AC 2007-93: THE INSTRUCTIONAL DESIGN AND REDESIGN OF AN UNDERGRADUATE-LEVEL, SIMULATOR-BASED COURSE ON 'FLIGHT TEST TECHNIQUES'

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The instructional design and redesign of an undergraduate-level, simulator-based course on "Flight Test Techniques"

Abstract

A summary is presented of the initial development and curricular impact of the course "Flight Test Techniques" first offered at Virginia Tech in the Spring of 2006. Employing Virginia Tech's motion based flight simulator, which is a highly modified A-6E Intruder Operational Flight Trainer (OFT), students enjoy a semester-long flight testing experience that gives the realism of flight testing, without the costs, risks, and delays of using actual aircraft. Lessons learned from the first course offering and the redevelopment of the course for a second offering in the Spring of 2007 is presented. The course is taught in a combined classroom/laboratory format. This serves to assimilate material from the entire aerospace curriculum with particular emphasis on real-world application of aerospace dynamics and control principles.

Introduction

In the Spring of 2006, Virginia Tech's Department of Aerospace and Ocean Engineering offered for the first time a course titled 'Flight Test Techniques, AOE 4984'. The course was designed to expose senior level undergraduates to industry and government accepted methods used in aircraft flight testing. Offering this course allowed real world problems to be introduced into the department's curriculum in a controlled environment. Building on the concept that hands-on application of concepts learned in an academic setting is key to deep understanding, this course serves as a capstone where concepts previously taught in several classes are integrated to give students an overarching view of aircraft operation, putting the theory students are taught in previous courses into practice. In order to facilitate a learning environment and mitigate safety issues associated with using real aircraft, two modern high performance aircraft models in the Virginia Tech Flight Simulation Laboratory are used instead of test aircraft. This allows for accomplishment of targeted learning objectives, while alleviating operational costs, weather concerns, and liability and safety concerns. It also gives students the ability and opportunity to serve in all of the various roles required to flight test an aircraft, from test pilot, to test conductor, to discipline engineer.

The goals of the course are threefold:

- Reinforce concepts taught in aircraft performance and stability and control classes
- Expose students to flight testing by reproducing the flight test environment in a classroom setting,
- Teach students flight test techniques based on currently used manuals in government evaluation of aircraft to prepare them for careers on flight test teams.

The team teaching and supporting this course has unique credentials to enable this effort branching the fields of flight test engineering, test piloting, and engineering education.

The primary text used in this course consisted of two manuals used at the U.S. Naval Test Pilot School; Fixed Wing Stability and Control[1] and Fixed Wing Performance[2]. Supplemental texts included the student's previous classes texts and notes, as well as Harper and Cooper's Handling Qualities and Pilot Evaluation[3] and *Aircraft Control and Simulation* by Stevens and Lewis.[4]

Facilities Description

Simulator

The simulator used for this course was delivered to the Aerospace and Ocean Engineering Department on March 5th of 1996 from NAS Oceana in Virginia Beach. Originally an A-6E Intruder Operational Flight Trainer (OFT), the simulator was declared "in excess" when the Navy retired its A-6E's and replaced them with F/A-18's. The transfer was made possible with the help and support of research sponsors at Naval Air Systems Command Headquarters and at the Manned Flight Simulator branch of the Naval Air Warfare Center, Patuxent River, Maryland. A diagram of the simulation system can be found in Figure 1. The left (pilot's) seat of the trainer cockpit represents the cockpit of a A-6E Intruder. The right seat has been modified to accommodate either an instructor or a flight test engineer with a computer driven CRT that can be custom configured with instrumentation as desired. The simulation computer has been converted to a SGI Origin 2000 computer. This allows the simulation of many different aircraft models, from a Cessna 152 to a Boeing 737, to an F-18. The A-6E Intruder aircraft flight controls, instruments, and systems, as well as its visual, aural, environmental, and motion sensations are combined with the desired aircraft software model to create a realistic flight experience. The three window visual display shows the surrounding terrain throughout take-off, maneuvers, and landing approach as a function of the aircraft attitude, altitude, and speed. Motion cues are provided by a 3 degree of freedom cantilevered motion system. The simulator was originally procured by the Navy to provide pilot and aircrew training in carrier based takeoffs and landings. While heavily upgraded, it retains its original capability.[5]

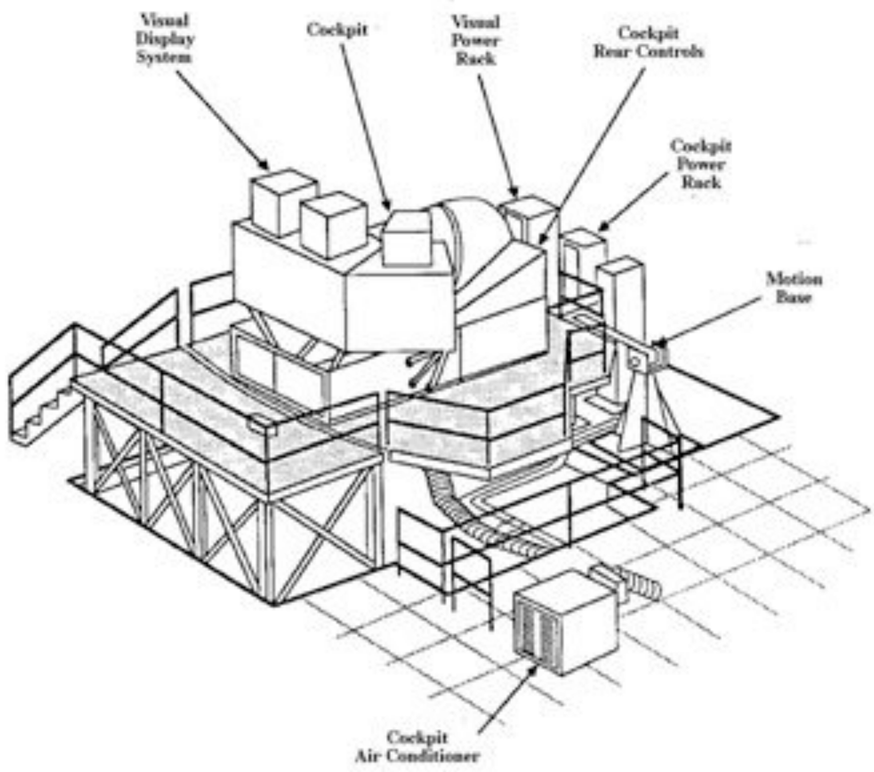
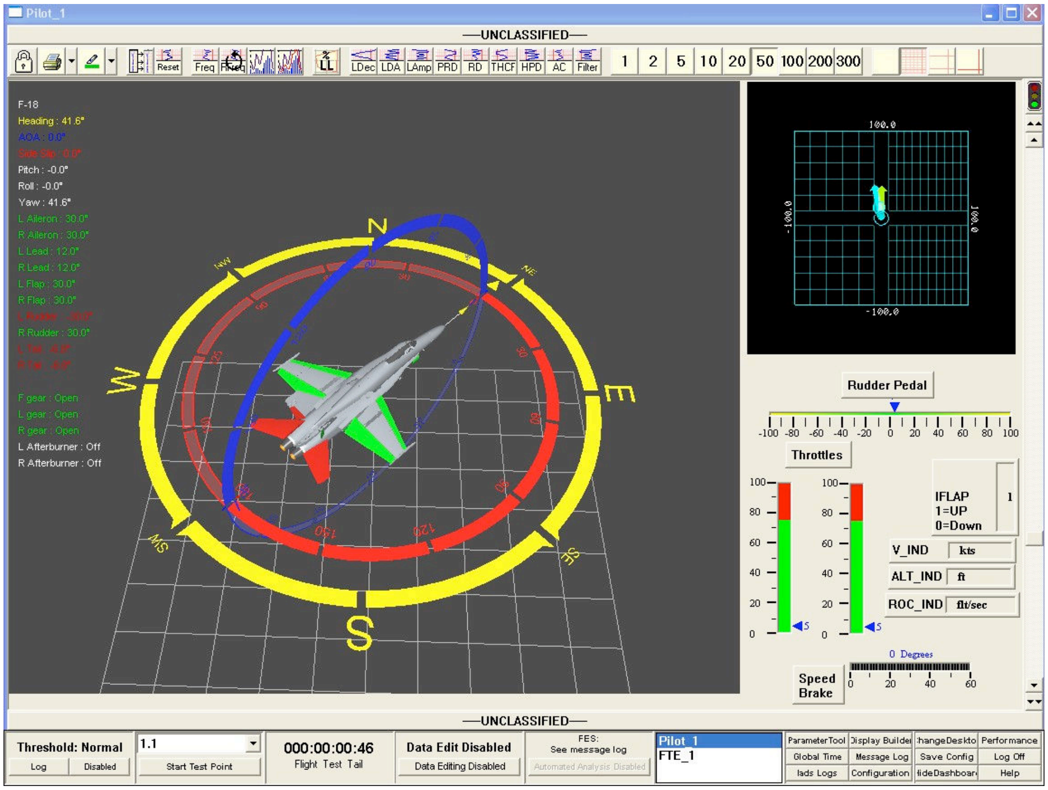


Figure 1 Diagram of Simulation System at Virginia Tech

IADS

Symvionics Inc. of Arcadia, CA has donated its flight test instrumentation software package called IADS® to Virginia Tech for use in the Flight Test Techniques course. IADS® is a real-time data viewing tool that allows its user to view parameters from the aircraft simulation while the test is occurring. IADS is an industry standard tool that is used in Flight Test by NASA, the US Air Force, and US Navy for flight testing. IADS® also archives the data it displays for analysis purposes after the test. IADS® allows the user to customize the data displayed on the computer screen. The user can create data screens that are customized to each test's requirements. IADS® has served as an important teaching tool allowing the students to visualize data during the flight test and recognize the impact of changing a given parameter on the aircraft during a test. An example of IADS® displays used in this course can be found in Figure 2.



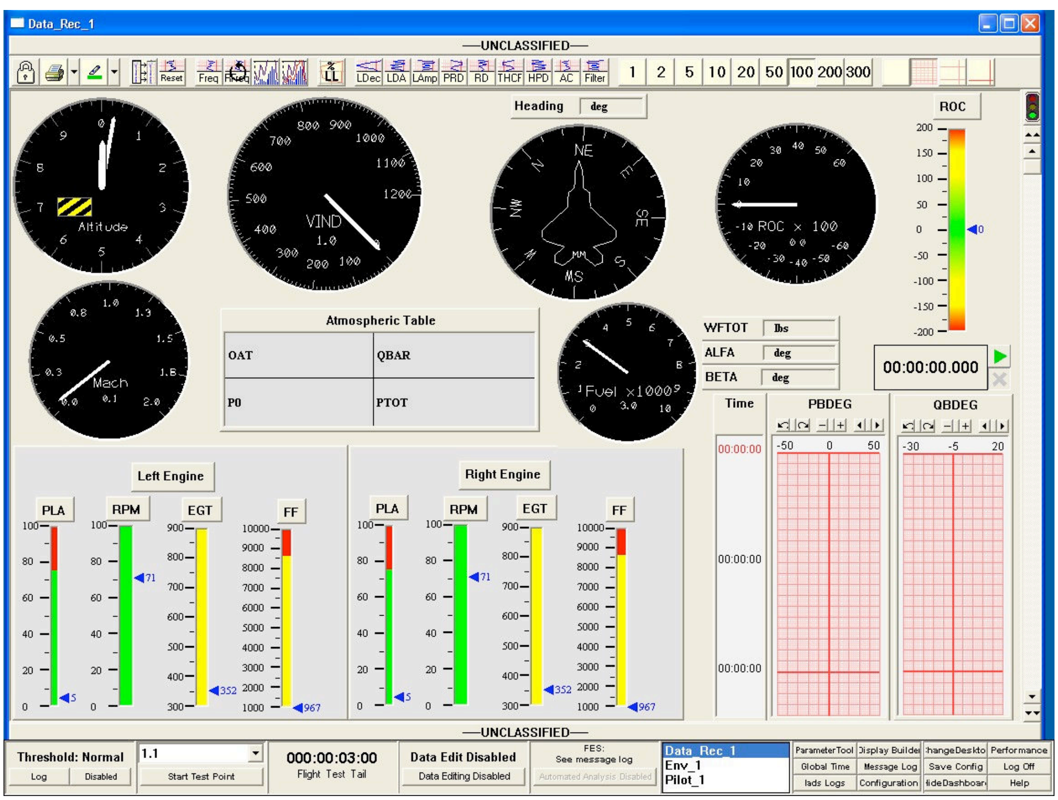


Figure 2 Examples of IADS Displays

Course Overview

In the spring of 2006, the Flight Test Techniques class met twice weekly for 75 minute sessions. This time was split into a two week rotation, where the first week was spent in classroom instruction and the second week was spent in simulation testing. Two optional laboratory times of one hour and fifteen minutes each were established for each test team to work with the simulator as they desired. The twenty student class was divided into four test teams of five students each. The students grades were based solely on flight test reports that were due one week after a test was performed. With the exception of the first report, used to gauge each individual student's report writing capabilities, each report was submitted as a group effort thus requiring the students to work together as a flight test team. Students were given a basic reporting format to follow, and were required to provide percentage of work by each team member on the report.

Each section of the course begins with a specific, complex, real-world problem to solve. The in-class portions serve to supplement the student's knowledge by addressing procedures and overarching principles required for the flight test.[6] At the start of each laboratory, students are presented with a list of objectives and requirements, which must be fulfilled; such as quantifying aircraft climb performance. They must then use knowledge from prior classes to determine the data required for the flight test.

Lectures are presented to address student questions and to assist with the general formulation of the presented problem. Specifically, the classroom portion of this course was used to revisit students' prior coursework on aircraft performance, equations of motion, basic stability and trim analysis, and energy management. Additionally, flight testing procedures were introduced. After discussing the theory behind the test, a preflight briefing for each test was done in class. This preflight briefing included the test cards to be used, reporting objectives, safety requirements, and any special procedures required for the test. The exception to this pattern is Laboratory 5, where students must develop their own test cards and present them to a flight safety board (FSB) in a briefing.

Students then proceed to the simulator to conduct the flight test, and reduce the data for their team-generated topical report. The time the students spent in the Flight Simulation Laboratory was split into two defined periods, an unstructured practice period, and a structured, compulsory test period. While roll was not taken during either period, each test was designed to require a full test team. In order for the data to be taken for a given test report a full team was required, and students learned quickly to work together to ensure all were present during testing.

Specific responsibilities were assigned to different stations during the flight test. The flight test tasks were broken down to the following positions: Test Pilot, Flight Test Engineer (FTE), Test Conductor, Simulation Console Operator, and Discipline Engineers. A graphical representation of the organization of each position can be seen in Figure 3. While not required to do so, students were encourage to rotate positions so that they could experience all aspects of flight testing during the semester. For further detail on the specific conduct of this course see Cotting, et al[7].

The Flight Test Techniques course centered around performing and analyzing six mock flight tests with the simulator. These six tests were broken into 3 categories, overall familiarization with the facility, performance flight testing, and flying qualities flight testing. The six labs were:

- Lab 1: Facility Familiarization and Basic Operations Principles
- Lab 2: Level Performance
- Lab 3: Excess Power Determination
- Lab 4: The Use of Sawtooth Climbs
- Lab 5: Climb Performance
- Lab 6: Longitudinal Flying Qualities

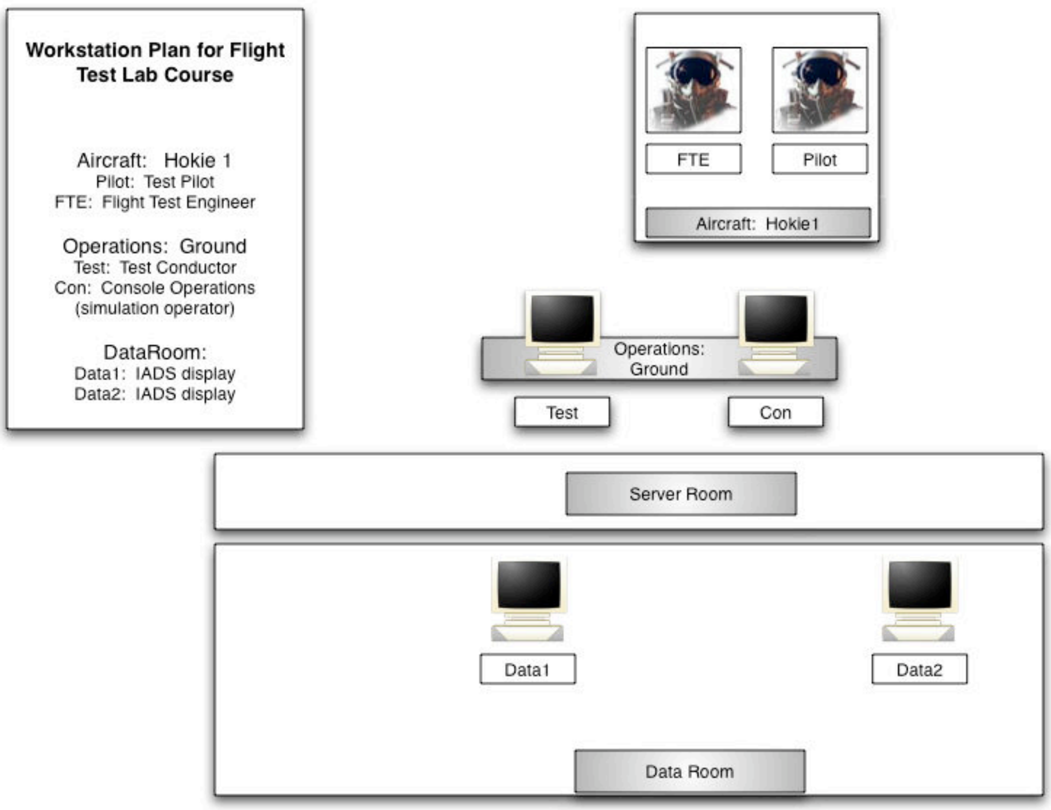


Figure 3 Test Team Positions

Lessons Learned

Based on student feedback and instructor review of the material covered during the semester a list of lessons learned was established. This list will be used as a guide to modify the course for the next course offering with the hope of improving the overall educational experience, and is shared herein to help guide others who may wish to replicate this type of program. The lessons learned will be presented in two categories, overall lessons, and lessons from specific lab tests.

Overall Lessons Learned

The overall lessons learned can be found below:

- Student motivation is fueled by the appearance of realism. It is imperative in creating realism to use freely available government documents as the basis for the curriculum instead of a textbook, since government documents will be the basis for reference in industry flight test.
- When reviewing concepts introduced in previous courses, making references to the texts used in those courses creates a link to those courses to aid in the student's recall of those concepts.
- Ensure the class stays on the two week rotation between theory and testing. If the schedule slips, student interest begins to wane on a given topic.
- Do not underestimate the talents of the students. Today's students as part of the "millennial generation"[8] have been exposed to a wide range of media that was unavailable to prior generations of students. Their experience in playing video games is directly applicable to flying an aircraft. Student test pilots for this course should be trained early, and should be fully capable by mid-way through the semester.
- Create a dedicated laboratory time for the course. A full hour is needed for each mock flight test, and compressing the time to fit within normal classroom times only reduces the overall experience. Briefings had to be shortened, and roles of players in the test had to be minimized in order to keep on schedule.
- Because of shortened test times, the role of test conductor was minimized. The role of test conductor is significant in real world test. This position should not be overlooked as student test conductors will require coaching and time in the learning process to become proficient.
- The role of FTE was minimized in the debriefings of the test to save time. The FTE's input is valuable and should be encouraged. The FTE is the technical "eyes and ears" present in the aircraft during the test, and should be able to make engineering comments based on observations made during the test.
- Students were confused by some of the testing requirements. A review of test requirements is required to ensure the necessary specificity of the requirements.
- Requiring students to plan their own flight tests, and then conduct them exposes the students to a part of flight test engineering that normally is not addressed in a classroom setting. Further, by requiring students to plan a test, the criteria that define a given test such as risk level are given meaning.
- Giving students a list of requirements to fulfill for a test instead of specifying exact calculations fulfills two objectives. First it exposes students to the real-life processes that would be required of a flight test organization. Second, it gives a moderately defined assignment that requires students to use creativity to fulfill their assignments.

Lessons Learned from Specific Lab Tests

Lessons learned from each mock flight test lab can be found below:

Lab1:
During the first lab it is important for the students to have a firm understanding of how the atmosphere impacts aircraft performance, and the measurement of aircraft performance. Students need to be able to demonstrate the difference between calibrated airspeed, equivalent airspeed, and indicated airspeed. Further students should be able to use provided data analysis tools on their own computers so that later data reduction will happen smoothly. An assignment should be made for students to create a utility to convert equivalent airspeed into true airspeed, and in reverse, and also be able to calculate Mach number from equivalent airspeed and altitude inputs. Students may not remember the details of the atmosphere impacts from their previous coursework, but it is imperative for them to have a firm grasp on this concept in order to begin to attempt further work in this course.

Lab 2:
The range and endurance flight test is a good opportunity to introduce atmospheric effects on testing. Upgrades to the simulation software to include atmospheric dispersions are needed to demonstrate the effects of variances in the atmosphere on test results. The simulation does not currently have a pitot-static model. The simulation atmospheric model would also need to be upgraded to support this test. By introducing atmospheric dispersions in this test the concepts reviewed in Lab 1 are solidified for the rest of the course.

Lab 3:
The mock flight test was performed at full afterburner to show the effects of supersonic flight upon specific power. This made the flight test more difficult at lower altitudes, and made correlation with future labs very difficult. The test will be conducted at a lower power setting accommodate the low altitude tests. The precision flying required for this test will prepare the student pilots for future labs.

Lab 4:
The sawtooth climb is a very important technique in performance flight testing, but using it in test requires considerable time, and the results are similar to the level acceleration tests done in Lab 3. Considerable lab time was spent on this test, but the value of the test did not equal the time spent in the lab at the end of the test. The results from this lab should reproduce selected points from Lab 4, and serve to reinforce the concepts from Lab 3.

Lab 5:
The flight safety board needs to be given more time in order to be effective. Only one class meeting was allotted to the flight safety board for all four groups. It was difficult getting all four groups through the board in one class meeting. The requirements for the test need to be more precisely stated. Students confused minimum time to climb and minimum fuel to climb. The students did not choose hazards well, and need to delineate between safety of flight and safety of test. The student's hazards should focus on safety of test issues. This lab serves to tie together the concepts from the first four labs. By completing this test students demonstrate proficiency in

the concepts covered to this point in the course. Relevance to Labs 3 and 4 is given by having the students demonstrate an aircraft capability based on concepts studied in Labs 3 and 4.

Lab 6:
This longitudinal flying qualities testing in the laboratory took longer than expected. Each flight test took a full hour to complete. Students had a hard time judging the criteria from a test pilot's perspective. Students took the task as a personal challenge as opposed to evaluating the task's feasibility for an average pilot. The task was a fine tracking task that did not always expose the deficiencies in aircraft. A gross tracking task followed by a fine tracking task would make a better evaluation.

Lab 7:
This test was a lateral-directional flying qualities task, and was not formally performed due to time constraints. It was demonstrated to the class on the last class day of the course. More time is required for students to fully benefit from the test.

Revision of Course

In order to apply the lessons learned to the next course offering, several changes will be made to improve the course. These changes will be presented as overall changes and changes to specific labs.

Overall Changes

The largest impact to the course will be the changing of the laboratory time for the course. This will be done to ensure that ample time will be allowed for each mock flight test. In the first course offering, three credit hours of class time were scheduled as two 1:15 classes per week. This time was used interchangeably with compulsory laboratory time. The students were broken into four groups of five students each, and each group was also given two hours per week of option "practice" lab time. This schedule was created to give the instructors the maximum amount of flexibility in the first course offering. However, this schedule created a compromise in compulsory lab time, offering each group only 38 minutes of compulsory lab time every two weeks for formal testing, and no course instruction time during this period. In order to keep the lab and lecture rotation of a new topic every two weeks, compulsory lab time had to be sacrificed, or students had to agree to do their flight tests during their optional practice sessions. While students were accommodating for this course offering, it is not wise to count on this for future course offerings. To remedy this time conflict, a revision of the class and lab time will be made to have one 1:15 class per week, and then a compulsory lab time of 1:15 per week for each group. This compulsory lab time will now be scheduled at four different times, one for each group, so that each group will get a full, dedicated 1:15 of lab time for testing. The students will then be given a second hour of "practice" lab time for each group that will not be compulsory. It is anticipated that this unconventional split of course and lab time will allow for more material to be covered in the semester, and adequate time for each student in the laboratory as well as the classroom.

Additionally, by having more dedicated compulsory time, it is hoped that more emphasis can be placed on the FTE and test conductor positions, to ensure a well-rounded test experience. This rotation should also allow for two more flight tests to be introduced to the curriculum.

A review of the test objectives and requirements will be made for each flight test, and revisions will be made to ensure that the requirements for each test result will be clearly communicated to the students. With added laboratory time more emphasis will be placed on pre and post flight test briefings, adding more emphasis on test requirements directly before and after each test.

Revisions to Specific Tests

Lab 1:
For the first flight test lab, a stronger emphasis will be made on atmospheric effects on basic aircraft performance. Principles relating to basic atmospheric parameters and how they vary with altitude will be reviewed with the class. Students will be required to submit source code from basic tools that they will generate for use throughout the semester. These tools will include functions to access the course supplied atmosphere model, conversion from equivalent airspeed to calibrated airspeed and vice versa, and the calculation of Mach number from input of equivalent airspeed and altitude.

Lab 2:
For the second flight test lab, the simulation will be modified to include a pitot-static model and an upgraded atmospheric model. This will be used in test so that students can experience the effects of nonstandard day testing on their results. The flight test requirements for the lab will be changed to require students to take data on a standard day and a nonstandard day and then compare their results to asses the impact of a changing atmosphere on their data.

Lab 3:
The third flight test lab will be split into two parts. The first part will have a demonstration of transonic effects on excess power. The test will then focus on one engine out testing for excess power using level acceleration as the test method.

Lab 4 (Demo):
The fourth flight test lab will be replaced with a one-week demonstration of sawtooth climbs. This method is a valuable test method, and should be covered, but not with the time consuming detail as experienced with the first course. Data points from the third lab will be used to show that they can be reproduced using this method.

Lab 5:
For the fifth flight test lab where students design their own test, the flight safety board (FSB) will be modified to take one hour per test team during one of their compulsory lab times. Emphasis will be placed on detailed review of their test plan, in a closed setting. The concept of safety of flight versus safety of test will be emphasized, and aid will be given to students in their hazard determination process.

Lab 6:
Lab 6 will be a new flight test to the course. The students will plan and conduct an operational flight test with the climb schedules they created for the fifth lab, and data that they gathered from the second lab on level flight performance. This test will consist of an aborted approach to an aircraft carrier due to a bingo fuel (low fuel) condition. The aircraft will then use a minimal fuel climb schedule to climb to an altitude for a landing at a predetermined alternate landing site on land. This test will also be planned and conducted by the students with guidance from the instructors. Students will also be required to build their own IADS® displays for this test.

Lab 7:
The next flight test lab will be the student's first flying qualities test. Tasks involving gross longitudinal tracking will be assessed for use in this test. An example may be starting well below the target aircraft and then tracking the target aircraft at its altitude. The students did not deviate from the aircraft trim position in the currently used task enough to encounter the handling qualities difficulties that were planned for the test. A review of the STEMS (Standard Evaluation Maneuver Set)[9] will be done to find any further test techniques that may be feasible for the simulator.

Lab 8:
The lateral directional flying qualities test will be offered as a full test in this course offering, and not just a demonstration. The test will involve doing a last minute correction to an offset runway during a landing task. Different flight control models will be used, similar to the longitudinal flying qualities test to demonstrate good and bad aircraft flying qualities.

Pedagogical Impact

The need for 'rigorous research in engineering education' is clearly identified in references such as Streveler *et al*[10]. The course outlined in this paper presents an excellent opportunity to both qualitatively and quantitatively study the effectiveness of problem-based inductive learning on aerospace engineering curricula. As stated by Felder[11], inductive learning promotes deeper learning and retention of information than deductive learning. By its very nature, this course fosters an inductive approach. Each section of the course begins with a specific, complicated, real-world problem to solve. The in-class portions serve to supplement the student's knowledge by addressing procedures and overarching principles required for the flight test [6]. At the start of each laboratory, students are presented with a final task which must be accomplished, such as quantifying aircraft climb performance. They must then use knowledge from prior classes to determine the data required for the flight test. Lectures are presented to address student questions and to assist with the general formulation of the presented problem. Students then proceed to the simulator to conduct the flight test, and reduce the data for their team-generated topical report. As reported in Prince and Felder[6], studies have found numerous positive effects associated with problem-based learning including "understanding the interconnections among concepts", "deep conceptual understanding", "self-directed learning", and "the adoption of a deep (meaning-oriented) approach to learning, as opposed to a superficial (memorization-based) approach." It is these benefits that the course seeks to capitalize upon in serving as a culminating senior undergraduate experience.

A unique aspect of the Flight Test Techniques course is that it accommodates a variety of learning styles. According to Fleming and Mills[12] students address the learning of information in one of four ways; Visual, Aural, Read/Write, and Kinesthetic. The Flight Test Techniques course presents its topics to the students in all four ways, maximizing the chance that a student has to learn the material presented. Each topic is presented in a classroom lecture and pre-flight briefing where the theory and technical background for the test is presented, representing the aural learning style. Students are given text and reference information regarding the topic, aiding in their preparation for the flight test, and addressing the read/write learning style. During the test data from the test is presented in a visual format that the students must watch, and judge as to its quality, allowing the exercising of the visual learning style. The test also allows the students to see first hand how their actions to the aircraft impact the results of the test, giving them an experiential learning environment, accommodating a kinesthetic learning style. Finally, a report is written at the end of the test allowing the students to demonstrate their understanding of the material presented, further reinforcing the read/write learning style.

To appeal to and retain students from diverse backgrounds, this course aims to serve all psychological and learning types. Typical engineering curricula teach toward intuitive students with the majority of faculty falling into the Myers-Briggs category of intuitors[13]. However, most engineering students are sensors[14]. Thus Wankat and Oreovicz[14] suggest designing courses to appeal to sensors and serial learners with global summaries presented at the end of each class thus serving both learning styles. By designing the course to serve both learning types, requiring both recall of prior information and open hypothesis, stressing both how to evaluate data and the possibilities that arise from the data, and requiring team-work in the completion of flight tests and reports, diversity in the attraction of students with varied learning approaches and backgrounds is fostered.

Future Work

After the flight test course has been revised and taught for the second offering, a new set of lessons learned will be created. From these lessons learned, the course will again be modified to increase the learning experience offered to the students. Collaboration with other universities has been discussed as a possible future goal of the course. This collaboration would involve the Virginia Tech Distance Learning Program in teaching the course work remotely and then having students participate in the flight test via remote Internet link. Students would also be given the opportunity work in the simulation lab during a special summer session to experience flying the simulator. In aiding this distance learning, a visual system upgrade to the simulation is needed in order to transmit the aircraft visuals to remote location. A visual system upgrade would also allow for both a nighttime and day time testing environment as well as for a fully programmable Heads Up Display (HUD). When appropriate funds are available to support the upgrade, the course will then be modified to include the benefits of daytime testing and a heads up display as part of test instrumentation.

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