An Undergraduate Course in Unmanned Air Vehicles

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This paper describes some recent hands-on teaching and learning experiences at the Pennsylvania State University in the area of unmanned air vehicles. A two semester course at the senior-level in the Aerospace Engineering Department has been developed to introduce students to unmanned aircraft. The first semester is designed to teach the students about aircraft construction, electric power systems, servos, transmitters and receivers, and aircraft performance. During this semester, each student built and learned to fly a small aircraft with low wing loading. In the second semester, teams of students worked together to build a larger aircraft from an almost-ready-to-fly kit and add onboard sensors such as flight data recorders and wireless cameras to the aircraft. The teams carried out flight tests using these onboard sensors. These hands-on experiences were designed to help students better appreciate their other courses (such as aerodynamics, dynamics and control, structures, and propulsion) and understand aircraft as complex systems. The past, current, and future of unmanned air vehicles and the importance of computer, information, and communication systems in aerospace engineering were also discussed.

I. Introduction

It is encouraging to see a number of university aerospace engineering programs moving to educate students in all aspects of information-enabled aerospace systems. In addition to aerodynamics, propulsion, dynamics/control, and structures; students need to learn about aerospace information technology (IT). Together these subjects represent the five "pillars" of aerospace engineering.[1, 2] Students also need to understand the design process, software engineering, and systems engineering, which tie the five pillars together.

This is a difficult transition for many traditional aerospace engineers, but it must be recognized that the original four technical areas of aerospace engineering are fairly mature compared to IT.[2] Computer capability is improving exponentially. We are only beginning to understand the implications that this will have for aircraft and spacecraft, especially unmanned systems. For aerospace engineers to remain relevant, they need to understand computer systems, information systems, and communication systems. At the Massachusetts Institute of Technology aerodynamics is optional for aerospace engineers, but embedded computer systems are not! At the very least, aerospace engineers need to be able to communicate well with electrical, computer, software, and systems engineers. Hopefully, the AIAA Journal of Aerospace Computing, Information, and Communication (JACIC) can have a positive impact in this area. At one point in 2004, Lockheed-Martin had 4096 job openings. More than half of these (51%) were in the areas of electrical engineering, information technology, software, or systems. There were only 109 openings (2.7%) for aerospace engineers. It is difficult to admit that Lockheed-Martin does not need many aerospace engineers. They need people who understand modern complex aerospace systems, most of which is IT related. Boeing is no different, their webpage states: "Today, we expect most of our future revenue to come from the sales of aircraft-related information products and services." On the Raytheon employment website they list openings primarily for electrical, software, and systems engineers.

This two semester[3] course attempted to provide a valuable experience in modern aerospace systems, specifically unmanned air vehicles. The course aimed to help the students gain practical experience in integrating multiple aspects of aerospace engineering and understand onboard sensors, electronics, and systems that can be used on

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aircraft. Working with these UAV's also can help reinforce theory that is taught in other aerospace engineering courses such as aerodynamics, dynamics and control, structures, and propulsion.

II. Course Goals and Outline

The first semester of the unmanned air vehicles course was only one credit and the second semester was two credits. This two-semester approach was very effective because many of the construction and flying aspects of the course were very time consuming and subject to weather delays.

The first semester course, during which each of the 31 students built and learned to fly a small aircraft, met one evening per week for 15 weeks. There were also flights scheduled for outdoors and indoors. The class was tentatively scheduled for 6:30 - 8:30 PM, but many students arrived early and stayed late. Many of them said this was their favorite course. There were several guest lectures on topics such as UAV history, UAV's in the DoD, small propulsion systems, and R/C helicopters. The goals for first semester were to teach students about the history and future prospects for UAV's, how to construct small UAV's, how to fly small UAV's, and how basic electronic components work in small UAV's.

A brief outline for the first semester is given below:

- Introduction to Course: Course goals were introduced.
- Adhesives: A member from the State College Radio Club discussed some common model aircraft adhesives including cyanoacrylate, aliphatic resin, and epoxy.
- Presentation of a variety of aircraft: Several different models, both fixed wing aircraft and helicopters, were brought to class and discussed.
- History and Future of UAV's: An introduction to the terminology, technology, history, and future directions of UAV's was presented.
- Army & West Point UAV's: Dr. Hansen (one of the authors here) discussed the importance of UAVs in the military and how a senior design course at West Point has utilized R/C aircraft in the past.
- UAV Propulsion Systems: A guest lecturer talked about engine theory with a focus on small propulsion systems with applications in unmanned air vehicles.
- Hands-on flight simulator in class: The flight simulator (GreatPlanes) was introduced in class and each student gained experience in using the software and flying.
- Background lectures: An introduction was given in the following areas: R/C Helicopters, transmitters and receivers, servos, batteries and charging, and soldering.
- Movies shown in class:
    - "Spies That Fly" is a documentary that aired on PBS that showed the current capabilities and the great potential of unmanned air vehicles.
    - "Monocote covering" is a video that provided instruction in covering a R/C aircraft with modern iron-on heat activated plastic materials.
- Aircraft Construction and Flights: Each student built a Dandy[7] aircraft (described below) for them to keep at the end of the fall semester. Although outdoor flights were not possible due to poor weather, the students were able to fly their aircraft in an on-campus indoor facility (the Penn State football team practice field).

For the second semester, the students worked in teams to construct larger R/C aircraft (80 inch wingspan) that were ordered as almost-ready-to-fly kits to minimize the time spent on construction of the airframes. The teams added wireless cameras and onboard data recorders to these vehicles and they performed some flight testing of the aircraft using the onboard sensors. This second semester also met one evening per week in addition to flights at a flying field. This class tentatively met 6:30 - 9:00 PM, with flights on several Saturdays. There were 28 students in this course. For the flights and construction it was very important to have experienced R/C aircraft experts involved; we were very fortunate to have two members (Niessner and Gurney) from the State College Radio Control[4] club involved.

The course outline for the second semester was as follows:

- Movie-"One Week to Solo" is a flight instruction video featuring an instructor with years of experience in training R/C pilots. A nice feature of this video is the ability to simultaneously view the R/C aircraft in flight and the radio transmitter and the inputs that are being used to fly the aircraft.
- Construction of aircraft: The students formed teams of four to five students to construct the aircraft for the semester.

- Glow plug engines: The operation of glow plug engines was discussed and the engines to be used in the aircraft were broken in using an engine test stand.
- Wireless video systems: The wireless cameras, transmitters, and receivers were passed out and tested in the classroom.
- Onboard Flight Data Recorders: The flight data recorders were configured and the students familiarized themselves with the program to interface the recorders and a PC.
- Autopilot Systems: A guest lecturer discussed waypoint navigation, automatic guidance and control, and typical sensors for UAV guidance and control. A demonstration of the Piccolo[15] autopilot's capabilities was given.
- Flights: Three different trips were made to the local flying field. The first trip confirmed the airworthiness of the aircraft. The second trip tested the wireless video systems. The third trip was after implementation of the onboard flight data recorders and included numerous flight tests.
- Final Report: Each student team wrote a paper detailing the construction of the aircraft, the onboard sensors, the flight tests, and the processing of data from the flight tests.

III. Facilities Required

An effort such as this requires numerous facilities and supplies. Fortunately, many of these exist at Penn State. The tools, supplies, software, and laptop required for the course cost roughly $5000. The course is also very time intensive, we usually had an instructor and three assistants in the classroom. This course probably requires 2-3 times the amount of instructor time that a traditional lecture course requires. It also required numerous trips to the flying fields and a van to transport all the equipment.

For most of the two semesters the class met in a classroom/design studio that has workbenches, lab stations, and plenty of storage cabinets and is maintained by Penn State's Center for Engineering Design and Entrepreneurship[5]. The lab stations contain many tools for design, construction, and analysis such as spectrum analyzers, dynamic signal analyzers, mixed signal oscilloscopes, data acquisition switch units, waveform and function generators, desktop and handheld multimeters, and power supplies. The storage cabinets housed items such as protoboards, portable vises, thermocouples, soldering irons, wires, connectors, hand tools and were used for storing materials and tools for the class. The room also has a projection screen which was used with a LCD projector for class presentations and using the flight simulator during class meetings.

Adjoining the workshop classroom is a model shop that has machines for use with wood and soft metals. This shop has drill presses, vertical band saws, a compound mitre saw, a metal cutting band saw, scroll saws, a belt and disk finishing machine, and a rapid prototyping machine. Access to these machines was very beneficial, especially during the second semester of the class.

A flight simulator room was also utilized during this class to allow the students to practice flying aircraft without possibility of destroying the actual aircraft. The GreatPlanes RealFlight R/C Simulator (G2)[6] was set up using a PC and a 50 inch plasma screen and a 8x8 foot Fakespace RAVE system.

Another facility that proved very useful for the course was the indoor practice facility. This indoor practice field was made available for flying the models as an alternate to the outdoor flying in inclement weather. This on-campus facility has a floor space in excess of 300 feet by 300 feet. The ceiling height at the center of the building was high enough that the loops and horizontal figure eight maneuvers could be flown with the Dandy.

The outdoor facility used to fly the large aircraft of the second semester was a flying field near campus. The field is an Academy of Model Aeronautics (AMA)[16] associated site, run by the State College Radio Control club[17], which was very helpful and generous to us. For safety and insurance purposes, it is essential to fly these large aircraft (used in the second semester) at AMA associated sites.

IV. Aircraft and Tools used in Course

The aircraft selected for the two semesters had to fill some basic requirements as follows:

I. First Semester
   a. Relatively simple construction
   b. Accurately cut parts for a true structure
   c. Provide an opportunity to use proven construction techniques
      i. Working with balsa wood
      ii. Using modern adhesives: CA (cyanoacrylate), aliphatic resin, epoxy
      iii. Application of covering, heat adhesive and heat shrink

iv. Good structural alignment without the use of specialized rigs (such as a wing jig)

d. Electric power for possible indoor flying
e. Stable flight design
f. Minimum 4 channel radio suitable for future use by the students
g. Reasonable cost to the student

II. Second Semester

a. Stable aircraft design
b. Several pound payload capacity
c. Minimum construction/assembly time
d. Detailed manual with separate component instructions for team participation
e. Rugged landing gear for grass field operation
f. Gas powered for minimum power system maintenance

The small aircraft built during the first semester was the Dandy from Mountain Models[7]. This aircraft is shown in Figure 1. These aircraft cost under $200, and the students paid most of that cost. These lightly-loaded aircraft (wing loading of 5.4 oz/sq. ft) ideal for learning how to fly radio control aircraft because they fly very slowly and are forgiving of pilot errors. The Dandy has three controls: elevator, rudder, and throttle. Two servos control the elevator and rudder surfaces and an electric speed controller and electric motor control the throttle setting. Every student successfully built and flew one of these aircraft.

Figure 1. Dandy Aircraft from Mountain Models.

The Dandy package came as a kit complete with laser cut balsa and plywood parts, power system (motor, prop, speed control and battery), two servos for the control surfaces and covering material. The Dandy kit furnished for the class had four wing options available which allowed small differences in flight performance. Two different wing spans could be built with dihedral and polyhedral configurations. The polyhedral wing design helped to make the aircraft a stable flyer once it was trimmed for normal flight. When full power is applied, the Dandy is quite maneuverable and is capable of demonstrating stall and spin capabilities.

The tools that were needed to construct the Dandy kit were an Xacto knife with #11 blades, thin and thick CA glue, 200 grit sandpaper, wax paper to protect the work table, needle nose pliers, wire cutters, a hobby iron for applying covering to the wings, and other miscellaneous tools. Additional tools and supplies that were helpful especially for the Dandy flights were a battery charger, lead weights for balancing, extra propellers, Velcro, scotch tape for hinge repairs, voltmeter, soldering iron and a scale.

Construction of the Dandy aircraft was completed in late fall. Several attempts were made to fly the aircraft outdoors but the cold weather and high winds made the flying all but impossible. It can be seen from Figure 2 that the conditions were not conducive to outdoor flying. The availability of the indoor practice facility (Figure 3) and the choice of electric powered aircraft allowed all the students to fly the aircraft they had constructed during the first semester. At the end of the course the students kept the aircraft, the transmitter, receiver and all the auxiliary equipment necessary to fly an electric RC aircraft. The quality of the supplied components was such that the student could use the equipment in future projects. Another valuable tool utilized for learning how to fly R/C aircraft was the GreatPlanes RealFlight R/C Simulator (G2)[6]. Students were able to fly a variety of aircraft using a controller essentially the same as the transmitter they used to fly their Dandy and the aircraft used in the second semester. The previously mentioned flight simulator room was made available so the students could practice flying outside of class. This allowed the students to learn to fly the aircraft without harming the actual aircraft. We also brought a laptop with an LCD projector to class each week, and the students could practice flying as shown in Figure 4.

Figure 2. Some of the class members outdoors with the Dandy models

Figure 3. Dandy flying indoors

Figure 4. R/C Flight Simulator in Classroom.

One of the stronger points of the simulator is helping the student cope with the control reversal perspective that takes place when the aircraft is flying either toward or away from the pilot. When the aircraft is flying away from the pilot, the left/right controls work as anticipated. However, when the aircraft is coming toward the pilot, the left/right controls appear to be reversed. The effect of the controls is reversed in that moving the rudder to the left causes the aircraft to yaw to the right when it is flying toward you. This problem does not occur when you are sitting in the cockpit of a full-sized aircraft because you always have the cockpit perspective, but it is sometimes difficult to teach new R/C pilots. The student use of the simulator minimized the amount of time required for flight training at the flying field.

Figure 5. SIG Kadet Senior Aircraft.

For the second semester, students worked in teams of five to assemble the almost-ready-to-fly (ARF) version of the SIG Kadet Senior[8], shown in Figure 5. Teams of five allowed certain construction tasks to be performed in parallel, allowing the class to minimize construction time to focus on using the onboard sensors. These aircraft have a wing loading of 13 oz/sq. ft and are capable of carrying a significant payload of onboard sensors. A 0.46 cubic inch two-stroke glow-plug engine (SuperTigre[9]) was used to power the aircraft. A Futaba six channel transmitter and receiver[10] was used for flight control. The four basic flight controls (elevator, rudder, ailerons, and throttle) were driven with five servos (one each for elevator, rudder, and throttle and two for the ailerons). These aircraft cost about $700 without the flying field equipment that is needed and the onboard sensors.

The ARF Sig Kadet Senior powered with the Super Tigre engine was very well suited to the second semester aircraft requirements. Designed as an R/C trainer, it is very stable and will fly out of most bad attitudes when the controls are neutralized. The balsa wood and lite plywood construction along with generous wing area gives a light aircraft with a large payload capacity. The ARF version of the aircraft is accompanied with a very detailed manual with a large number of photos shown the details of the assembly process. A tricycle landing gear gives the aircraft good ground handling capability for easy takeoff and landing (however the nose gear proved to be too fragile for some of the less-than-ideal landings). The Super Tigre engine provides more than enough power to fly the aircraft and supports many aerobatic maneuvers. Figure 6 shows one of the aircraft in flight and the students at the flying field.

Some tools that were utilized during the second semester were screwdrivers, pliers, wire cutters, a hobby iron, a heat gun, a propeller reamer, a Dremel rotary tool, CA glue, foam rubber for padding payloads, and a soldering iron. The model shop adjacent to the workshop classroom was used extensively during the construction of the aircraft. Supplies that were useful in preparing the constructed aircraft for flights were a center of gravity balancer, lead weights for balancing, a battery charger, and an engine stand for breaking in the engines. Some materials that were needed to perform the flight tests were containers to weigh fuel before and after flights, a thermometer, a barometer, a glowplug heater, a scale, a TV and VCR for wireless video system, a starter, weights to act as extra payload, extra glow plugs, extra propellers, materials to clean the aircraft, fuel, a laptop for the data recorders, and a large van for transporting the aircraft to the flying field.

An essential part of the flight testing was the use of a "buddy box" where an experienced R/C pilot and the student pilot each had transmitters connected in an Instructor/Student configuration. The Instructor has control of the aircraft until he activates a spring loaded switch that gives control to the student transmitter. The most common form of operation with a new student has the instructor controlling the aircraft during takeoff and landing. Once airborne at a safe altitude and attitude, the student is given control. This configuration allows a student pilot to gain confidence and experience in flying the aircraft while maintaining a way to prevent aircraft crashes. Should the student get the aircraft into a bad flight condition, the instructor takes control until the aircraft is again at a safe altitude and attitude.

V. Onboard Sensors and Flight Testing

Once the Kadet Senior aircraft were successfully constructed and flown, onboard sensors were installed. The students mounted small (.90" X 1.0" X .75"), light-weight (less than one ounce) wireless video cameras[11] on the side of the aircraft fuselage. The 2.4 GHz Wireless Color Cameras had 350 lines of resolution. The video transmitter and receiver system has four channels so four cameras can be viewed using a single receiver. This system can transmit up to a range of 300 feet. To increase the range of this system to 2500 feet, a super high gain antenna receiver[11] that measured 8.5" x 8.5" x 1.2" was positioned on the ground to allow the video from the camera to be viewed on a television monitor. This set-up of the camera, receiver, and television allowed those on the ground to see the view from the aircraft in real time. A VCR was used to record the camera transmissions and these recordings were helpful in conjunction with the data from the flight data recorder.

Figure 6. SIG Kadet Senior in flight.

Figure 7. Photograph from Onboard Video Camera showing Landing Strip, Students/Faculty, and Automobiles.

Figure 7 shows an image taken from one of the SIG Kadet Sr. aircraft. Using the onboard wireless video camera and high-gain antenna these images were displayed live on a ground station during the flights.

When increased resolution is required, small digital cameras can be employed. These cameras can be triggered manually with an additional servo or electronically with some electronics coupled to the receiver. A sample photo taken from a small electric powered aircraft by an SCRC Member is displayed in Figure 8.

An onboard flight data recorder[12] was also installed in the aircraft. The Version 1 data recorder used for this class is capable of monitoring altitude, airspeed, battery level, and servo (rudder, ailerons, elevator, and throttle) controls. Version 2, the current version, can now record the engine RPM and temperature as well as the variables recorded with the original recorder. The flight data recorder is both lightweight and small: it weighs less than 3 ounces and its dimensions are 3.15" by 1.57" by 0.67".

Figure 8. The SCRC Flying Field taken with an Aiptek 1.3 MB Megacam

The flight data recorder is easily interfaced to a personal computer through a USB connection. An application is included with the recorder that is used to set the different recording options (parameters to be recorded, capture rate, etc.) for the flight data recorder. After the recorder has been used in flight, this application is needed to download the data from the recorder. The application can be used to view the recorded data, any error messages, and an artificial horizon simulation of turns, climbs, or dives. The downloaded data can also be saved as a data file which can then be easily opened in Microsoft Excel or similar software.

The Properties capable of being measured are:

- **Elevator, Aileron, Rudder, Throttle controls**: The recorder can record the commands sent to the aircraft servos. 'Y' cables must be installed between the radio receiver and elevator, aileron, rudder, and throttle servos. The 'Y' cables consist of the three wires used for a servo: ground, power, and servo signal and allow these three wires to reach the servos and the flight data recorder. These cables also allow the recorder to receive its power from the battery used to power the servos.

- **Receiver Battery Voltage**: The recorder can measure the voltage of the battery that is being used to power the servos. The recorder will shut itself down if the battery voltage is consistently below around 4.5 volts to save power for the receiver. An error will be recorded if this happens and a message will be displayed when data is downloaded using the computer application.

- **Servo Glitches**: The recorder detects and logs three different types of servo glitches: short, long, and missing servo pulses. These errors are also displayed during download when using the computer application.

- **Altitude**: Altitude is recorded by an altimeter that is used to measure slight pressure differences.

- **Airspeed:** Airspeed is recorded using pressure differential. A Pitot tube is mounted to the aircraft and attaches to a nipple through a small hole in the data recorder. Under normal settings, the range of detectable airspeeds is 24 to 150 MPH. The range of measurable airspeed can be changed to fit the requirements of different applications. To allow the flight data recorder to measure lower speeds (~9-70 MPH), a 100 ohm resistor must be soldered to the circuit board in the recorder. To measure higher speeds (~40-255 MPH), a trace on the circuit board must be removed. A simple change to the recorder configuration must be made with the computer application to use these different speed settings.

The data capture rate is also adjustable and can be set to 5 different settings. The recorder automatically adjusts this rate depending on how fast the parameters that are being recorded are changing. When the aircraft is performing turns or loops, the capture rate will be greater than when the aircraft is stationary on the ground. The default capture rate is 4 Hz and the manufacturer says this rate will give reasonable resolution and recording time. The recording time depends on number of parameters being recorded, the capture rate, and how quickly the parameters change.

The book *Understanding Performance Flight Testing*[13] was used to provide background and tests used in the flight testing portion of the class. Several measurements were made and combined with data recorded from the flight data recorder to determine properties of the aircraft.

Using information from the flight data recorder and measuring quantities such as atmospheric temperature, pressure, density, aircraft weight (with and without fuel), onboard sensor weight, a number of flight parameters were calculated including: lift coefficient, rate of climb, range, endurance, maximum speed, stall speed, and the phugoid mode. The students had to post process this data and write a report describing the aircraft and their flight tests. In particular, they performed the following:

- The lift coefficient was calculated by measuring the weight of the aircraft, the area of the wings, and the density of air and measuring the velocity of the aircraft during level, trimmed flight with the flight data recorder.
- Flight tests were also performed to calculate the rate of climb for multiple throttle settings and aircraft payload weights. The starting and ending altitude and the time between these two altitudes were measured with the flight data recorder.
- The range of the aircraft was determined for low, medium, and high throttle settings. The speed, amount of fuel in tank, and the rate of fuel consumption need to be measured to determine range. The speed can be determined by averaging the airspeed recorded by the flight data recorder over the total flight time. The weight of the fuel was measured before and after the flight and the flight was timed so the amount of fuel in the tank and fuel consumption could be determined.
- The endurance was also calculated from the speed and range for the three throttle settings that were used to determine range as described above.
- The maximum speed was determined at different altitudes by using full throttle and finding the highest airspeed recorded by the flight data recorder at each altitude.
- The stall speed was found for three different payload weights. The aircraft was stalled at idle throttle settings by using the elevator to slowly increase the aircraft angle of attack. The video from the onboard camera was very helpful in determining when stall occurred and finding the appropriate speed reading on the flight data recorder corresponding to when stall occurred.
- Oscillations in altitude and airspeed corresponding to the (longitudinal) phugoid mode were also recorded from the flight data recorder.

There was one accident (and only one) during the entire second semester, which was due to an elevator failure on the SIG Kadet Sr. We actually saw the elevator separate from the tail in flight. The data from the accident was all captured onboard using the flight data recorder. Figure 9 shows roughly the last 25 seconds of the data. It shows the rapid loss in altitude, the increasing speed, and the pilot input commands. The data recorder was set to low-speed mode and so the maximum speed that could be measured was roughly 70 MPH. The data shows the pilot futilely trying to control the elevator as well.

There are additional onboard sensors that could be incorporated into the future classes. We have GPS receivers that have built-in telemetry so the aircraft positions can be viewed on a moving map display on the ground. This system even allows the positions of up to ten aircraft to be viewed at the same time on the same screen.[14] We also have an autopilot system designed for R/C aircraft (the Piccolo Autopilot from Cloud Cap Technologies[15]) that we hope to incorporate in the future. This autopilot system has a GPS receiver, an inertial measurement unit, and pressure transducers for pitot and static ports and can communicate with a ground station using UHF radio. These autopilot systems are quite expensive however (roughly $15,000). Incorporating the GPS receivers would allow students to gain experience in performing surveillance missions in which objects are placed around the flying field. The students could use GPS coordinates to find these objects and take pictures of them. The autopilot could give students experience designing controller gains using hardware-in-the-loop simulations or flight planning using waypoint navigation. Both of these systems could support using aircraft together to work as teams of coordinated UAV's.

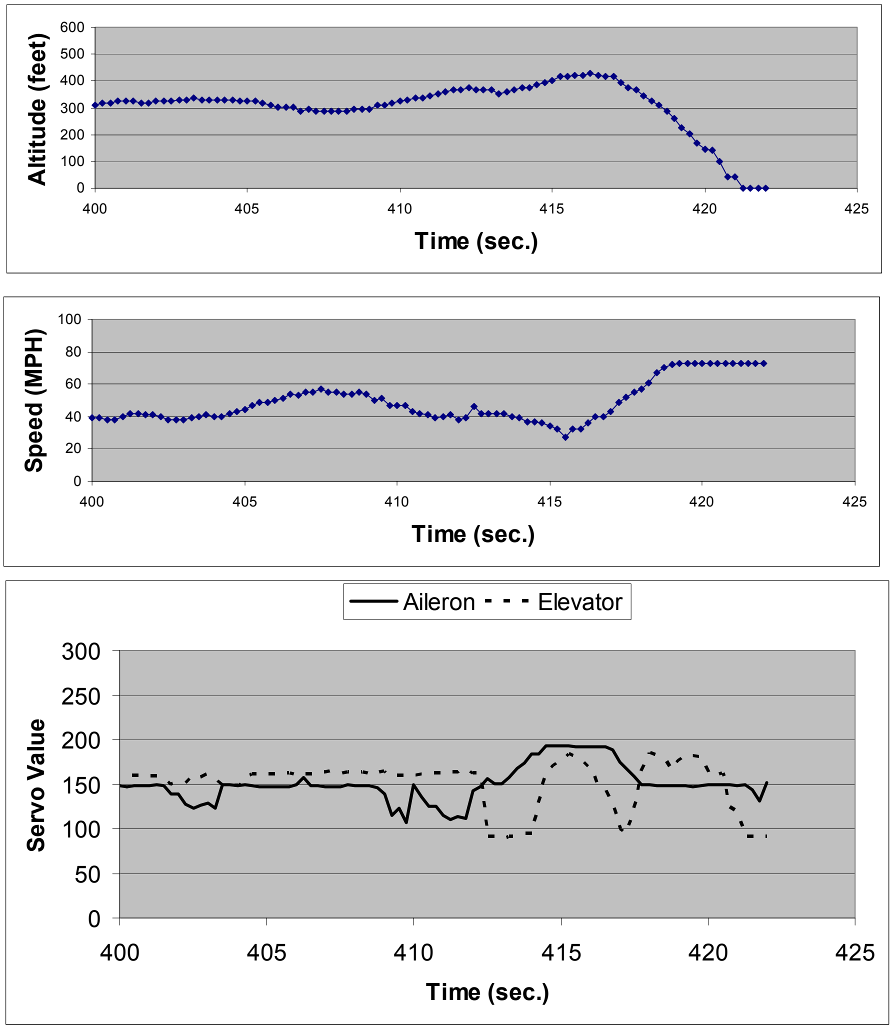

Figure 9. Onboard Flight Recorder Data from Accident.

VI. Conclusion

Students built and learned to fly small R/C aircraft which they kept for future use. They learned techniques for constructing UAVs, applications of UAVs, and the theory behind some of the technology used in R/C aircraft. They also built larger almost-ready-to-fly aircraft and added wireless video systems and onboard flight data recorders to these aircraft; and conducted flight tests using these sensors. These larger aircraft can also be used in the second semester of future courses to save construction time and allow integration of more advanced onboard systems such as GPS, telemetry, and an autopilot.

As the course evolves we will incorporate more onboard systems. These small inexpensive aircraft systems allow us to teach the students the importance of considering the entire system, and the importance of sensors, communications, and computing. Courses such as these are tremendous supplements to traditional aerospace engineering courses.

The splitting of the course into two semesters worked out very well. In the first semester we concentrated on building simple aircraft and flying them. In the second semester we used more sophisticated aircraft and onboard sensors. This allowed the students to learn to appreciate a wide range of aspects of UAVs, from airframe construction to sensor systems.

The success of the flight tests conducted during the second semester of the course indicate that there is great potential for developing an exciting and interesting aircraft performance course using R/C aircraft and onboard sensors.

Acknowledgments

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