AC 2012-4473: VIRTUAL FLIGHT TEST: AN EFFECTIVE PEDAGOGICAL APPROACH

Dr. M. Javed Khan, Tuskegee University

M. Javed Khan is professor and Head of the Aerospace Science Engineering Department at Tuskegee University. He received his B.E. in aerospace engineering from the PAF College of Aeronautical Engineering, Pakistan, M.S. in aeronautical engineering from the U.S. Air Force Institute of Technology, and Ph.D. in aerospace engineering from Texas A&M. His research interests include human factors of training on flight simulators and engineering education.

Mr. Bruce Edward Heath, Tuskegee University

Bruce Heath has a B.S. in aerospace science engineering and M.S. in mechanical engineering from Tuskegee University. He also has an B.S. in airway science from the University of Maryland, Eastern Shore. His research interests are in human factors of training and teaching strategies for undergraduate students. He is currently an instructor at the Department of Aerospace Science Engineering at Tuskegee University.

Virtual Flight Test: An Effective Pedagogical Approach

Abstract

The paper describes a virtual flight test approach to learning of various aircraft stability and control and aircraft performance concepts. Several virtual flight test scenarios have been developed to understand the various concepts. Details of a virtual flight test to estimate the neutral point of an aircraft are provided in the paper. The virtual flight test environment is PC-based running freeware and commercial off-the-shelf software. While the approach can be used on desktop PCs, a setup with three large out-of-window views driven by three LCD projectors and PCs is used to enhance the realism of the experience.

Introduction

It has been observed consistently that an environment in which students are passive participants is less conducive to learning than an environment in which students are actively engaged. Techniques such as cooperative learning, collaborative learning, experiential learning, problem-based learning and active learning, also referred to as inductive learning have been extensively researched. While the results of these various pedagogies vary, in general, their effect on student learning has been demonstrated to be positive in comparison to traditional lecturing.

A hands-on approach to learning concepts of aerospace engineering is therefore not a new pedagogical approach and has found wide usage, and enhanced learning has been reported in the literature. This aspect has been acknowledged by professional societies who have supported its adoption. Thus, while engineering education over the years has emphasized capstone design activities, more recently aerospace engineering curricula have incorporated elements of building and flying along with design due to active support from professional organizations such as the AIAA[1] and SAE[2] through their design/build/fly (DBF) competitions. These competitions are excellent venues for engineering students to practice their engineering knowledge and skills. However, participation in these competitions requires considerable investment of time and financial resources and has been limited to schools with larger programs[3]. This is not to mention that such activities may not always yield successful results[4] having possible negative impact on learning, motivation and self efficacy. The importance of *success* has been cited as the basis of the design-build fly experience in the Unified Engineering sequence at MIT[5]. A number of examples are available where the DBF approach has been used to enhance learning of engineering concepts[6, 7, 8, 9].

Flight Test Engineering (FTE) as an important element of the design & development cycle of an aerial platform certainly is well known. In view of this aspect, teaching of FTE is incorporated in aerospace engineering curricula at some engineering schools across the US for example[10, 11, 12]. FTE facilities are also utilized as flying laboratories for explaining concepts in aircraft performance, stability & control.

Engineering students need to be exposed to important aspects such as teamwork, time and space management, planning engineering tasks, operations, analyses of results and presentations. These activities are generally incorporated in capstone design. The above cited activities provide effective opportunities to students to develop these important professional skills. However for obvious reasons including costs associated with initial investment, and continued operations, most of the aerospace engineering students in the US are not exposed to hands-on experiences resulting from a course in FTE.

Fortunately, the availability of low-cost PC-based flight simulation software with accurate flight physics (at least at in the linear aerodynamics range) provides an opportunity to expose students to aspects of flight test engineering in a virtual environment at a fraction of the cost of a full-scale flight test engineering curriculum. A 'virtual' flight test can complement the learning of various aspects of aircraft performance, and stability & control. Planning, managing, executing and analyzing data from such a virtual flight test mission provides additional opportunities to groom engineering students in these important skills.

This paper describes the integration of 'virtual flight testing' in an undergraduate Aircraft Stability & Control course using commercial off-the shelf software and hardware in an immersive flight simulation environment. The students conduct 'virtual flight tests' to determine various parameters of an aircraft and compare their experimental results with the theory. The students work in teams consisting of a flight test director, flight test pilot and flight test engineer. The planning, flying, data collection for the purposes of estimating the neutral point of aircraft is a typical virtual flight test conducted by the students. The development work was conducted as part of an NSF HBCU-UP grant. This approach is now being used routinely since several semesters and has been assessed through student surveys to be an enjoyable and effective learning approach. The paper provides details for implementation of the virtual flight testing approach.

Hardware and Software

The underlying motivation to the approach has been low cost, hence, the decision to select either an open-source or an off-the-shelf PC-based software and hardware. Several software packages were considered on which to base the system. These included FlightGear[13], X-Plane[14] and Microsoft Flight Simulator FS2004 (the most recent version being FSX). It was decided to use FS2004 due to its maturity as compared to the other choices and the availability of a large community of developers. It was also decided to configure the system with three large (LCD-projector driven) out of the window views in addition to the instrument panel display (Fig. 1). Each of the LCD projector display is driven by its dedicated PC that is synchronized with the control PC that also drives the instrument panel display. This synchronization is achieved through two commercial-off-the-shelf (COTS) software, the FSUIPC[15] and WideView[16]. The flight data including aircraft and engine parameters are recorded using a freeware flight data recorder, FLTREC.dll[17]. The FSEDIT software[18] is used to modify/edit among other things the aircraft aerodynamic model, its geometric and inertial characteristics. The four PCs communicate through a high speed Ethernet hub. Additionally a KVM switch is used to transfer control of a single keyboard and mouse between the four computers. A schematic of the setup is shown in Fig. 2.

This immersive flight simulation environment has been used to provide experience to students as part of the Aircraft Stability & Control course and Aircraft Performance course to plan and fly 'virtual' flight tests, collect relevant data and analyze this data to determine the aircraft characteristics targeted in the flight test. In this paper one example from aircraft stability and control will be detailed.

Figure 1: Flight Simulation Setup

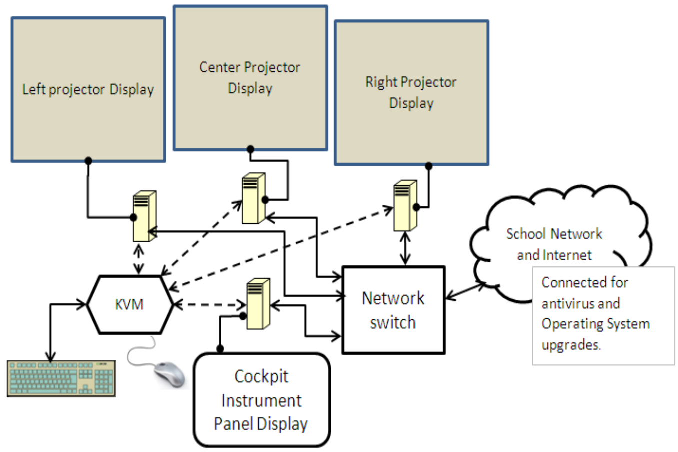

Figure 2: Hardware Schematic

Flight Test Objective: Determination of Neutral Point of an Aircraft

The neutral point of an aircraft is a critical static pitch stability characteristic of an aircraft. Its determination is a typical component of the Aircraft Stability & Control course. The procedure requires the determination of the elevator angle to trim (δ_{etrim}) for a certain trim lift coefficient (C_{Ltrim}) using the relations given below [19], where

$C_{mo} = Pitching\ moment\ coefficient\ at\ zero\ angle\ of\ attack$
$C_{L\propto} = Slope\ of\ lift\ coefficient\ versus\ angle\ of\ attack\ curve$
$C_{m\propto} = Slope\ of\ pitching\ moment\ coefficient\ versus\ angle\ ofattack\ curve$
$C_{m\delta e} = Slope\ of\ pitching\ coefficient\ versus\ elevator\ deflection\ angle\ curve$
$C_{l\delta e} = Slope\ of\ lift\ coefficient\ versus\ elevator\ deflection\ angle\ curve$

$$\delta_{etrim} = \frac{C_{mo}C_{L\alpha} + C_{m\alpha}C_{Ltrim}}{C_{m\delta e}C_{L\alpha} - C_{mo}C_{L\delta e}}$$

and

$$\frac{d\delta_{etrim}}{dC_{Ltrim}} = -\frac{C_{m\alpha}}{C_{m\delta e}C_{L\alpha} - C_{mo}C_{L\delta e}}$$

Then for the center of gravity (cg) at the neutral point, $C_{m\alpha} = 0$, and therefore $\frac{d\delta_{etrim}}{dC_{Ltrim}} = 0$. Data for δ_{etrim} for a specific C_{Ltrim} for various cg positions is used to determine the $\frac{d\delta_{etrim}}{dC_{Ltrim}}$ for each cg and is plotted and extrapolated to determine the cg position for which $\frac{d\delta_{etrim}}{dC_{Ltrim}} = 0$. This location of the cg is then the estimate of the neutral point of the aircraft.

The student teams typically consist of three members i.e. flight test director, flight pilot and flight test engineer. Since there is only one large screen setup, student teams have to plan and reserve the facility for their virtual flight tests. The team selects an airplane available in the MSFS software (usually a single engine propeller aircraft e.g. Cessna 172). The team develops a flight test plan which consists of flight speeds, flight altitude, and loading to determine the C_{Ltrim} and cg. Based on the flight test plan, then the aircraft is loaded using the FSEDIT software. The test pilot then the flies the test campaign while the FLTREC software is used to record the flight and aircraft parameter data. The flight test engineer ensures that the right data has been chosen to be recorded and establishes the error bands for the 'trim' altitude and speed conditions. The flight test director ensures that the flight test is according to planned parameters. The recorded flight data is then reduced by the team members and the neutral point estimated. The virtual flight test experience is reported in the form of a technical report.

This approach has been implemented for several semesters and data has been collected to gage the effectiveness of the approach through student surveys. The survey is based on a 5-point Likert scale with 5-being Strongly Agree and 1-being Strongly Disagree. The survey questions are given in Table I below:

Table I: Student Survey

1. The virtual flight test project enhanced my ability to better understand:
(a) Aerodynamics Concepts (e.g. Lift Coefficient)
(b) Stability & Control Concepts (e.g. static margin, neutral point, trim, elevator angle to trim)
(c) Performance Concepts (e.g. interdependence of power setting, speed, altitude, true and indicated airspeeds)
(d) Planning a flight test (e.g. altitude, speed, c.g. location, data collection)
(e) Executing a flight test
(f) Working in a team (Test Director, Test Pilot, Test Engineer)
(g) Data Collection Needs & Analysis
2. The virtual flight test project is a useful complement to the theoretical (classroom) development of concepts
3. The large out of the window three views made the flight simulation environment realistic
4. I would NOT prefer to have this experience on a single PC display
5. The virtual flight experience was enjoyable

Typical responses from the students are shown in Fig.3. As can be noted, majority of the responses were positives with just a few disagreements. The students also provided comments on the virtual flight test, some of which are given below:
"Flight simulation was a great way to improve understanding. "
"I enjoyed the virtual flight test, so I would suggest to have a few more visual aids to help understand stability concepts more."

"The large screen displays made the experience very realistic."

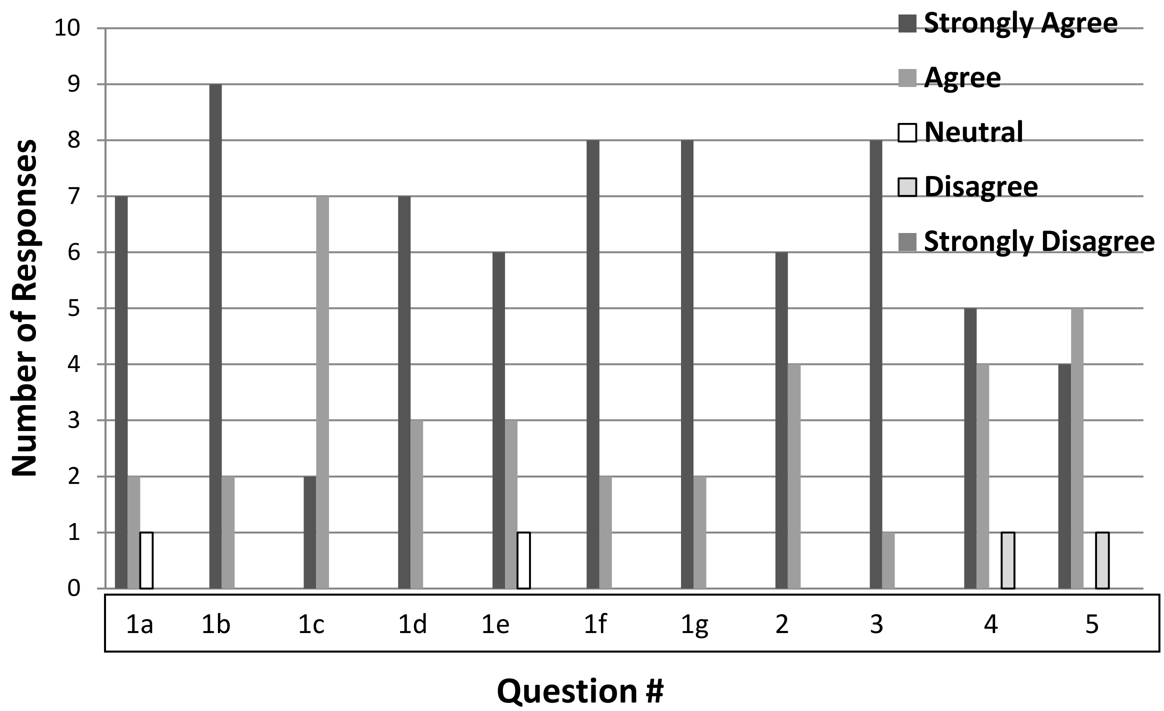

Figure 3: Students' Responses to Questions of Table 1

Conclusions

Virtual flight tests have been used as part of aircraft stability & control and aircraft performance courses at an undergraduate level. Several modules have been developed and are used in these courses. The topics covered in these modules include determination of neutral point, drag, radius of turn, dynamic characteristics such as oscillation frequencies and damping ratios. Data indicates that it is an effective pedagogical tool to strengthen concept, increase motivation of students, develop teamwork and time and space management. The flight test plan and reports can be used to for ABET Program outcome (e): an ability to identify, formulate, and solve engineering problems, as well as outcome (g): an ability to communicate effectively.

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