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Teaching an Undergraduate Flight Dynamics Class for Three Semesters During PhD Studies to Prepare for an Academic Career

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Teaching Undergraduate Flight Dynamics Class for Three Semesters during PhD Studies to Prepare for an Academic Career

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Abstract. This paper describes the author's learning experience as the instructor of record for a junior-level flight dynamics class for three semesters during his PhD studies at the Department of Aerospace Engineering at Texas A&M University, College Station. This experience is extremely valuable to prepare for a career in academia. The author did not come from an undergraduate background in aerospace, so to prepare for teaching the course he learned the material by taking the flight dynamics class in Spring 2015 and grading for it in Fall 2015. The first two semesters of teaching were part of the Graduate Teaching Fellows program hosted by the College of Engineering. The class size was a small section of nine students in the Spring of 2016 and increased to 66 in the Fall of 2016. In the Fall of 2017 the author taught a section of 32 students as a Graduate Assistant Lecturer of the department. This paper demonstrates how the author implemented the theory of integrated course design in his teaching practice. A list of situational factors related to the course context, student background and instructor background is presented. It is shown how the situational factors led to the choices of the learning outcomes, assessments and teaching strategies. How students responded to these choices and how those responses were used to teach the course better are explained. From student performance and feedback it can be concluded that students were able to demonstrate effective learning of the intended outcomes as each semester progressed. Moreover, student responses indicated that they enjoyed the process of learning through the different activities planned for the course.

I. Introduction

PhD students in an engineering major are in general expected to devote the majority of their time to research. For a few semesters during the PhD program, they may be funded as graduate teaching assistants for an undergraduate course taught by a faculty member. Responsibilities of a graduate teaching assistant typically include grading, holding office hours, leading labs and help sessions, and substitute-lecturing when the faculty member has other engagements. Serving as the instructor of record for an undergraduate course for one or more semesters requires a lot more involvement on part of a PhD student. Not many engineering PhD students get the opportunity to teach a class in the field of their research for an entire semester.

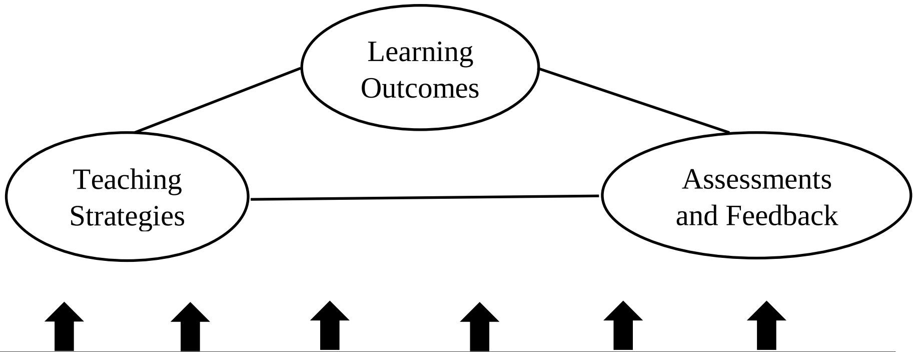
However, it is a very valuable learning experience with some major advantages. For students exploring career options after PhD, it gives them a chance to figure out whether they enjoy teaching and would like to become a professor. For a student already interested in an academic career, it gives them a platform to practice and get better at one of the three pillars of a professor's job: teaching, research and service. Even if a student wants to join the industry or a research lab, or start their own company after PhD, teaching is still a great tool to solidify their background in the field of research and learn how to transfer their technical expertise to people new to the field.

The author will pursue a career in academia upon graduation. His PhD research is closely related to flight dynamics, and he had the opportunity to teach AERO 321 – Dynamics of Aerospace Vehicles – for three semesters at Texas A&M University. Teaching this class gave him an insight into the following: how to structure and deliver the course material such that students learn effectively and within the stipulated time, enjoy the process and can demonstrate their learning. To structure the course, the author made a choice between two general approaches in pedagogy [1]. In the first approach, called the *content-centered* or the *list of topics* approach, the instructor consults one or more textbooks and makes a list of important topics to be covered during the semester. Subsequently the time to be allotted to each topic and the number and types of tests are decided. This approach is simple for the instructor. However, it does not address the big picture of how the course contents fit into the program students are enrolled in, and what students should learn so they are better prepared for the following courses and career paths. Being mindful of this big picture is very important for an instructor in an undergraduate aerospace engineering program. Therefore, for the flight dynamics class the author used the second approach, called the *learning-centered* approach. This approach first decides what students should learn given their background and future goals, and then figures out how the learning can be facilitated. A way to implement the learning-centered approach is the *integrated course design* shown in Figure 1.

The integrated course design begins with identifying the key factors related to the context of the course, nature of the course and characteristics of the students and the instructor. These are called *situational factors* and listed in Figure 1. They are used to make the following three key sets of decisions:

(a) *learning outcomes*: what students should learn in the course
(b) *assessments and feedback*: how the students and the instructor will know if the learning outcomes are accomplished
(c) *teaching strategies*: what activities the instructor and the students need to do so students accomplish the learning outcomes

These decisions are made so they support and reinforce each other, thereby making the overall course design an integrated one. A good way to sequence the decision-making process is to 'begin with the end in mind'. The first decision step in this sequence is to specify the end goals or the learning outcomes. The second decision step is to establish acceptable evidences of student learning or assessments. The third step is to plan the learning activities or teaching strategies. In pedagogy, this sequencing is referred to as the *backward design* [2]. The backward design sequence is illustrated in Figure 2.



Situational Factors

1. General context of the learning situation (expectations placed on this course by the university, college, professions, society, etc.)
2. Specific context of the learning situation (class size, level, type of class – live/online, lecture/lab, classroom facilities, etc.)
3. Nature of the subject (theory/practice/both, convergent/divergent topics, recent changes in the field, etc.)
4. Characteristics of the learners (students' prior knowledge, expectations, preferred learning styles, etc.)
5. Characteristics of the instructor (level of knowledge, teaching strengths, weaknesses, beliefs and values, etc.)

Figure 1: Integrated course design – a learning-centered approach

Step 1: Specify what all students should learn in the course (*learning outcomes*).

Step 2: Determine how students will demonstrate their learning (*assessments*).

Step 3: Devise ways to facilitate student learning (*teaching strategies*).

Figure 2: The backward design sequence

The author structured the course using the integrated design approach, and the three key sets of decisions – learning outcomes, assessments and feedback, and teaching strategies – were made using the backward design sequence. Depending on the course context and the students' background, the learning outcomes for the entire course were divided into chunks of small tasks. Each task was assigned a level of thinking based on the hierarchy specified by the revised Bloom's Taxonomy [3]. Appropriate action verbs were used in the syllabus to identify the levels. Corresponding to each learning outcome, appropriate formative and summative assessments were determined. Keeping in mind the Bloom's level of the learning outcomes and the assessments, appropriate teaching strategies were decided. Teaching strategies selected for each learning outcome were one or more from the five families of teaching strategies found in pedagogy [4]. In addition to the delivery of the course material, the author worked on fostering good interpersonal relationships with the students to facilitate student learning. The author's approach was motivated by the principles of the psychology for teaching [5].

In the literature, an extension of the integrated course design can be found to better the design of a course progressively over semesters. This is essentially a cyclic process, called the *course development cycle* [6], to be repeated every semester a course is offered. In addition to learning outcomes, assessments and teaching strategies in the backward design sequence, the course development cycle comprises of two more decision steps involving reflection and revision as shown in Figure 3. For the flight dynamics class, a thorough review of all the formative and summative assessments, questions asked by students from time to time during a semester and official student feedback at the end of the semester were utilized to better the design of the course for the subsequent semester.

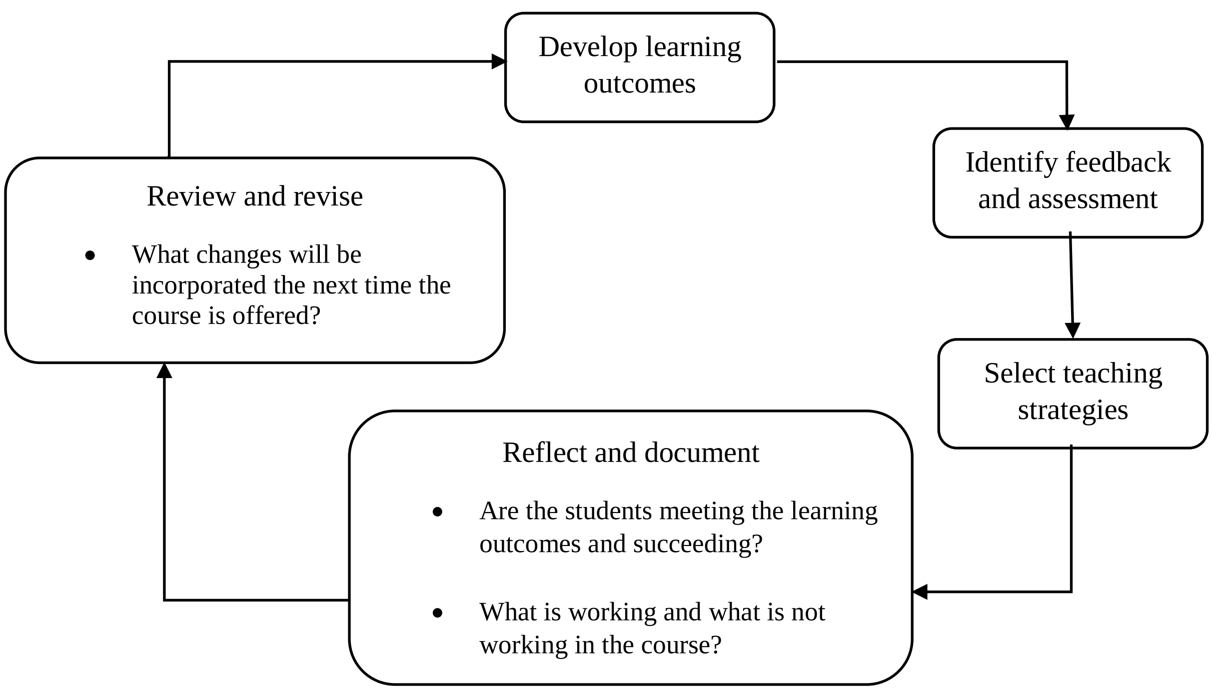


Figure 3: Course development cycle

Dr. John Valasek, the author's PhD advisor and a professor of the Aerospace Engineering department worked as the faculty mentor and guided the author through the entire process of the course development cycle. Prior to joining the academia, Dr. Valasek worked for a few years as a flight control engineer at the Northrop Corporation, now known as the Northrop-Grumman Corporation. In addition, he had taught AERO 321 for two decades and currently serves as the department coordinator for the course. Frequent interactions with Dr. Valasek helped the author set appropriate learning outcomes, assessments, teaching strategies and revise them from semester to semester based on student performance and feedback. The rest of the paper details the situational factors that influenced the decision steps in the course development cycle for the flight dynamics course, how the decision steps were executed, and how students responded to them. Some changes to be made for teaching this course in the future are presented at the end.

II. Situational Factors

The situational factors for this course may be grouped according to the categories shown in Figure 1. They are listed in Table 1 below.

Table 1: Situational factors

Category	Description
1. General context	1.1. This is a required course in the curriculum. 1.2. After this course, students are required to take courses on flight control and aircraft design. The department also offers senior-level technical electives on flight test engineering, cockpit systems and displays and digital flight control. This course is a pre-requisite for all of these required and elective courses. 1.3. Within a year or two of taking this course, one section of students will join the aerospace industry; another section will start graduate school; a third section will join some military organization. All the students will need to have a good physical understanding of flight dynamics as well as a good grasp of the mathematics to describe the physics. 1.4. Aerospace engineers need to develop an appreciation for the historical development of the concepts, methods and tools which are regularly used in practice today. 1.5. Aerospace engineers need to be good at independent learning as well as teamwork. 1.6. Aerospace engineers need to be good at communicating their work professionally and concisely to their colleagues.

2. Specific context	2.1. The class size varies depending on whether there are one or two sections. In Spring 2016 and Fall 2017, there were two sections, so the author taught 9 and 32 students respectively. In contrast, there was only one section in Fall 2016, so the class size was 66. 2.2. Most of the students were second-semester juniors in the undergraduate program. Some students were repeating the course. In Fall 2016, the class had a few exchange students from Swansea University of the United Kingdom. The exchange students were sophomores. 2.3. The instruction is face-to-face. 2.4. This course has both lecture and lab components. 2.5. The lecture rooms have marker-boards and projectors. 2.6. The lab computers have engineering flight simulators installed. 2.7. All the course material can be put up on a server so students can access them any time.
3. Subject nature	3.1. Part of this class involves mathematical derivations using tools from algebra, trigonometry and calculus. 3.2. Part of this class is about how the derived equations make physical sense and how they are relevant for real aircraft. 3.3. The rest is to help students learn using an engineering flight simulator how to fly an airplane and what test pilots look for when they fly airplanes.
4. Learner characteristics	4.1. Prior to taking this course, all the students took prerequisite courses on aerodynamics, rigid body dynamics in three dimensions, matrix algebra and differential equations. The exchange students from UK were not familiar with some of the tools used in this course. 4.2. Historically some students taking this course are good at identifying and describing aircraft, but their math skills need improvement. Some other students are good at math, but lack the exposure to aircraft. 4.3. Before taking this course, students have studied important parts of an aircraft (e.g. wings) but never an entire aircraft as a unit.
5. Instructor characteristics	5.1. The author's undergraduate background was in electrical engineering; he switched to aerospace for his PhD research. To prepare for teaching this course, he took it with his faculty mentor in Spring 2015 and graded for it in Fall 2015. 5.2. In all three semesters of teaching, the author had the chance to consult his faculty mentor whenever needed. In addition, the first two semesters were part of the Graduate Teaching Fellows program hosted by the

	College of Engineering. The author had the scope to interact periodically with his peers and other professors to discuss and improve teaching. 5.3. As part of the Graduate Teaching Fellows program, the author was required to attend a certificate program called Academy for Future Faculty (AFF), intended to train graduate students interested in an academic career on several aspects of college teaching, such as course development cycle, syllabus design, addressing diversity in classroom, etc. The author had a chance to practice what he learnt in AFF.

III. Learning Outcomes

The learning outcomes were created keeping in mind the situational factors 1.1 – 1.4, 3.1 – 3.3 and 4.1 – 4.3 mentioned in Table 1. They were classified from lower to higher levels of thinking according to the revised Bloom's Taxonomy [3]. At the lowest level of this taxonomy is remembering, where students are expected to retrieve details from memory. The immediate higher level is understanding, where students make mental connections among the bits and pieces of a concept. The next level is applying, where students make use of the concepts or tools they know to solve problems or deduce new results. The subsequent level is analyzing, which requires students to draw insights from a set of presented data or a sequence of steps. The second highest level is evaluating where students learn to make judgements or decisions based on the analysis and a knowledge of the acceptable standards. The highest level is creating where students come up with a new concept, model or design using all the learning outcomes in the lower levels. The learning outcomes at each Bloom's level are made specific with suitable action verbs. Some examples of learning outcomes for this class are shown in Table 2.

Table 2: Examples of Learning Outcomes Using Bloom's Taxonomy

Level of thinking (from lower-order to higher-order thinking skills)	**Learning outcome:** Students will be able to …
Remembering	• **identify** an airplane by its manufacturer, designation, name and stability and control characteristics, given a picture of the same • **list** the assumptions made to derive the equations of motion • **recall** the important historical landmarks in aircraft stability and control since the first successful flight in 1903
Understanding	• **explain** the phenomena of inertial, gyroscopic and kinematic couplings observed in aircraft

	• **discuss** the advantages and disadvantages of class-I methods for obtaining aircraft models • **distinguish** between static stability and dynamic stability
Applying	• **derive** the kinematic equations using Direction Cosine Matrices • **compute** the angle-of-attack and elevator deflection at trim • **linearize** the aircraft equations of motion using direct substitution and Taylor series
Analyzing	• **interpret** the signs of the stability derivatives • **infer** which modes are present in a given state-space model
Evaluating	• **rank** aircraft from more prone to less prone to inertial coupling • **estimate** the flying quality levels of the different dynamic modes of an aircraft
Creating	• **generate** a parametric linear mathematical model of an aircraft from a given 3-view and necessary parameters

IV. Assessments and Feedback

In the course development cycle shown in Figure 3, the acceptable evidences of students having accomplished the learning outcomes are established so they are aligned with the learning outcomes themselves. This is how the formative and summative assessments for this course were designed. In addition, situational factors 1.5 – 1.6 in Table 1 regarding expectations from future aerospace engineers and 4.1 – 4.3 regarding students' background were considered while formulating the assessments. This step of the course development cycle also includes how to convey feedback to the students on how they are doing.

IV. I. Formative Assessments

Before the first semester of teaching, the author had a rough idea of the student difficulties from his previous experience of taking the class and grading. However, he needed to develop a more comprehensive idea of which learning outcomes require more time and effort on part of students. In the first semester of teaching, all nine students were given note cards in the beginning of a lecture. They were asked to write down on the cards what they found difficult to understand from the day's lecture. Often one or two concepts were found common to all or most of the note cards, and some time was spent in the beginning of the next lecture to cover the concepts. The note cards from the first semester helped the author modify the pace of lectures in the second and third semesters of teaching so those difficulties could be addressed more carefully.

For the purpose of assessment, homework assignments served primarily as formative assessments. Each assignment counted for only 3% or less towards a student's final grade, and for grading more weightage was placed on participation and effort than accuracy. The first assignment was a review of the essential aerospace and math prerequisites to be used in this course from time to time. This was to make sure that students get an opportunity to get up to speed with the fundamentals the course builds on. This helped the exchange students who were not familiar with some of the prerequisites to learn them with adequate help from the instructor and their peers. After being graded, this assignment was reviewed in detail in class so the major deficiencies of the students in the prerequisites could be addressed. How students performed on each of the subsequent homework assignments gave the author a good indication of which topics needed to be reviewed in class in the ongoing semester, and how to cover the same topic in a more student-friendly way in the next semester. Moreover, the questions asked by students while working on each homework assignment gave the author a good perspective on how to better the learning experience for the students.

In addition to being formative assessments, homework assignments were structured to address the situational factors related to the aerospace engineers' need to learn how to be good at independent learning and teamwork, and communicate their work professionally and concisely with their colleagues. Many of the assignments had both analysis and modeling components. The analysis component often had students figure out on their own the approach to get to the solution based on what were covered in class. The modeling component had students learn on their own after a basic training how to use a computer-based modeling tool to generate a mathematical model of an aircraft. For some assignments towards the end of the course, students were made to work in groups of three so they could learn how to share the tasks and learn from each other while working as a team. Students were required to submit neat and detailed work and box their final answers or conclusions for their solutions to be graded. This was done specifically so students learn how to present their work to their professional colleagues.

IV. II. Summative Assessments

Quizzes and the final exam were the primary summative assessments for this class. In order to ensure continuous assessment of student learning, there was one 15-minute quiz every two weeks. Each quiz counted for 8% of the final student grade. To address both the physical and mathematical aspects of flight dynamics specified in the learning outcomes, each quiz had a few questions that tested the concepts, and one or two short numerical problems or derivations. Sometimes the questions were designed in a way that tested whether students could correlate multiple learning outcomes. Each quiz tested only the material covered after the previous one, plus one or two topics that most students needed to review. This was done to minimize the burden on the students taking up to 18 credit hours in a semester and at the same time keep them up-to-date with all the material. The final was a multiple-choice exam covering all the material since the last quiz and the bare essentials of the remainder of the course. The final exam counted for 20% of the student grades. It was designed to test the students on the lessons they were supposed to remember in the long term after taking this class. All the quizzes and the final exam were reviewed by the faculty mentor for their length and correlation with the learning outcomes before they could be administered to the class.

IV. III. Feedback

Appropriate steps were taken to communicate to-the-point and timely feedback to the students on their learning. For both written and oral feedback, emphasis was given on effort instead of ability to enhance student motivation [5]. Homework assignments and quizzes were returned on time, and the errors were reviewed in a way that enabled students to learn from their mistakes. Students were encouraged to visit the instructor during office hours to discuss homework and quiz questions. Instead of solving the problems himself, the author asked the students to share their approach and steps, and guided them with little hints so they could figure out the answers on their own. This was done on purpose to encourage critical thinking and make students more confident on their technical skills. In addition, the author's own background helped him be more sensitive to student difficulties and address the questions and concerns of students effectively instead of dismissing them as simple or trivial.

V. Teaching Strategies

The integrated course design depicted in Figure 1 suggests to choose methods of instruction in sync with learning outcomes and assessments. For this course, the strategies were chosen from a family of five: direct instruction, indirect instruction, experiential or hands-on learning, interactive instruction and independent study [6]. For many of the learning outcomes it was often needed to adopt a combination of multiple teaching strategies belonging to different families. Examples of how learning outcomes, assessments and teaching strategies were kept in sync are illustrated in Table 3.

Table 3: Examples of Learning Outcomes, Assessments and Teaching Strategies

Example Number	Description
1	• **<u>Learning outcome:</u>** Students will be able to **recall** the important historical landmarks in aircraft stability and control since Wright brothers' first successful flight in 1903. • **<u>Level of Thinking:</u>** Remembering • **<u>Assessment:</u>** Multiple choice questions in the final exam • **<u>Teaching Strategy:</u> Independent study** • **<u>Activities:</u>** Students were asked to read a paper and watch a movie both of which have some major historical developments of the concepts taught in this class. Students were encouraged to go through these at the same time the concepts are covered in the lectures. A suggested list of important items from the paper and the movie were provided so they could make notes.

2	• **<u>Learning outcome:</u>** Students will be able to **discuss** the advantages and disadvantages of class-I methods for obtaining aircraft models • **<u>Level of Thinking:</u>** Understanding • **<u>Assessment:</u>** Short answer type questions in the quiz • **<u>Teaching Strategy:</u> Hands-on learning** • **<u>Activities:</u>** As the modeling part of homework assignments, students were trained to use a computer software that builds an aircraft model using a class-I method. They worked on building the aircraft model over several weeks.
3	• **<u>Learning outcome:</u>** Students will be able to **linearize** the aircraft equations of motion using direct substitution and Taylor series • **<u>Level of Thinking:</u>** Applying • **<u>Assessment:</u>** Numerical problems in the quiz • **<u>Teaching Strategy:</u> Direct and indirect instruction + independent Study** • **<u>Activities:</u>** Students were shown in a lecture how to distinguish between linear and nonlinear differential equations, and how to linearize nonlinear equations using the two methods. They were assigned homework problems to practice the methods on a few simple examples and eventually the long and complex flight equations.
4	• **<u>Learning outcome:</u>** Students will be able to **infer** which modes are present in a given state-space model • **<u>Level of Thinking:</u>** Analyzing • **<u>Assessment:</u>** Multiple-choice questions using numbers in the final • **<u>Teaching Strategy:</u> Direct instruction and experiential learning** • **<u>Activities:</u>** Students were lectured on the characteristic features of first-order and second-order modes and how to recognize them in a mathematical model. They were taken to the engineering flight simulator and trained to fly airplanes. Subsequently they were given brief instructions on how to use the different controls to excite the different dynamic modes of an aircraft so they could develop a feel for the modes.
5	• **<u>Learning outcome:</u>** Students will be able to **generate** a parametric linear mathematical model of an aircraft from a given 3-view and parameters • **<u>Level of Thinking:</u>** Creating • **<u>Assessment:</u>** A series of homework assignments with different parts of the model and finally putting it all together • **<u>Teaching Strategy:</u> Direct instruction, hands-on learning and interactive Instruction**

	• **Activities:** Students were lectured on modeling of the aerodynamics of an aircraft in terms of stability and control derivatives. A guest lecture was on aircraft math models was delivered by an engineer working in the industry. Students were trained on a computer software to be used for modeling a real aircraft and given team assignments to build the model part by part so they can collaborate with and learn from their peers. They were also taken out to two hangars so they could inspect real airplanes up close and closely and interact with people flying and/or doing research using those airplanes. This gave them an insight of how the model they would develop are useful.

Besides showing how the teaching strategies were chosen to fit the learning outcomes and assessments, Table 3 also gives a glimpse of the different activities for this class to enhance student motivation and facilitate learning. In addition to the traditional lectures, homework assignments and quizzes, this class had students learn a new modeling software and how to fly an airplane on a flight simulator like a test pilot. The class activities also included visits to hangars to inspect real airplanes up close and guest lectures from experts in the field. In addition to the technical material, students also had the chance to learn the history of aircraft stability and control. When a specific feature of aircraft flight was covered in class, pictures or videos of real airplanes were shown, and it was explained how the specific feature was implemented on those airplanes. Sometimes anecdotes such as accidents due to engineers not being aware of a specific concept a few decades ago were shared. All these activities together helped students develop an appreciation for this field and motivated them to pursue it further. In addition, the author scheduled the office hours according to the availability of the students. The author also scheduled all-day office hours for one or two days before the final exam. As a consequence, he was able to assist a significant majority of students one-on-one or in small groups with difficulties outside of class time, and help them make connections between the different building blocks of the course.

VI. Student Responses and Revisions to Teaching

Students had the opportunity to enter their feedback on the course and the instructor anonymously on the Personalized Instructor/Course Appraisal (PICA) system of Texas A&M University. Student feedback for all three semesters suggested that the majority of the students enjoyed the learning experience they had in this course. Most of them appreciated how the course was structured and how the activities were organized. They enjoyed the real-world relevance of this course, which was included as an important situational factor in the course design. It was seen from their performance in homework assignments and quizzes that the class got better with the technical concepts as the semester progressed. The chance to have an in-class review of every assessment while handing it back and the inclusion of the topics of difficulty in the next assessment significantly improved students' understanding of the subtleties. The experience to fly an airplane in an engineering flight simulator and look for specific performance measures enhanced their understanding of the theory. Students also appreciated the chance to learn directly from experts in this field through guest lectures and be able to inspect, touch and sit in real airplanes during the events organized specifically for this course.

Based on the class size, interactions with faculty mentor and student feedback, the author made a few changes in teaching from one semester to another. Since the class size went up from 9 in the first semester to 66 in the second, it became difficult to know everyone in the class in person. The author scheduled one-on-one office-hour meetings so every student could meet the instructor in person once in the semester. This proved to be of great help to make the learning experience better. The author could learn more about the students' backgrounds, interests and learning styles and make the activities more student-friendly. On the other hand, it made the students feel more motivated towards learning the material and less hesitant to ask the instructor for help when needed. This was continued during the third time of teaching. During the first two semesters of teaching, the author rushed many lectures in the last 5-10 minutes and went a few minutes over. The third time he shortened the review of previous lectures in the beginning to avoid the rush at the end. For the first two semesters, students wanted more time and help in the last module of the course, which they were unfamiliar with. The third semester the author planned the lectures so he could go slower over the last module and solve more example problems in class. To make the grading faster, the quizzes were in part multiple-choice questions for the first two semesters. In order to help students explain their reasoning clearly, the author switched from multiple-choice to short-answer type questions. Moreover, the note card questions from the first semester were used to generate homework assignments in the following semesters so students could learn the conceptual subtleties more effectively. Implementing all these changes made the author better at teaching and in the long run better prepared for an academic career.

VII. Changes to Make in the Future

Based on the experience of three semesters, the author would like to make the following changes while teaching this course in the future.

1. Students will be assigned pre-class activities so they can be more involved during lectures. The pre-class activities for each lecture will include reading an article or watching a short video related to what will be covered in class, and responding online to a few questions related to the article or the video. In addition to enhancing student motivation, this will also serve as a formative assessment. Going over the student responses will enable the instructor to better decide the starting point for the lecture.

2. The visits to the hangars to inspect real airplanes up close are optional at present, but it is very important that all the students use this opportunity to correlate theory with practice. In the future, these events will be made mandatory. At present, pilots who fly these airplanes guide

students during the visits. The instructor will work with pilots to come up with questions that students can answer only from a personal experience during the visits. Each student will be given the list of questions before the start of a visit, and asked to write their answers before they leave. The responses will count towards the final grade. In addition to increasing student participation, this will ensure that students know beforehand what they are going to learn specifically during these events.

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