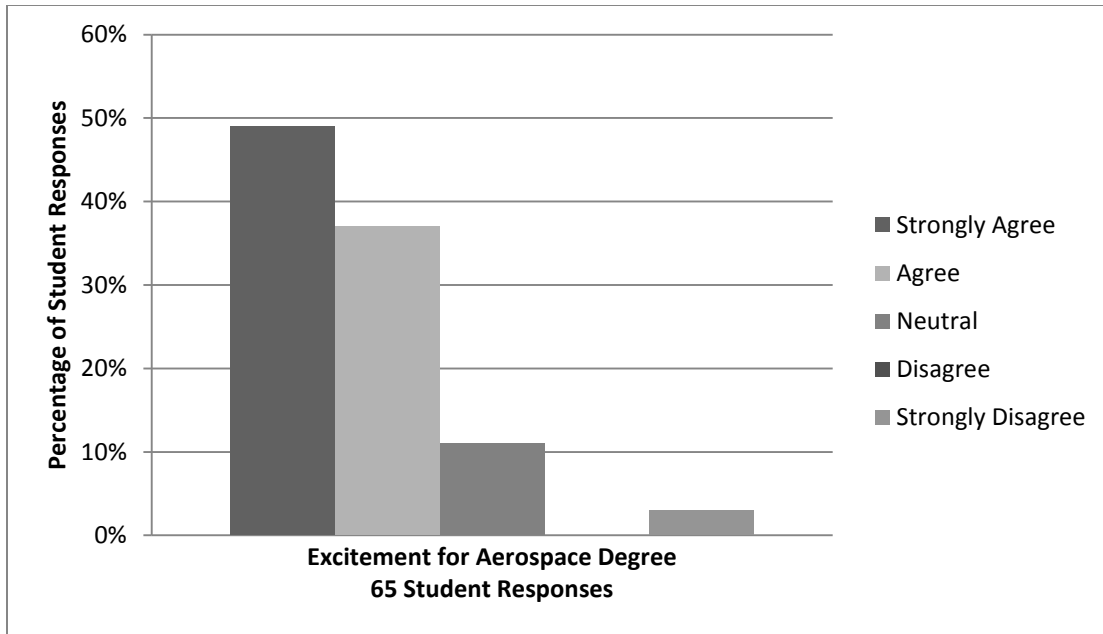


Figure 7. Student response to “I am excited about pursuing my Aerospace degree”.

In addition to the technical aspects of the course, AERO 101 exposes students to opportunities that exist beyond the coursework. Students are introduced to undergraduate research opportunities, internships and co-ops, and student groups. The following results display the student’s interest in pursuing additional learning experiences (Figure 8).



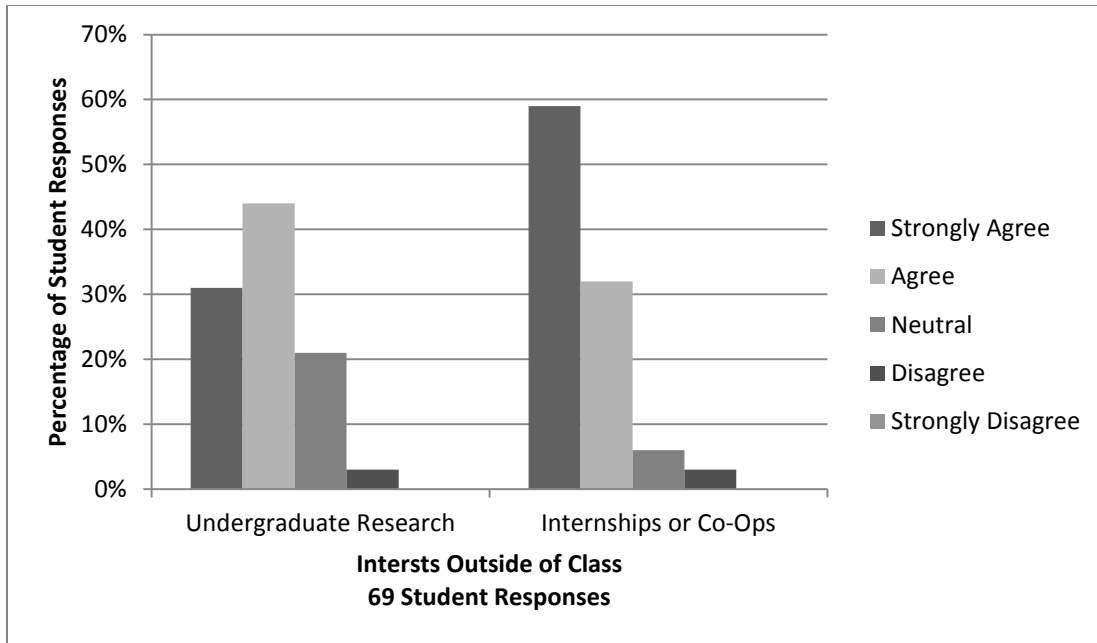


Figure 8. Student responses to “I am interested in participating in [activity]”.

One student in the introductory course commented:

*“The class was outstanding. The greatest thing I took away from the class was a successful opportunity working for Dr. White, after his presentation on Aerodynamics for our Wing Project. I am now working with him, only because I spoke to him following his presentation to our class that was prepared as a part of the AERO 101 program. Thank you guys!”*

This success story implicates two features of the course. The course has the potential to introduce the core disciplines of aerospace engineering and encourage research in undergraduates. The course can also provide an environment for incoming students to approach aerospace faculty.

An additional source of feedback was received from the mentors. Many mentors expressed as much excitement in the projects as the students. Often, the mentors would attend more than the minimum number of classes, make suggestions on improvements, and share the course accomplishments with the Department. Mentors who took the class with the old format expressed benefit would have been received from the experience provided under the new structure.

## Conclusions

The major changes to the course were a transition to a more design-centered learning environment. The projects and course are modeled around developing more capable engineers. The concept of capability presented requires students to experience changing and challenging

environments and to constantly assess and improve the work. The project format and the student responses suggest the course objectives were met. Students exited the course with the ability to implement the design process and with better technical communication, both written and oral. Referring back to Table 1, students exhibit many of the qualities expected of effective design engineers. Furthermore, the course projects promote these qualities and develop them further. The performance of the students leaving the course suggests that the students will be better prepared and more successful throughout the undergraduate and professional career.

The project structure also accommodates variable technical depth. The student is able to research and develop at a personalized speed, level, and style. The course has two supplementary sessions per week that facilitate individual learning. Student questions range from clarifying basic concepts to senior level questions. The project structure is crucial in allowing each student to uniquely expand competence and capability.

To truly capture the effectiveness of the new course structure, tracking of the students throughout the aerospace curriculum will occur. Class performance, professional opportunities, and maturing opinions of the AERO 101 experience will be gathered. As seen in the survey results, competence can be measured and represented graphically. However, the authors will need to develop metrics that more clearly capture the development of capability.

It is important to note that methods employed do not work for all students. It will be important as the course matures to continually address the current class profile and feedback provided. Overall, the changes implemented over the past year were well received by the students. There still exists an opportunity to further improve the freshman engineering design experience.

## Future Work

It is evident from both the student responses and instructor observations that learning objectives for the spacecraft presentation could be met through a different approach. This element of the course will be further developed to include more classroom interaction and more dynamic learning of spacecraft. The future implementation of this segment will be a simple spacecraft mission design in a simulated work environment using simplified and supplied components.

The inclusion of multimedia has great potential for this type of course. Two of the emerging formats for college courses are the “Hybrid” format and the “Inverted Classroom” format. The hybrid format mixes online or secondary instruction beyond the main classroom setting. The additional instruction offers methods of presenting lecture or additional course material outside of the classroom, which in turn enables the professor to utilize a portion of class time in other ways (e.g. working examples). The inverted classroom extends the hybrid concept, so that the traditional lecture takes place outside of the classroom and the class time is strictly used to accomplish educational tasks traditionally performed outside of class (e.g. homework problems, research, etc.) This course, since it is limited by classroom time, could greatly benefit from including online lectures and content. Including other instructional formats enables greater exploration into the engineering design process during class. The content could also be variable, such as requiring some minimal amount of lecture but enabling students with further interest to

go deeper. All improvements are geared towards attaining the ultimate goal of offering students the opportunity to explore engineering through design.

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