DWC FLIGHT TEST EDUCATION AT UNDERGRADUATE LEVEL IN REALIZATION OF CDIO INITIATIVES

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ABSTRACT

Most undergraduate aeronautical engineering programs do not contain a significant amount of flight test engineering experience. In line with the CDIO philosophy of engineering education, Daniel Webster College has incorporated flight test education into its Flight Dynamics I (Aircraft Performance) and Flight Dynamics II (Aircraft Stability and Control) courses. Three flight tests plans are designed and executed by students in Flight Dynamics I to investigate and analyze three aircraft performance topics such as pitot-static calibration, saw tooth climb, and turn performance. Also, three flight tests are designed and flown in Flight Dynamics II to investigate three aircraft stability and control topics such as neutral point determination, lateral-directional static stability, roll controllability, phugoid dynamics and Dutch roll dynamics. In the past two years, we have learned several valuable lessons and made a few adjustments. This paper presents our experiences in this area and makes recommendations to other universities that might be interested in establishing flight test engineering in their undergraduate aeronautical/aerospace engineering programs. Highlights of the effectiveness of this experiential learning are presented.

KEYWORDS

Active, experiential, flight, test, stability, control.

1. INTRODUCTION

During the past decade a concerted effort has been made to close the gap between aeronautical engineering education and practice. Major aerospace engineering companies (e.g. Boeing) published lists of desired attributes, and leaders of industry urged a new look at the way students were being educated. Two key reasons account for the lack of convergence between engineering education and engineering practice: an absence of rationale and an absence of necessary experiences.

In surveying the literature, we did not find any papers that address the inclusion of flight tests in undergraduate aeronautical engineering programs. However, Queen's University [1] has presented a module built on problem-based learning in the area of flight handling qualities for senior level aerospace engineering students. This module does not include any flight test experience but is a good reference for schools looking to enhance student learning in the area of flight stability and control. They provide details of how they incorporated flying qualities into a flight dynamics course. Normally this content is reserved for graduate-level study.

The four-year aeronautical engineering program at Daniel Webster College (DWC) evolved from a long standing two-year associate degree transfer program and was designed and implemented four years ago. DWC joined the CDIO [2, 3] initiative in June 2006. Features of the DWC engineering program include:

- Students will be well-grounded in theoretical bases of engineering;
- Small class size will allow for regular presentations and one-on-one communication;
- Students will get extensive machine shop experience beginning with the first semester;
- Students will have multiple open-ended design experiences beginning with the first semester;
- Students will receive multiple concurrent engineering experiences, taking a product from design and analysis to simulation to manufacturing to assembly and testing; and
- Students will have systems integration experience: sensors, controls, software.

In line with CDIO Standard 8--active learning [4]--that is, “Teaching and learning based on active experiential learning methods,” a flight test engineering experience was integrated into the Aeronautical Engineering program.

Junior and senior Aeronautical Engineering students take a two-semester sequence of courses: Flight Dynamics I (Aircraft Performance) followed by Flight Dynamics II (Aircraft Stability and Control). Augmenting the classroom presentation of theory, students develop test plans and perform in-flight experiments using an aircraft equipped with flight test quality instrumentation developed and produced by the Calspan Corporation.

This rest of this paper is organized as follows: Section 2 introduces flight test engineering and its features. In section 3, the role of flight test engineering in undergraduate education at DWC is described. The details of flight test education requirements are examined in Section 4, including instructor qualifications, test pilot requirements, aircraft requirements, and most importantly flight data recording system requirements. Section 5 is devoted to the details of six flight test plans that we conduct in the two courses. Several samples from students’ test reports are reviewed in Section 6 to describe the influence of flight tests on student learning experiences. Finally, lessons learned, future plans, and several recommendations to any institution considering adding flight tests to its undergraduate aeronautical/aerospace engineering program are presented in Section 7.

2. FLIGHT TEST

Flight test is a branch of aeronautical/aerospace engineering that develops and gathers flight data during the flight of an aircraft and then analyzes the data to evaluate the flight characteristics of the aircraft and validate its design, performance, flying qualities, and systems operation with emphasis on safety features. The flight test phase accomplishes two major tasks: first, finding and refining aircraft design problems, and second, verification and documentation of the aircraft capabilities for certification or customer acceptance purposes. The flight test phase can range from the test of a single new subsystem for an existing aircraft to the complete development and certification of a new aircraft. Therefore the duration of a flight test program can vary from a few weeks to several months.

Modern aircraft are complex integrated systems with propulsion, avionics, aerodynamics, and structure blended together to achieve optimum performance, stability, and control and systems operation. The flight testing of such aircraft is an endeavor involving a number of engineering disciplines in addition to the study of the man-machine interface that is referred to as human factors. The human crew, which has both tremendous capabilities and known limitations, must interact with the aircraft and its systems. In addition, the management of a flight test program for a modern aircraft requires management skills that are not often included in most engineering curricula.

The primary purpose of today's flight testing is to determine if the aircraft and its crew can safely accomplish the intended mission. Other purposes may include collection of aerodynamic, power plant, and system data, and research into these or related fields.

The flight test process involves the engineering test pilot, engineering test crew, specialized flight test instrumentation, flight test plan, data acquisition, data analysis, and development of conclusions and recommendations. The flight test process typically involves a planning phase, an execution phase (the actual flying), and a report writing phase (involving data reduction and presentation of conclusions and recommendations).

There are a number of reasons for flight test. One has been the desire of man to push the frontiers of knowledge, i.e., research. Another is for product development and determining the characteristics of the new product. A third and most important reason is to ascertain if the new air vehicle will accomplish its intended mission. The final reason for flight testing is to comply with established requirements and regulations for safety of flight by organizations such as the Federal Aviation Administration (FAA).

Although the flight test is costly compared to flight simulation, the flight test data are very valuable and extremely reliable. On the other hand, flight test is labor intensive and requires a large number of man-hours to conduct. Thus, extreme care must be taken into account if flight planning is going to have necessary and accurate results. For these reasons, any flight test plan must be presented for approval to a panel of experts including operational, technical, and safety officers. Flight test engineers must have relevant communication and briefing skills to satisfy panel members that their plan is adequate, safe, addresses the requirements, and will generate satisfactory results. The panel members usually will ask several questions, and at the end will come up with a list of recommendations to the engineers to update and revise their plan. Approval of the flight test panel is a must in the flight test planning loop and is an important part of flight test engineering. At DWC, we have established a review panel consisting of the Dean of the School of Aviation Sciences, the Chair of the Engineering Division of the School of Engineering and Computer Science, several faculty members from both schools, plus Flight Operations and flight safety personnel.

3. THE ROLE OF FLIGHT TEST ENGINEERING IN UNDERGRADUATE EDUCATION

The area of flight dynamics, namely aircraft performance and stability and control, is the first time that the undergraduate aeronautical engineering student typically deals with the total aircraft. Therefore a flight dynamics laboratory using an actual aircraft provides the student with the opportunity to obtain some hands-on experience while augmenting the classroom theoretical experience. The laboratory portion of the DWC flight dynamics courses are in no way a complete course in flight test engineering. They are, however, a flight test experience that illuminates the theory taught in the classroom and allows the student to design an airborne experiment that follows a typical flight test process (plan, execute, report). The flight test exercises are designed to be simple enough to allow the students to follow the flight test process with some faculty guidance, and they gradually increase in complexity and technical difficulty throughout the two-course sequence.

Adding a flight test engineering experience into an undergraduate aeronautical/aerospace engineering program enriches the quality of the education. The students will be more confident when they discover that flight test will confirm what the equations of motion are predicting. This will directly impact their in-class education by helping them to better comprehend the theory. When students experience a real aircraft and feel its complexity and capability, they will learn the relevant questions to ask in class. Afterward, they have a very real feeling about various aircraft components such as flaps, elevator, stick, pitot-static system, and center of gravity. They comprehend why safety planning is a crucial part of any flight and appreciate why instructors are critical about planning and briefing. Also, the graduates should have a greater range of job opportunities. For example, one of our recent graduates has been hired as a member of a flight test team for one of the advanced aircraft development programs in the U.S. Air Force.

4. FLIGHT TEST EDUCATION REQUIREMENTS

Flight test education requires some resource requirements that are unique in a normal collegiate academic environment. Specialized personnel, equipment (aircraft and instrumentation) and software are needed to enable students to execute a flight test exercise and analyze the results. These include qualified faculty, qualified pilots trained in appropriate flight test techniques, appropriate aircraft, a flight test data acquisition system, and appropriate software for data reduction.

a. Qualified Instructors

The Flight Dynamics courses have two instructors, one professor to teach the theory of flight dynamics in a classroom setting and the other to manage the flight test experience laboratory portion of the course through a classroom recitation and the actual airborne flight experience. The professor who manages the flight test experience portion of the courses must be a pilot, preferably with flight test education and/or expertise.

b. Flight Test Committee

Any flight test plan must be approved by a panel of experts with safety, technical and operational expertise prior to the actual flight test. This step requires students to brief a committee of flight experts and answer their questions. The committee consists of representatives from flight operations, safety, and technical (professors). Every single flight test plan must be presented to this committee and the test plan must be signed by all committee members prior to flight test.

c. Test Pilot

Daniel Webster College was originally formed as the New England Aeronautical Institute and has more than forty years of experience in flight training education in its School of Aviation Sciences. For flight training, Daniel Webster College uses the Cessna 172 for all primary flight training, the Piper Arrow for complex aircraft training, and the Piper Seminole for multi-engine and crew training operations. Aviation Sciences has faculty with engineering and engineering flight test experience who have trained selected flight instructors in the flight test techniques necessary for the support of this program in cooperation with the School of Engineering and Computer Science.

d. Aircraft (Cessna-172)

The Cessna 172 Skyhawk is a four-seat, single-engine, high-wing, fixed-landing gear aircraft. It is probably the most popular flight training aircraft in the world. With a maximum takeoff weight of 2,450 pounds and wingspan of 36 feet, the 172 accommodates one pilot (as flight instructor/test pilot) and has a capacity of up to three passengers. We have selected and equipped one of these aircraft as the test bed for our flight test program. Figure 1 shows our Cessna 172 that is equipped with the Calspan flight test data recorder system.

Figure 1. DWC Cessna-172 N688DW

e. Calspan Miniaturized Flight Data Recording System (MFDRS)

The heart of a flight test is a powerful flight data recorder. While it is possible to obtain usable data in light aircraft by using just a stopwatch and the production flight instruments, one of the learning objectives of these flight test exercises is for students to experience the process of data gathering and reduction using relatively sophisticated flight test instrumentation. DWC purchased a small but advanced flight test instrumentation system, the Miniaturized Flight Data Recording System (MFDRS), from the Calspan Corporation. We modified the college-owned Cessna 172R Skyhawk, N688DW, with the MFDRS. In addition to the MFDRS this particular aircraft is equipped with the Garmin GNS 430 GPS navigation system and an accelerometer instrument. This aircraft, as instrumented, provides a reasonably sophisticated flight test engineering educational tool for our students.

The MFDRS includes an integral NavCube, Calspan's own highly accurate measuring system that is the core of the measurement system. Figure 2 shows the NavCube with a quarter coin for size comparison. It is a small six degree-of-freedom sensor that measures the three orthogonal axes of acceleration (longitudinal, lateral, and vertical, or Nx, Ny, Nz) and three orthogonal rotation rates (roll, pitch, and yaw, or p, q, and r). Sensing is performed by dual axis accelerometers and single axis gyroscopes on individual boards on five faces of the cube. Calspan developed MFDRS as a low-cost alternative to others found in the industry costing much more and that are much bulkier.

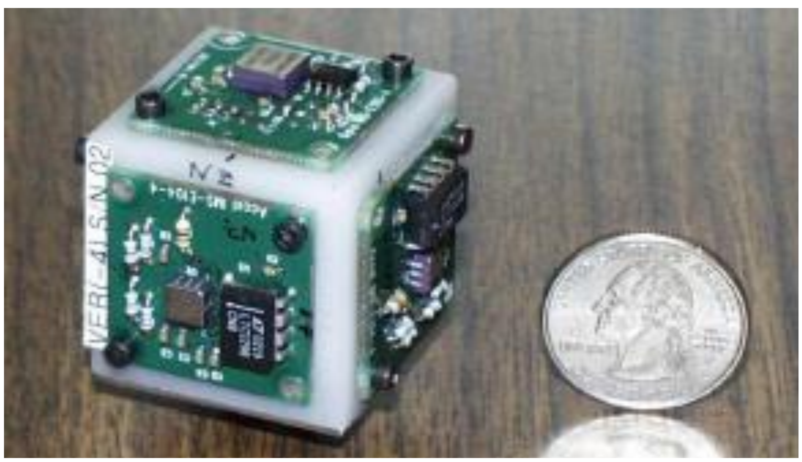

Figure 2. MFDRS--NavCube

The MFDRS primary parameter list includes normal, lateral and longitudinal accelerations: N_z ($\pm$ 10 g), N_x, N_y ($\pm$ 2g), angular speed: pitch, roll and yaw rates: p, q, r (+/-150 or +/-300 deg/s), airspeed, and altitude. In addition, the MFDRS records flight control and surface positions, heading, and GPS parameters from its integral GPS system. The MFDRS has a processor that stores data in a compact Flash Data Storage. Figure 3 shows the complete MFDRS system installed between the front seats of the DWC Cessna 172. Figure 4 shows rudder and elevator transducer and magnetometer (the heading transducer) installation in the DWC Cessna 172.

Data recorded by the MFDRS are stored on an industry standard Compact Flash card for straightforward transfer to a PC or other device. The data are in a conventional DOS binary file format that can be conveniently read by MATLAB, Simulink, Excel, and other analysis tools. Figure 5 illustrates the installation/removal of the flashcard from the MFDRS cockpit unit.

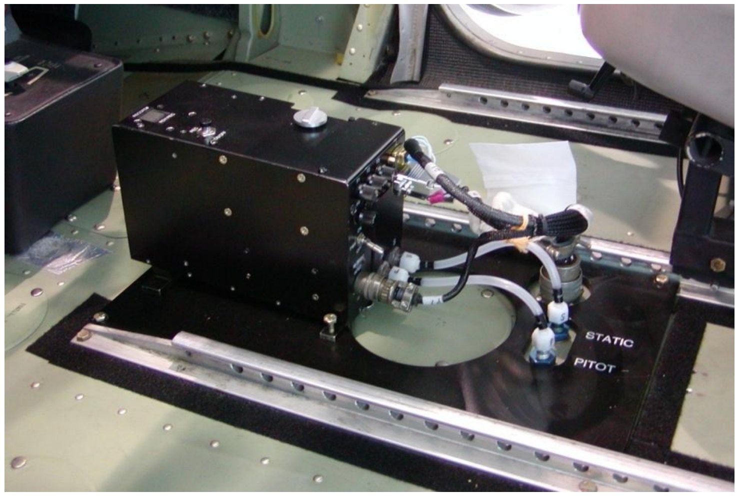

Figure 3. MFDRS Installation on Cessna 172

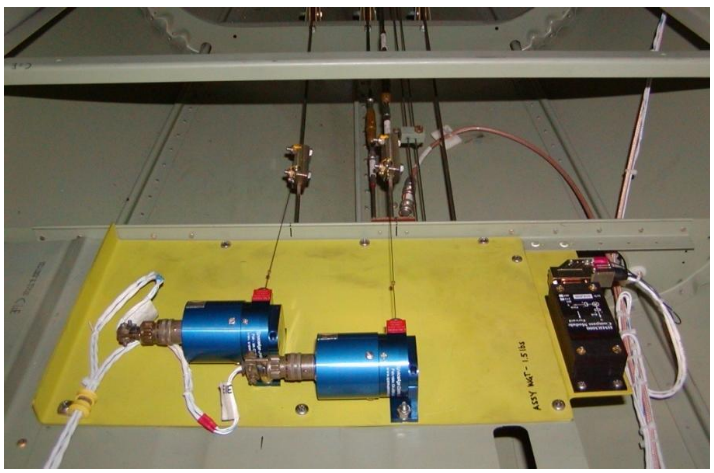

Figure 4. Elevator, Rudder, and Magnetometer Transducer Installation

Figure 5. MFDRS Flashcard Installation and Removal

f. MATLAB software

MATLAB is employed to download the flight test data collected by the data recorder during flight. MATLAB is a numerical computing environment and programming language. Created by The MathWorks, MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. As of 2004, MathWorks has claimed that MATLAB is used by more than one million people across industry and the academic world. All data recoded during the flight are reformatted by a MATLAB program into displays that are easily interpreted by students, who can then manipulate data, plot graphs, analyze results, draw conclusions, and make recommendations. Figure 6 shows a sample of some MFDRS data, a pitch doublet, with the red trace indicating elevator input while the blue and green traces represent output (pitch rate and normal acceleration).

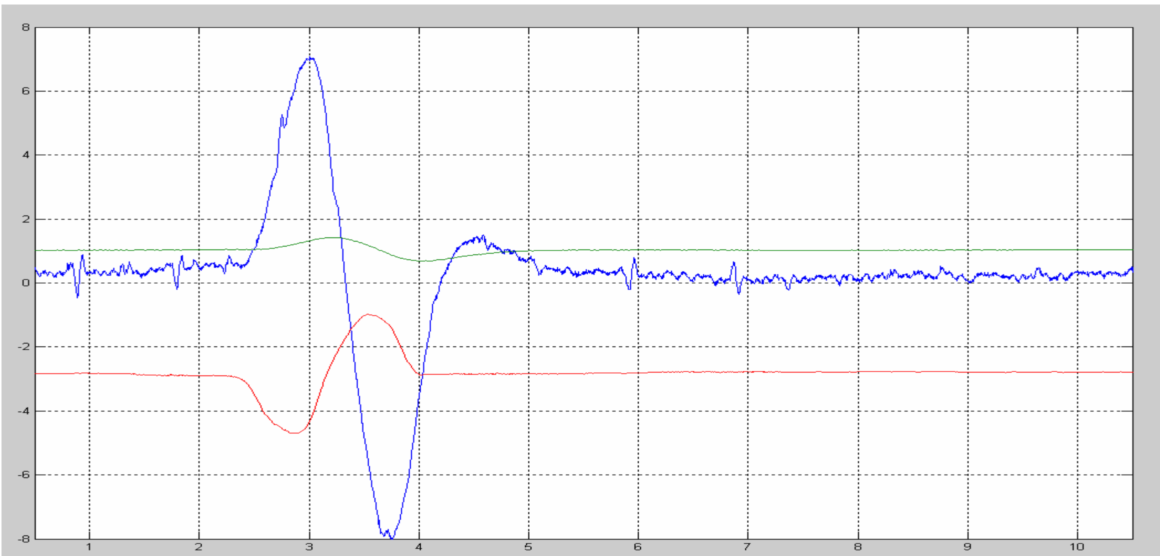

Figure 6. Sample Flight Data: Pitch Doublet

5. DWC FLIGHT TEST PROGRAM

Daniel Webster College has incorporated several flight test experiences into its Flight Dynamics I (Aircraft Performance) and Flight Dynamics II (Aircraft Stability and Control) courses to address CDIO initiatives. Three flight tests are designed and executed in Flight Dynamics I to investigate and analyze the three performance areas of pitot-static, climb performance, and turn performance. An additional three flight tests are designed and flown in Flight Dynamics II to investigate three stability and control topics such as neutral point determination, static stability, dynamic stability, and controllability analysis. Table 1 shows a summary of six flight test experiments that have been conducted in these courses over the past two years.

The Flight Dynamics I and II courses each have two instructors: one to teach the theory of flight dynamics in a classroom setting and the other to manage the flight test experience laboratory portion of the course through a classroom recitation and the actual airborne flight experience. The professor who manages the flight test portion of the courses is a former US Air Force F-4/F-111/F-16 flight test pilot and USAF Test Pilot School instructor. The students are divided into several groups of two to four members. Each flight test is planned after the relevant section of the theory has been covered. The students write a test plan and obtain approval through a formal oral presentation to a Technical and Safety Review Group of faculty and DWC Flight Operations staff personnel.

Table 1

Summary of Six Flight Test Experiments

No	Flight test	Semester	Course
1	Pitot-static calibration	Spring of Junior year	Flight Dynamics I
2	Climb performance analysis	Spring of Junior year	Flight Dynamics I
3	Turn performance evaluation	Spring of Junior year	Flight Dynamics I
4	Aircraft neutral point determination	Fall of Senior year	Flight Dynamics II
5	Static lateral-directional stability and roll control analysis	Fall of Senior year	Flight Dynamics II
6	Dynamic longitudinal stability analysis	Fall of Senior year	Flight Dynamics II

Following official sign off on their test plans, the students are authorized to schedule and fly the test missions. Each flight test experience for a student group is two flights. Two flights allow the students to collect enough data for reasonable analysis, give them an opportunity to check data collection between flights and make test plan changes if necessary, and keep the flight-hour cost reasonable for the college. It is important to understand that these flights are not a complete flight test of the aircraft or system but an experience to allow the students to attain the learning objectives. Following the flights the students reduce and analyze the data and write a formal technical report documenting their results, conclusions, and recommendations. Each team receives a team grade for each individual flight test experience (e.g., pitot-static) which includes grading of the test plan, oral review presentation, and the final technical report.

DWC has included these flight test experiences in the flight dynamics courses from their first offering, so there are no “before” and “after” data to determine the improvement in performance of the students as a consequence of these flight experiences. Observations of the recitation portion of the course as well as flight debriefings have anecdotally shown the faculty instructors that students tend to more completely understand the material after their flight experience. For instance, after watching the Cessna 172’s climb performance over a range of speeds from near stall to V_{max} they seem to have a better appreciation for the behavior of the power required and power available curve . . . they “get it” better after the flight experience.

There are a number of interesting areas in the Aircraft Performance and Aircraft Stability and Control courses from which to choose flight test experiences. We chose three topics in Aircraft Performance to be most relevant to undergraduate study: pitot-static calibration, climb performance, and turn performance.

In the first flight test, students deepen their understanding of various types of speed such as indicated airspeed, calibrated airspeed, equivalent airspeed, true airspeed, wind speed, and ground speed. They also learn to fundamentally appreciate how a pitot-static system measures the total pressure and static pressure, and where the sources of errors in the speed measurement process are. This experience gives them a better understanding of the theory and operation of a conventional airspeed indicator. Then terms such as position error, lag error, instrument error, and calibration remind them that they are flying in a real world and how errors influence the measurement of aircraft performance data. This flight test is composed of several cruising flights with a constant airspeed and a constant altitude in various headings. More than ten test methods are introduced to students and the pros and cons of each are briefly described.

Flight safety requirements and regulations are reviewed in the first flight test, the students' dealing for the first time with issues such as flight planning, briefing and debriefing, test flight airspace considerations, test proposal, and flight test reporting. This is usually a simple test, but since students are not experienced in the fundamentals of flight test at the beginning of the course they are often faced with problems such as flight planning, teamwork, communication, technical report writing, preflight procedures, safety review, and most importantly, how to answer the unexpected questions that review panel members ask.

The second flight test is devoted to climb performance through the saw tooth flight test technique. In this test, students experience the effect of available power, required and excess power, and plot the available power and required power versus speed. They are also required to analyze various aspects of this plot such as minimum power speed, minimum drag speed, maximum speed, maximum climb angle, and maximum rate of climb. This test consists of several climbs and descents in a limited range of safe altitudes. Students experience the application of the equations of motion as they pertain to climb and compare the flight test results with theoretical predictions. The hard-to-believe truth of "the lift is less than aircraft weight in a climbing flight" is revealed to the students in this test.

The third flight test in Flight Dynamics I is turn performance because it is of primary importance in the evaluation of military fighters. Students enhance their understanding of parameters such as load factor, normal acceleration, turn radius, turn rate, bank angle, level turn, slip and skid. They are required to draw several plots from test data and analyze turn performance of the aircraft, including turn radius versus speed, bank angle versus load factor, and turn rate versus bank angle. This flight test also includes several turning flight data points at various bank angles and speeds.

In Flight Dynamics II three flight tests address aspects of aircraft stability and control: determination of neutral point, static stability and control, and dynamic stability. Compared with the three flight tests in Flight Dynamics I, these are harder to plan and harder to perform and analyze, as might be expected.

In the fourth flight test, students are required to measure an aircraft neutral point through a flight test procedure. Prior to this test they have been introduced to the theoretical methods to identify the location of aircraft neutral point (or aircraft total aerodynamic center) in the longitudinal axis. But this flight helps students understand the practical importance of the location of neutral point.

They learn to appreciate the relationship between the pitching moment coefficient (C_m) versus angle of attack (α) curve, neutral static stability, and the neutral point. This flight test consist of two series of flight tests at two distinct aircraft centers of gravity and with data points collected at different speeds while stabilized longitudinally though the application of elevator deflection. The students determine the location of the neutral point by plotting the variations of the slope of the rate of change of elevator deflection versus aircraft speed. This test is their first experience with the phenomena of static stability and they will thus comprehend why an aircraft must have its center of gravity in front of the neutral point in order to be statically stable in the longitudinal direction.

The fifth flight test deals with the lateral-directional static stability and roll control power. In this test, students experience yaw angle, heading angle, sideslip angle, roll, yaw, relative wind, wind axis, body axis, side force, trim, and coordinated turn. The study of lateral-directional static stability examines the reaction of the aircraft when its flight path deviates from the plane of symmetry. In this flight test the students also experience the coupling between lateral stability and directional stability. The significance of dihedral angle, sweep angle, wing vertical location, and vertical tail in lateral-directional static stability is also presented to students. They analyze lateral-directional static stability and roll control power through several plots such as bank angle versus sideslip angle, aileron deflection, and rudder deflection versus bank angle.

The last flight test addresses dynamic stability. Students identify the features of short period mode and phugoid mode longitudinal motion. With these data they are then able to analyze dynamic stability of the aircraft. The purpose of this flight test is to evaluate dynamic stability of the C-172R in phugoid, Dutch roll, and spiral modes. In theory, dynamic stability occurs when the parameters of interest tend toward finite values as time increases without limit. “Phugoid” describes a longitudinal motion mode with a long period and light damping. During a phugoid, the angle of attack is nearly constant with variations in airspeed and altitude-–which can be thought of as an exchange between potential and kinetic energy. Because the period for a phugoid is typically 45 to 90 seconds, the pilot is usually able to correct for flight path deviations. There is also a short period longitudinal mode oscillation which is not tested because the C-172 typically demonstrates this motion mode in an over damped fashion.

The Dutch roll mode is a second-order lateral-directional motion mode characterized by coupling between yaw and roll. A Dutch roll may occur after a yawing motion that also generates a rolling motion. For a laterally stable and directionally stable aircraft, an opposite yawing moment will be generated, resulting in a Dutch roll to the opposite direction. An important parameter for measuring Dutch roll is the ratio of bank angle to sideslip angle. A low ratio indicates little bank angle during the Dutch roll and is considered more favorable than a high ratio for general aviation aircraft. To analyze spiral mode, a Bank Angle vs. Time plot will be generated using hand collected data. The dynamic stability of the aircraft will be analyzed through upsetting the aircraft using elevator deflection and doublet rudder input and the measurement of aircraft reaction to these inputs.

This section introduced the details of six flight tests in brief. As mentioned before, the test aircraft is a Cessna-172, a subsonic general aviation (GA) aircraft with a piston prop engine.

The aircraft is safe and highly reliable, and aircraft data are available through the manufacturer. The aircraft has sufficiently observable performance, stability, and control characteristics as well as DWC-installed flight test instrumentation to allow students to attain the learning objective of the laboratory portions of Flight Dynamics I and II.

6. SAMPLES FROM STUDENT REPORTS

This section contains two excerpts from student reports (one each from Flight Dynamics I and II). These writings appear to demonstrate the value of flight test education in helping students grasp fundamentals and develop experimental skills. Student interest and motivation in the flight test education are also apparent.

a. *Flight Dynamics I: Turn Performance Test*

The objective of Test Flight 3 was to gather data to plot the V-n diagram and turning radius versus velocity, for the Cessna 172R. The students successfully prepared and presented their test plan to a board of professors overseeing the process. The team flew two sorties and collected data for banked stalls and max power banked flight. The calibrated air speed and the load factor, recorded by the MFDRS, were used to calculate the aerodynamic limit, the power limit and the turning radius at predetermined bank angles. Hand collected data was taken for reference, but MFDRS data was relied on for data reduction. As a result of previous experience, both teams were prepared for flight, and the changes in the procedure adapted from the previous test plan were implemented and resulted in successful flights. For this test flight the data from sortie one was reduced and discussed before sortie two flew. This resulted in better data collection from the second sortie. The test team found it helpful to discuss flight test techniques with other groups. Another important consideration is the minimum weather conditions that permit accurate data collection.

Figure 7 shows some actual student turn performance data applied to a report showing aerodynamic limit (stall) and at the power limit (full throttle). Note that a hypothetical limit load factor of 2 g was imposed to keep the flight within FAA limits for flight without a parachute.

b. *Flight Dynamics II: Dynamics Test*

This flight test VI was performed on June 3rd, 2008 with Sortie 1 comprised of pilot Garrett B. and Benjamin K. acting as flight test engineer. The team flew and analyzed data points used to determine the dynamic stability of the C-172-R in the phugoid, Dutch roll, and Spiral Modes (The roll mode was analyzed in a previous flight test). Graphs were generated to illustrate the dynamic stability of the aircraft. As expected, the aircraft possesses positive dynamic stability. This is favorable for a general aviation aircraft used in flight training for civilian purposes.

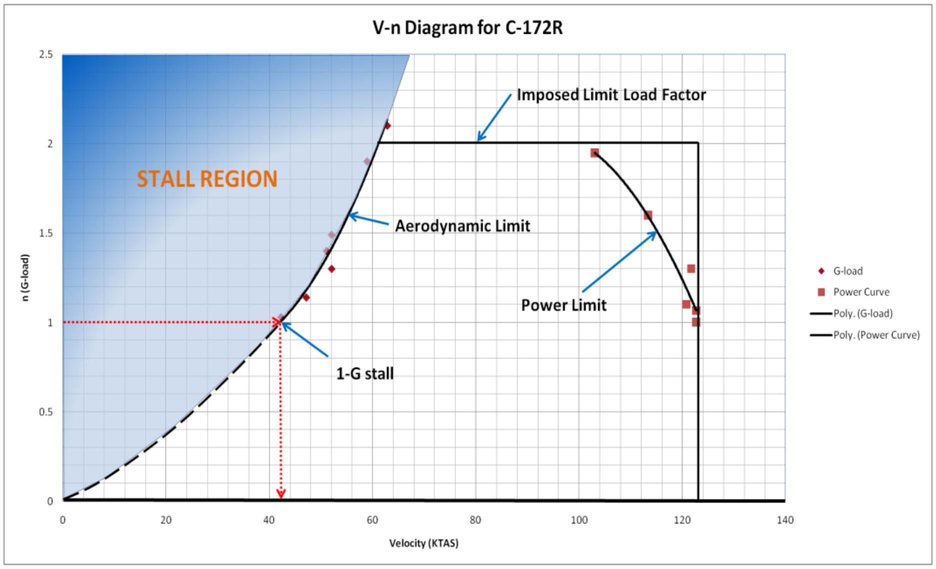

Figure 7. Some Student Data from a Turn Performance Test

Recommendation 1: Develop a better method for analyzing Dutch roll. The intended method was not feasible due to the highly damped response of the aircraft. One possible aid may be to bring a portable inclinometer that can be placed in the aircraft to measure bank angle more accurately than the attitude indicator.

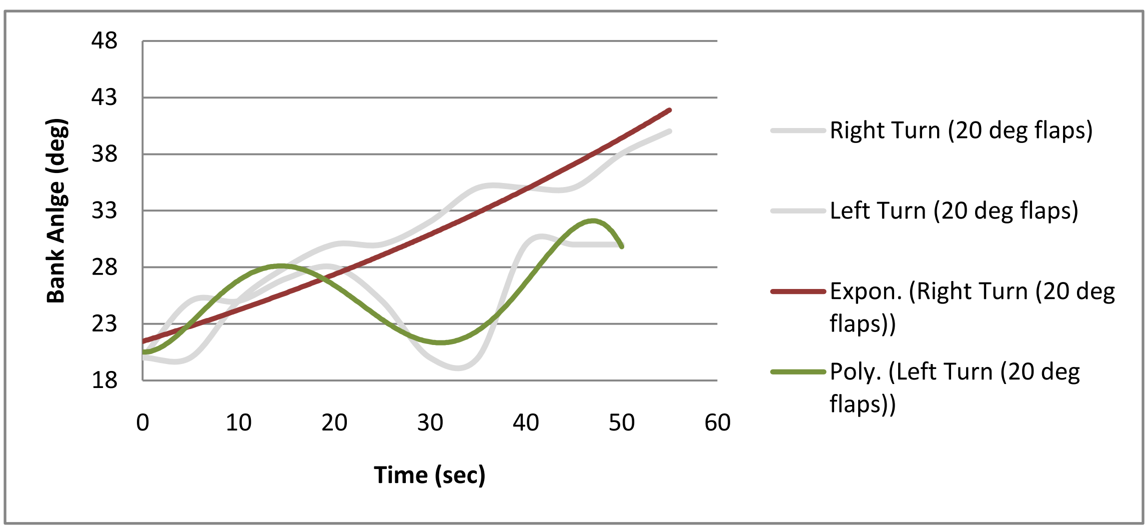

Figure 8. Some Student Data from a Spiral Stability Flight Test

Recommendation 2: Verify that the aircraft will fly straight and level trimmed to ensure that the control surfaces are properly calibrated. The team suspects that the unexpected left bank response during spiral mode may be due to the aircraft's prior mission as a spin aircraft.

Figure 8 shows some student spiral stability data from this dynamics test. The students incorrectly suspected that the left turn response was due to a flight control out of rig condition when it was, in actuality, due to wing fuel imbalance.

The flight test report provides a good indicator of the effectiveness of experiential learning. Through these written reports students demonstrate that they have deepened their understanding of flight dynamics-related topics.

7. EVALUATION OF PROGRAM EFFECTIVENESS AND LESSONS LEARNED

We believe that the root cause for the lack of convergence between flight dynamics education and practical application is the absence of experiential learning. The flight test experience requires students to develop skills such as flight planning and flight test execution, and it reinforces skills in data reduction, analysis, communication, and teamwork. The six flight tests cover a variety of topics so students can identify, formulate, and solve engineering problems at different levels of difficulty. Although each flight test addressed one major topic, the integration of lessons learned in preceding flights was required. In particular, the flight test experience provided motivation for absorbing and integrating the harder topics, such as turn performance and lateral-directional dynamic stability. Students gained a deeper understanding of the flight dynamics context in which aeronautical engineering is practiced. Table 2 summarizes the observations of the instructors with regard to the effectiveness of flight tests as experiential learning in various areas.

Students were also asked to submit comments regarding the effectiveness of “flight test” in their flight dynamics education. Their comments were uniformly enthusiastic and positive. The following quotes were taken from the survey:

1. *I think that flight testing is one of the best parts of the flight dynamics classes. They provide real world hands on experience that is relevant to the topics studied. I think they are very effective and provide experience that employers are looking for.*
2. *I believe they are very effective by reinforcing the topics learned in class.*
3. *I think it greatly aid my learning in this class. It is overall, very well integrated.*
4. *The flight tests are very useful in the course. Despite their extensive time demand, they are very interesting.*
5. *The flight test helped a lot about understanding the differences between speeds (true, equivalent, calibrated,…). More importantly it helped me understand how to account for non-ISA conditions during calculations.*
6. *The flight test was more complex and difficult for me to understand but after working through it, I feel that it helped tremendously with understanding and retaining the information.*
7. *Flight tests allow students to actually evaluate the accuracy of the equations and methods that are learned in flight dynamics.*

8. *The flight tests are crucial to the Flight Dynamics courses. They offer a unique experience to gain real world applications of course material.*
9. *The neutral point flights were very interesting. Loading the plane as far forward and backwards as we could while remaining in the envelope makes one really think about the ramifications of not properly loading a plane.*
10. *I believe they are very effective by reinforcing the topics learned in class. They are also fun, and a great way for engineers to see the pilots point of view. They personally helped me a lot. The pilot let us fly the aircraft during the longitudinal static stability test and you could feel the difference between the C.G. locations.*

Both the observations of the instructors, and student performance and attitudes, attest to the importance and effectiveness of CDIO Standard 8-active learning.

The flight test component has been offered in both Flight Dynamics courses since these courses were introduced two years ago. As such we have no “before flight test” and “after flight test” assessments to compare. However, several lessons have been learned and some recommendations can be made to institutions that would like to introduce this student experience into their programs. They are as follows:

1. Flight Dynamics I and II are both three-credit courses that meet three hours per week. It has been difficult to find sufficient class time for flight test briefings without sacrificing part of the theoretical education. This year, in order to maintain sufficient class time for the theoretical content of the courses, a weekly hour-long recitation was added to each course. Also, because the theoretical content in Flight Dynamics II is particularly challenging it will be changed from a three-credit to a four-credit course in order to gain additional class time.

2. The syllabus calls for three flight tests in Flight Dynamics I and three flight tests in Flight Dynamics II. But in practice it has been hard for students to complete all six flights within two semesters. Each flight test experience is naturally planned right after the topic is covered. The third flight test related topic is covered near the end of the semester, so the students have a very short time to plan and execute that flight test. We suggest planning all three performance tests in the first semester but flying only two. The reason is that there is just not enough time left for flying the third flight prior to final exam week. Since the plan is written and approved, the flight test can be done in the beginning of the second semester. The same problem occurs with the third flight test in Flight Dynamics II (i.e. dynamic stability), since the discussion of dynamic theory comes so late in the semester. Flight Dynamics II has now been moved to the first semester of the senior year. Therefore students can now finish up the final flight test during the second semester of their senior year.

Table 2.

Flight Test Effectiveness/Observations

Course	Topics Enhanced By The Experiential Learning	Effectiveness/Observations
Flight Dynamics I	Ground speed, true airspeed, equivalent airspeed, calibrated airspeed, and indicated airspeed.	Students are used to seeing the ubiquitous “V” in equations without a good understanding of the various airspeeds in aviation. A much better understanding of ground speed, true airspeed, equivalent airspeed, calibrated airspeed, and indicated airspeed is attained by going through an airspeed calibration process in an actual airplane.
	Equations governing rate of climb, climb angle, climb speed, excess thrust, and excess power,	This flight test strengthened understanding of the fundamentals of climbing flight by physically illustrating the airplane’s ability to climb at a range of speeds varying from near stall speed to V_{MAX}.
	Bank angle, turn radius, turn rate, load factor, and accelerated stall.	The relationship of bank angle, velocity, and load factor becomes very obvious when performing a series of turns at one g as well as elevated load factors at stall and at full throttle.
Flight Dynamics II	Neutral point, longitudinal static stability	This first flight test experience in the area of aircraft stability and control allowed the students to experience the relation between aircraft center of gravity and neutral point and established the basic foundation for students to solidify their knowledge of static longitudinal stability.
	Lateral-directional static stability, roll control	This flight test experience gave the students an opportunity to observe a static stability case as well as coupling (lateral and directional) in one simple exercise. The roll control exercise was chosen because it is fairly easy to analyze but illuminates visually and with data a controllability case.
	Dynamic stability	Aircraft dynamic motion is often difficult for students to imagine; however, when actually experienced (in this case we look at the phugoid mode and Dutch roll mode) the relation of aircraft motion to the second order equations becomes obvious.
General	Communication	Various communication skills such as writing, graphic presentation, and oral presentation were practiced through six flight test plan written preparations, oral presentations, and written flight test reports. The effectiveness of communication skills was gradually improved.
	Teamwork	Students gained a good understanding of the importance of teamwork. They also had to adapt to rapid changes which demanded flexibility and ultimately increased their self-confidence.
	Analytic ability	Students gained a good understanding of analysis of actual flight test engineering data through use of our instrumentation system and the reduction of the actual data produced.

3. The flight test pilot must be a qualified instructor pilot assigned by the college who is very familiar with the flight test techniques to employ in obtaining the airborne data. A Primary flight test instructor pilot has been identified as a formal policy. Engineering students now have a “go to” person for flying questions if the professor who manages the flight test laboratory is not available. The Primary can also coordinate and discuss flight test techniques with the other instructors. It should be noted that flight testing needs good clear weather with calm winds. This is often a challenge in New England in the winter. With appropriate scheduling, including spreading the flights across three semesters, bad weather can be mitigated.

4. In the course syllabus, we assigned only 15% of the total grade to the flight test portion of the course. Therefore other portions of the course such as homework assignments, midterm exams, final exam and the project assignment are all worth 85%. Our experience, as well as student comments, suggests that the flight test portion should count for about one third of the course grade because the work by the students on the flight test experience is much more than 15% of the total course load.

8. CONCLUSION

Daniel Webster College has incorporated flight test education into its Flight Dynamics I (Aircraft Performance) and Flight Dynamics II (Flight Stability and Control) courses to address CDIO initiatives. Three flight tests are designed and practiced by Aeronautical Engineering undergraduate students in Flight Dynamics I to investigate and analyze three aircraft performance parameters such as airspeed calibration, climb performance, and turn performance. Three additional flight tests are designed and flown in Flight Dynamics II to investigate three flight stability and control parameters such as neutral point, static stability, dynamic stability, and controllability. In the past two years, several valuable lessons have been learned and some adjustments have been made. This paper presents our experiences plus several recommendations to other institutions that might be considering doing the same. The DWC flight test education has given our students a deeper understanding of flight dynamics. Feedback from our graduates has indicated that they found the flight test experience to be important in their transition into the aeronautical engineering profession. Future plans include working with other CDIO partners to continue the development of undergraduate flight test experiences.

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Biographical Information

Mohammad Sadraey is an Assistant Professor of Engineering at Daniel Webster College. His main research interests are in unmanned aircraft design and robust nonlinear control. He received his BS in Mechanical Engineering in 1986 from Tabriz University, Iran; an MS in Aerospace Engineering in 1995 from RMIT, Melbourne, Australia; and a PhD in Aerospace Engineering from the University of Kansas, Kansas, USA. Dr. Sadraey is a member of American Institute of Aeronautics and Astronautics (AIAA).

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James O'Donnell is Professor of Arts and Sciences at Daniel Webster College. He received his PhD in 1981 from the University of South Carolina, with a specialization in textual criticism and analytical bibliography of colonial and early American literature. Courses he has taught include Humans and Technology, Nature and American Culture, Understanding Terrorism, Globalization, and Ethics for a New Century. For the past five years he has assisted the engineering faculty integrate writing, oral presentations, critical thinking, and ethics into the five-semester CDIO-inspired engineering design sequence.

Nicholas Bertozzi is a Professor of Engineering at Daniel Webster College and chair of the Engineering Division. He received his BSME in 1977 and his MSME in 1982 from Northeastern University. Since 1982 he has taught courses in physics, differential equations, engineering design, thermodynamics, fluid mechanics, aerodynamics, statics, dynamics, and strength of materials. His major interest over the past ten years has been the concurrent engineering design process. Professor Bertozzi has a particular interest in helping engineering students develop good communications skills and over the past few years has mentored four undergraduate student teams who have co-authored and presented papers and posters at EDGD and other ASEE and American Institute of Aeronautics and Astronautics (AIAA) meetings as well.

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