Virtual To Reality: Teaching Mathematics And Aerospace Concepts To Undergraduates Using Unmanned Aerial Systems And Flight Simulation Software

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ABSTRACT

Student engagement is an essential element for learning. Active learning has been consistently shown to increase student engagement and hence learning. Hands-on activities are one of the many active learning approaches. These activities vary from structured laboratory experiments on one end of the spectrum to virtual gaming environments and to for example building a solar car on the other end. Active learning has also been credited for developing critical thinking skills that promote metacognition. We have used virtual and real environments to promote student engagement and provide opportunities for developing a deeper understanding of science, technology, engineering, and mathematics (STEM) concepts. Several learning modules have been developed utilizing Unmanned Aerial Systems (UAS) with autonomous flight capabilities and a flight simulation environment . In this paper we explain three modules. Based on a survey, students reported positve impact of these modules and of the opportunity to assemble the UAS.

Keywords: UAS; Flight Simulation; Active Learning; STEM

INTRODUCTION

The challenge currently being faced by the US is the performance of its students in STEM disciplines and the low graduation rates. In 2008, only 4% of bachelors degrees awarded in the US were in engineering, as compared to 31% in China; similarly in the US, 31% were awarded in STEM as compared to 61 % in Japan and 54% in China (National Math + Science Initiative, 2014). According to the Level Playing Field Institute (2014), the World Economic Forum in its Global Competitiveness Report of 2011- 2012 noted that the US ranked 52nd in quality of math and science education. The US is placed 19th of the 23 countries in completion of tertiary education. (Organisation for Economic Cooperation and Development, 2013), The report also stated that currently more foreign students were studying in US graduate schools than US students. The President's Council of Advisors on Science and Technology noted in its report (Task Force on the Future of American Innovation, 2006) that for the US to maintain its preeminence in STEM it must produce an additional 1million STEM graduates in next decade, which means a 33% increase in the current STEM graduation projection. The same article also noted that 60% of students entering STEM fields in college switch majors to a non-STEM field. Thus to reach the stated goal of 1 million STEM graduates, these 60% students need to be motivated to continue with their studies in STEM fields.

Several approaches have been suggested in the literature to increase students' motivation and interest in STEM courses in college. Active learning has been identified as the most effective pedagogical approach to improve student engagement and development of critical thinking skills that lead to metacognitive behaviors to learning (Duch, Groh, & Allen, 2001; McConnell, Steers, & Owens, 2003; Prince, 2004; Silberman, 1996). Several dimensions of student engagement that impact academic success have been identified in research. Skinner and Belmont (1993) noted that teachers' behavior (i.e. involvement, structure and autonomy support) impact students' behavioral and emotional engagement. Kahu (2013) has investigated student engagement from the behavioral, psychological, socio-cultural and holistic perspectives where the behavioral perspective pertains to effective teaching practices (Skinner & Belmont, 1993). The National Survey of Student Engagement (2013) summarizes student responses in areas of level of academic challenge, learning with peers, experiences with faculty, and campus environment. Handelsman, Briggs, Sullivan and Towler (2005) identified skills, participation/interaction, emotion, and achievement as four reliable dimensions of student engagement at the course level. Kuh, Cruce, Shoup, Kinzie, and Gonyea (2008) studied the effect of engagement in meaningful academic activities on retention of first year students and showed statistically significant impacts on GPA and persistence. They also noted proportionally higher impact of educationally engaging activities on students from underserved groups. Pike and Kuh (2005) have even suggested a typology of colleges based on student engagement. Common themes in the literature on engagement are academic challenge and faculty and peer interactions. Carini, Kuh, and Klein (2006) conducted a survey of over 1000 students and determined a positive impact of engagment on critical thinking and grades. These dimensions of engagement are effectively addressed through active learning such as problem-based learning (PBL). A team environment for PBL that promotes interdependence of the team members has been shown to impact student learning outcomes (Smith, Sheppard, Johnson, & Johnson, 2005).

Computer and video games have become an ubiquituos component of the life of the current generation of students. The high quality of graphics, and challenging and immersive environment of these games keep the students totally engaged. As such there is a focused effort towards using this highly engaging modality as a pedagogical tool (Dickey, 2005; Klopfer, Osterweil, & Salen, 2009; McClarty et al., 2012; Mitchell & Saville-Smith, 2004; Ulicsak, 2010). While video games may provide an effective approach to developing critical thinking skills and decision making, they are twitch and turn-based; that is, they lack the associated physics distinguishing them from simulations. A number of web-based simulations have been developed to teach concepts of physics, for example the projectile simulator (PhET Interactive Simulations—Projectile Motion, 2011). Similarly, there is an increased emphasis on hands-on activities for engineering students. Several design challenges have been to provide hands-on authentic experiences to undergrduate students (American Institute of Aeronautics and Astronautics, 2014; National Aeronautics and Space Administration 2014a, 2014b).

The objective of this paper is to share a learning approach that was implemented to actively involve a multidisciplinary team of undergraduate students of math, aerospace, electrical engineering, and computer science using UAS and a flight simulator software. The pedagogical approach has been used successfully for several years in suppoting learning of concepts in math, aircraft performance and, stability and control. The approach explained in the paper provides opportunities for responding to several student learning outcomes articulated by the Engineering Accreditation Commission (2015) such as:

(a) Designing experiments, collecting, analyzing and interpreting data (Outcome c)
(b) Functioning on multidisciplinary teams (Outcome d)
(c) Communicating effectively (Outcome g)
(d) Use the techniques, skills and modern engineering tools necessary for engineering practice (Outcome k)

APPROACH

The approach to this hands-on activity was to utilize low-cost resources and techniques that could be easily replicated and provide authentic engineering experiences. The pedagogical philosphy driving this approach was to support classroom work with an environment simulating the real-life problem and then transition to the physical real-life problem. For this purpose, UAS and a flight simulation environment were chosen to implement the pedagogy. This approach has become viable due to the availability of (a) low cost commercial-off-the-shelf (COTS) UAS (<$1000) capable of autonomous flight thereby requiring minimal flying skills and contain real time data and video data links to provide real life experience, and (b) the low-cost COTS flight simulation software with 6 degrees of freedom (DoF) flight physics models (e.g., Microsoft FSX, X-plane). These UAS and flight simulators provide valuable experiences to students in team work and systems engineering/integration as well.

Students often perceive fundamental concepts of math as required rather than as key concepts and skills to open doors and empower them to pursue their education and careers in STEM disciplines. The reasoning (or concepts) are always better understood and retained if these theoretical concepts are linked to examples of their applications and especially when students implement them in a realistic project. This approach is well documented in literature on learning as problem-based learning or active learning (e.g., National Research Council, 2000). While instructors may know or envision the long-term benefits of the topics or concepts being taught, immediate illustrations of the usefulness of the concepts and skills strengthen the students' understanding. Concepts taught on a need base, rather than on some established premise that mathematics is necessary for everything will result in far better learning outcomes. The approach detailed in this paper is therefore considered having merit in helping students gain an intuitive and practical understanding of mathematics. The approach will engage students learning mathematics and engineering. They will enhance and strengthen their computational abilities as well as skills to visualize and interpret experimental data.

Low-Cost UAS

An important aspect of the pedagogy was not only the low cost but also its simplicity to implement. The real life experience was achieved through the use of low-cost UAS. These UAS consist of electric powered about-ready-to-fly (ARF) airframes (e.g. EasyStar, Bixler), and COTS arduino-based autopilot, GPS and telemetry modules. The software and GUI for mission planning is shareware available from Diydrones (2015). A typical set up from diydrones is shown in Figure 1a and the telemetry and mission planner GUI is shown in Figure 1b.

Figure 1a. UAS Airframe, Autopilot, Telemetry

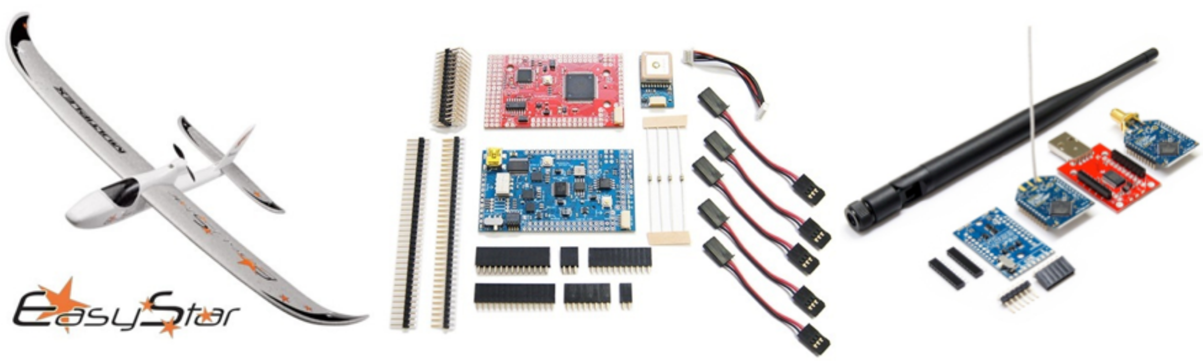
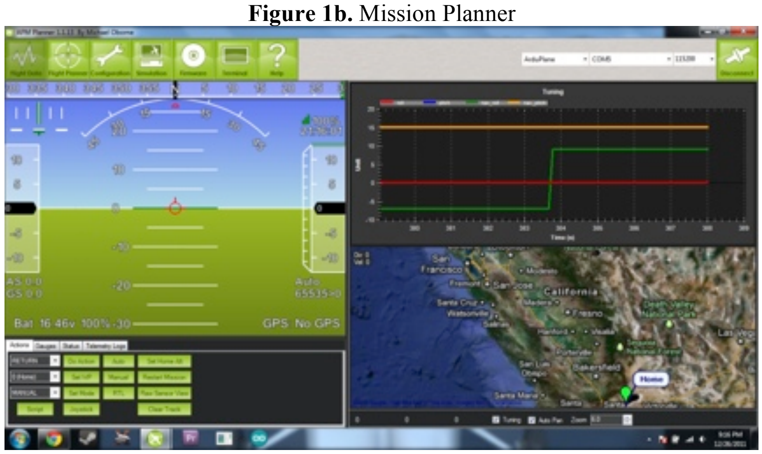


Figure 1b. Mission Planner



The flight data and position of the UAS are telemetered in real time to the ground station that consists of a transceiver and a laptop computer running the virtual cockpit software (Figure 1b). The telemetry data is saved as a text file. This data is then dumped into Excel for analysis. The data extraction from a text file to an Excel or Matlab file and subsequent plotting provide practice in using these essential computational and data visualization tools.

Later in this article, three of the several developed modules are used to demonstrate how the UAS and the flight simulator software can be used to engage students to enhance and reinforce mathematics and engineering concepts.

Flight Simulation Environment

The flight simulation environment consists of three large out-of-the-window (OTW) views, an instrument panel display, throttle, yoke and rudder pedals. The flight simulation software used was the Microsoft MSFS 2004. A shareware by Dowson (2013) was used to extract flight data to the flight data recorder (FLTREC, 2001). This software also allows to synchronize the OTW views with the instrument panel views using another shareware (Napolitano, 2004). The three OTW views were driven by three PCs and three ultra short throw LCD projectors. The simulation software running on a fourth PC controlled the instrument panel display and the simulations running on three PCs providing the OTW views. This fourth PC also was connected to the throttle, rudder and yoke. The aerodynamic and inertial characteristics of the flight test airplane can be easily edited using a freeware FSEDIT (2003). A schematic of the setup is shown in Figure 2a. The OTW views are shown in Figure 2b. The flight and other aircraft data are recorded as the flight progresses using the flight data recorder software. After the flight is completed, the data is dumped into a spreadsheet or MATLAB for analysis. While this setup provided an enjoyable and immersive environment, the approach is equally replicable using a single desktop PC.

Figure 2a. Schematic of Flight Simulator Setup

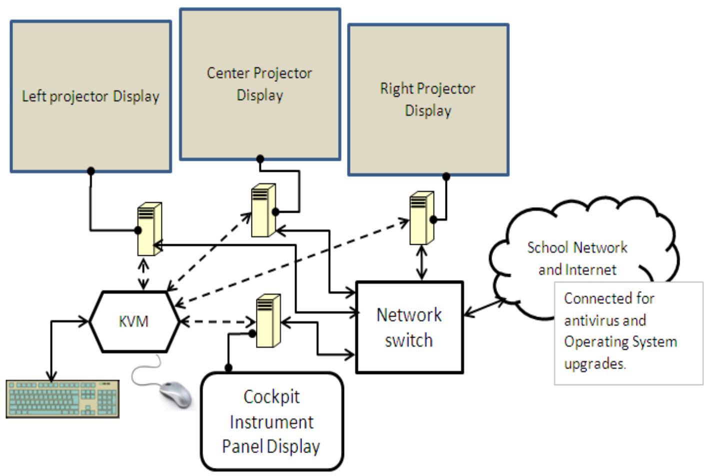


Figure 2b. Out of the Window Views

IMPLEMENTATION

A number of undergraduate students from aerospace, math, electrical engineering and computer science were recruited every semester to form interdisciplinary teams to assemble the UAS integrating the COTS hardware and software. Typically the students worked for 10 hours/week over a semester. We developed several learning modules incorporating the the UAS flights and the flight simulation environment for the hands-on activities. These hands-on activities are conducted by students registered in a typical aircraft performance or stability and control course. Students are organized into flight test teams. Each team consists of a flight test director, test pilot, and test engineer(s). Based on the objective of the flight test, the team develops a flight test campaign and presents to the instructor. This activity provides opportunity to develop team work as well as understanding the process of designing an experiment. The flight test team therefore knows exactly the parameters of the flight test (altitude, speed, bank angle etc.). Some examples of the learning modules are given below. The team presents its project in the form of a written technical report to enhance their ability of written communication. A typical virtual flight test is designed to take no longer than a 50-min class period. Similarly, the real flight test activity with the UAS is also designed such that it does not exceed a 50-minute class period. In addition, we required and guided the students to do some additional work such as designing the flight test plan, subsequent data analysis, and then submitting their final written technical report.

CONCLUSIONS

The approach has been enthusiastically embraced by the students. Surveys conducted on the interdisciplinary team of students involved with the integrating low-cost UAS from COTS components, show very positive impact of the activity (please see Figure 3 below). It is clear from this figure that on a Likert scale of 1-5, (where 1 is strongly disagree and 5 is strongly agree) all the responses show agreement or strong agreement with the statements. The following is a typical comment from a student: "This project really got me into circuits and systems, I started working on my own arduino projects. . . . During my internship interviews whenever I talked about this project, it always resulted in great interest, questions and discussion."

Figure 3. Student Responses (Aji & Khan, 2013)

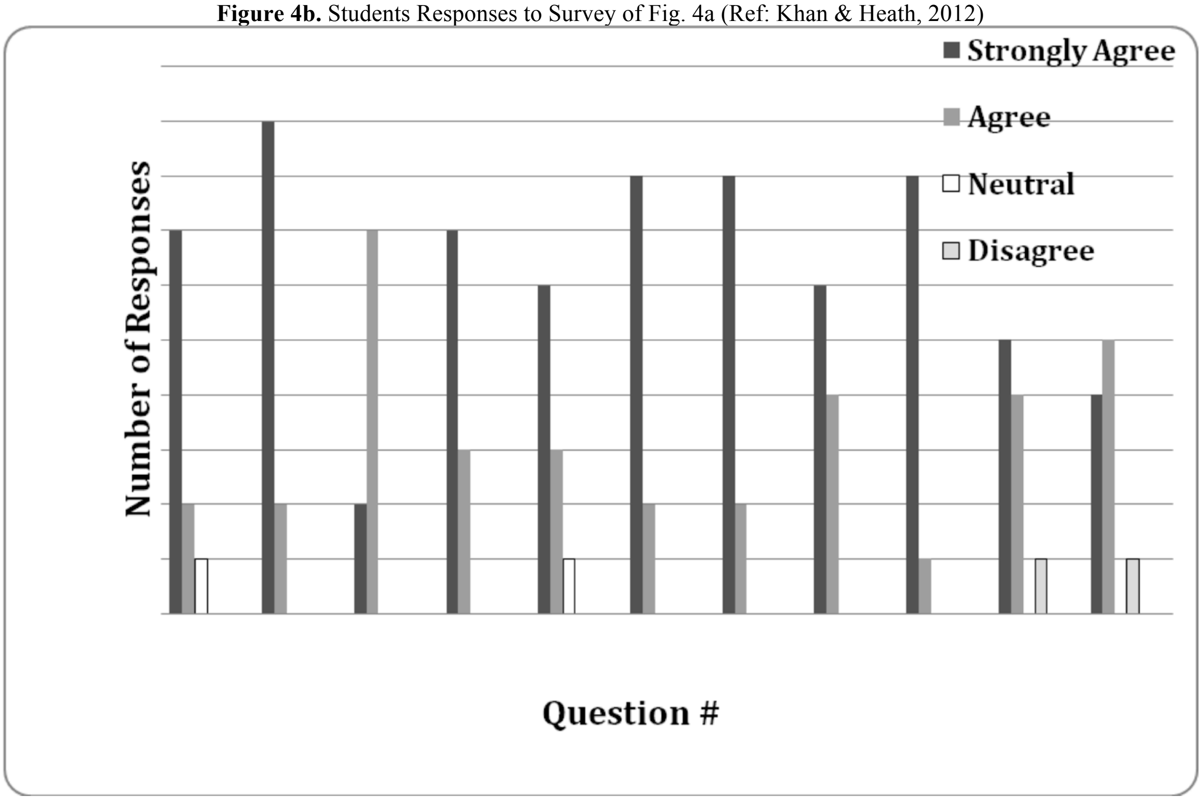
	As a result of working on the UAV project:	Student#								
		1	2	3	4	5	6	7	8	9
1	I have increased my understanding of aircraft performance	Strongly Agree						Agree		
2	I have improved my understanding of aircraft systems	Strongly Agree						Agree		
3	I have improved my presentation and writing skills	Strongly Agree					Agree			
4	I have increased my aerospace vocabulary	Strongly Agree						Agree		
5	I can work more effectively as a team member after this experience	Strongly Agree						Agree		
6	I have improved my ability to search for information to resolve problems	Strongly Agree								Agree

In addition, the responses of students to the virtual flight test component of the approach were measured through a survey instrument as shown in Figures 4a and 4b.

Figure 4a. Survey for Virtual Flight Test (Ref: Khan and Heath, 2012)

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 math and physics 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 multidisciplinary 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

Figure 4b. Students Responses to Survey of Fig. 4a (Ref: Khan & Heath, 2012)



The data collected clearly shows the effectiveness of the pedagogy in engaging students. The approach also has been effective in enhancing skills of the students as members of interdisciplinary teams as well as communications skills. The students not only assembled several of the UAS and flew them successfully as a team but also presented their work at on-campus and off-campus student conferences.

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APPENDIX: LEARNING MODULES

(a) ***Determination of the flight characteristics in a horizontal plane (level 360 turn)***. In this module the students learn that for example the radius of turn (R) of an aircraft depends upon the bank angle (Φ) and the airspeed (V_∞) only. Thus

$$R = \frac{V_\infty^2}{\sqrt{n^2 - 1}}$$

where $n = 1/\cos\Phi$.

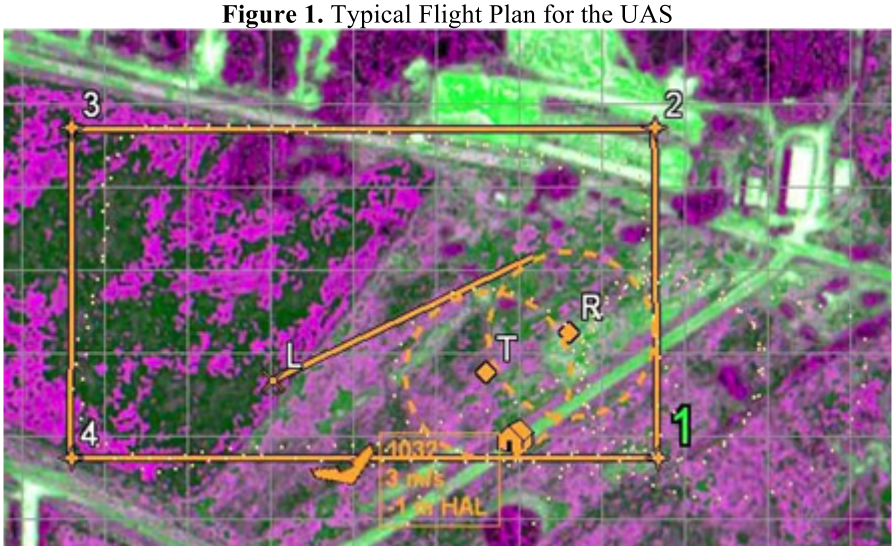
They first solve the problem with 'pencil-paper' to understand the effect of bank angle and speed on the radius of turn. The students then fly a 'virtual' flight test on the simulator and determine the radius of turns for various bank angles and speeds. The flight tests are conducted on at least two different types of aircraft to recognize that the type of aircraft does not matter. The data is then analyzed and presented as a report explaining the differences between pencil-paper results and virtual flight test results.

The flight test team then designs a campaign for the UAS flight. The flight test is conducted and data is collected. The data is again analyzed and presented as a report explaining the differences between pencil-paper results and flight test results as it is done with the flight simulation. The flight test consisted of the following:

- Take-off to a pre-determined altitude
- Loiter over pre-designated take-off point (several orbits) at a pre-determined speed and radius
- Fly to a designated Rally point at a pre-determined altitude and fly several orbits at a pre-determined speed and radius of turn
- Land at the designated location

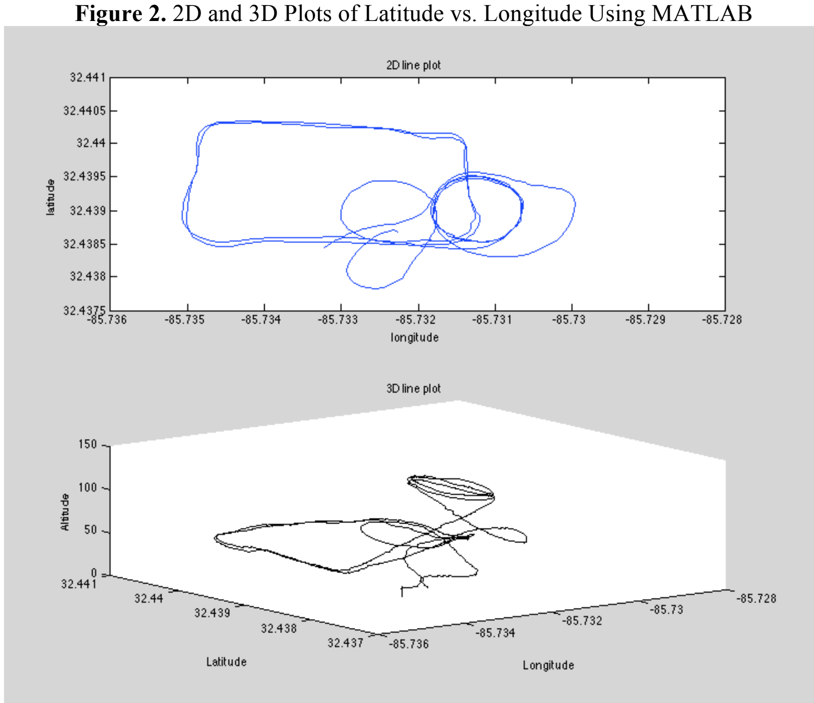
A typical flight test plan that has been designed using the flight planning software is shown in Figure 1.

Figure 1. Typical Flight Plan for the UAS



A group of undergraduate students from different disciplines, mathematics, aerospace engineering, computer science, electrical engineering, and mechanical engineering, had the chance to also learn how to import the telemetry data into MATLAB, extract the column needed for analysis and visualization. For some practice on how to use MATLAB, students graphed the 2 dimensional and 3 dimensional plot for latitude versus longitude as shown in Figure 2. The airspeed and bank angle data was also used by the students to determine the radius of turn and compared with calculations.

Figure 2. 2D and 3D Plots of Latitude vs. Longitude Using MATLAB



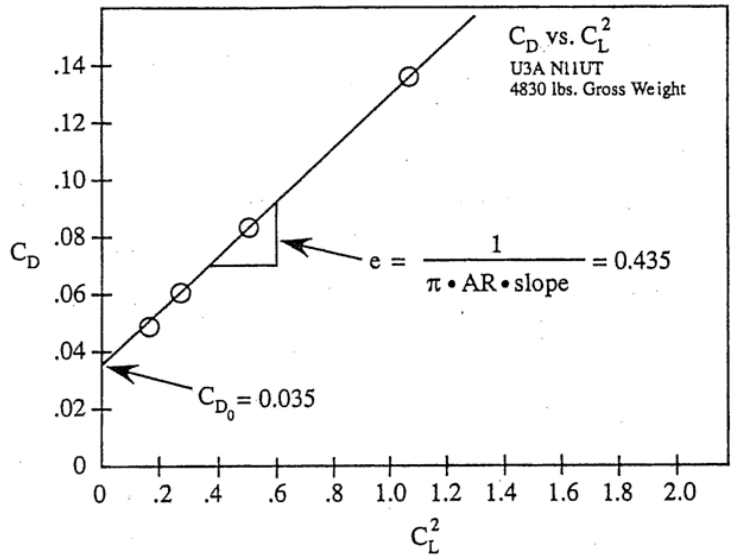
(b) ***Detemination of drag polar of the aircraft***. In this activity the students learn about the techniques of determining the drag polar of an aircraft. The technique studied specifically is to determine the zero-lift drag (C_{Do}), a quantity which cannot be determined analytically for complex configurations.

After paper-pencil exercises for estimating the drag polar, the teams design the flight tests. These flight test profiles are then flown using the flight simulator. The data is recorded, analysed, and reported. The team then plans the flight test for the UAS. The data collected during the flight is then analyzed and reported. Figure 4 shows a typical data analysis plot3

The procedure is as follows:

(i) Fly a constant rate of descent flight
(ii) Collect data for various constant rates of descent and calculate lift and drag coefficients
(iii) Manipulate and plot data using MATLAB
- Sin γ = Rate of Descent/Velocity
- C_L = WCos γ/qS, C_D = WSinγ/qS

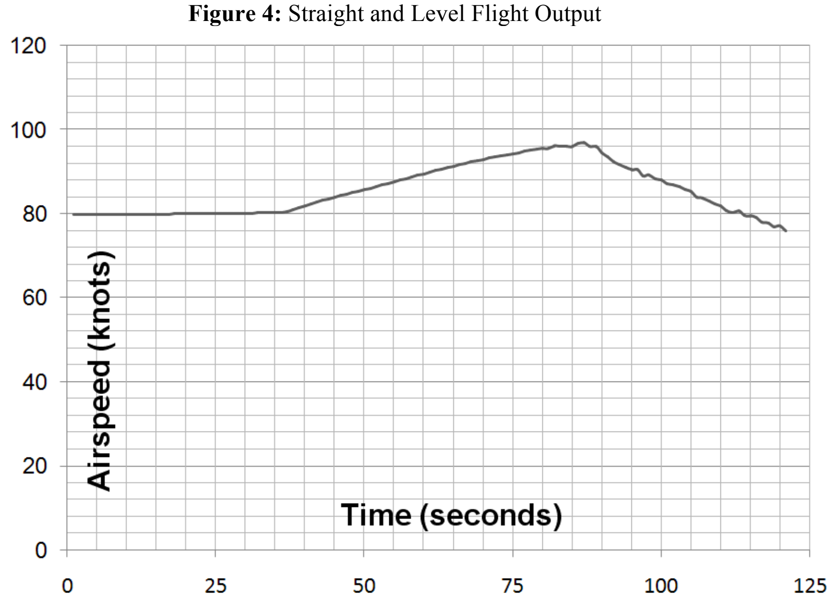
Figure 3. Plotting data for determining drag coefficient



(From: Kimberlin, R., *Flight Testing of Fixed-Wing Aircraft*, American Institute of Aeronautics and Astronautics, 2003, page 163.)

(c) ***Slopes, rates, velocity and acceleration***. Students are introduced to the concept of slope and its physical application using this module. This is a straight and level flight with constant speed segment, followed acceleration and deceleration segments. This module also provides an opportunity to teach spreadsheet formula manipulation and graphing. Figure 4 shows a typical output of this flight maneuver. As can be noted from this figure, it can be used for linear anlayis, or a more complex explanation of drag rise proportional to the square of the velocity. Also, data scatter seen in the deceleration phase can be a good example for using least squares curve fitting.

Figure 4: Straight and Level Flight Output



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