AC 2011-2719: DEVELOPMENT OF A SMALL UAV WITH REAL-TIME VIDEO SURVEILLANCE

Dr. Changho Nam, Arizona State University, Polytechnic campus
Scott Danielson, Arizona State University, Polytechnic campus

Dr. Scott Danielson is the Department Chair of the Engineering Technology Department at Arizona State University and has served in this capacity since 1999. He has been active in ASEE in the Mechanics Division and the Engineering Technology Division, currently serving on the Executive Board of the Engineering Technology Council. He has also been active in ASME; being awarded the 2009 Ben C. Sparks Medal for excellence in mechanical engineering technology education, serving as a member of the Vision 2030 Task Force, serving as chair elect of the Committee on Engineering Technology Accreditation, serving on the Board of Directors of the ASME Center for Education, and as a member of the Mechanical Engineering Technology Department Head Committee. He has been a program evaluator for both the Society of Manufacturing Engineers (SME) and ASME and currently serves on the Technology Accreditation Council (TAC) of ABET, representing ASME. He also serves on the SME's Manufacturing Education and Research Community steering committee. Before joining ASU, he had been at North Dakota State University where he was a faculty member in the Industrial and Manufacturing Engineering department. His research interests include machining, effective teaching and engineering mechanics. Before coming to academia, he was a design engineer, maintenance supervisor, and plant engineer. He is a registered professional engineer.

Development of a Small UAV with Real-time Video Surveillance

Abstract

This paper describes a capstone project whose objective was to design, build and successfully test an unmanned aerial vehicle (UAV) with real-time video surveillance capabilities. The student team was composed of seven students within an aeronautical concentration of their Mechanical Engineering Technology program. The students designed and built a UAV capable of flying under direct manual control and indirect automatic control. Direct manual control was accomplished via a model radio-control transmitter, while indirect control accomplished via the onboard autopilot system. Programmable autonomous flight software, utilizing global positioning satellites (GPS), controls the autopilot system. A ground control station (GCS) sends and receives telemetry from a 2.4GHz modem located in the UAV. The GCS utilized Paparazzi, an open-source hardware and software autopilot platform, which allows mission specific flight plans to be created, uploaded, and executed and monitored during the UAV's flight. Real-time video from the UAV is transmitted to the GCS via an antenna and receiver. This comprehensive design and build project, concluding with successful test flights, enhanced the student learning and performance during the course of the project. Assessment data gathered by the project faculty mentor are provided in the paper.

Introduction

Unmanned aerial vehicles (UAVs) are being used today less in military applications and more in the civilian sector as an inexpensive alternative to manned vehicles. Such civilian applications include reconnaissance, environmental monitoring or acting as relays for communication systems. A small UAV, depending upon its intended application, can be technologically advanced and capable of autonomously avoiding obstacles and track objects. Or they can be programmed with a flight plan utilizing way-points and flying along the programmed route at a preset altitude and airspeed.

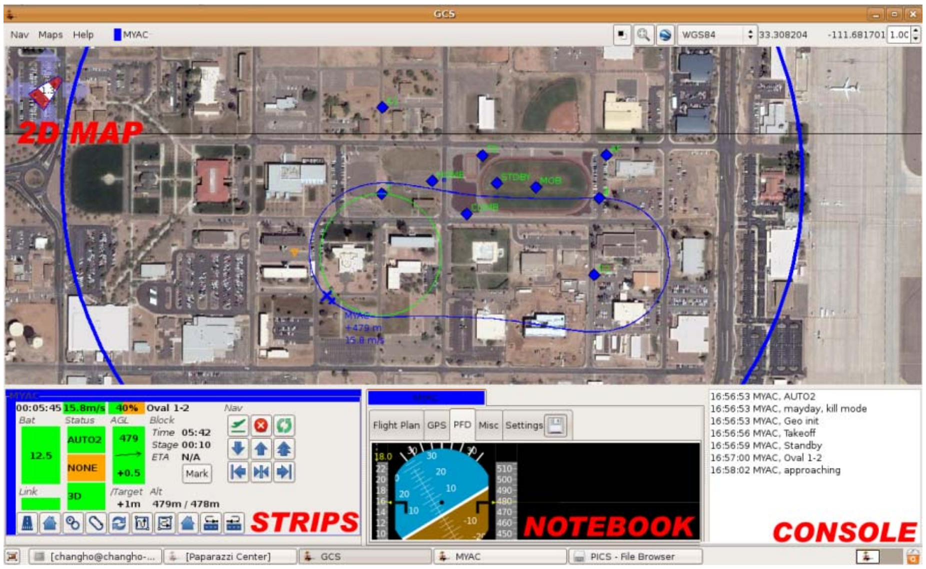
In either case, there are technical challenges to overcome during autopilot system development for UAVs. The autopilot system selected should not hinder the payload capability of the UAV, thus size and weight are key factors. Careful selection of components and use of inexpensive off-the-shelf microelectronic mechanical systems (MEMS) devices are necessary to meet these requirements[1]. In order to design a suitable controller, it is important to estimate an accurate aerodynamic derivative, especially at very low Reynolds numbers, as well as a structural model.

This paper discusses a capstone project whose objective was to design, build and successfully test a small unmanned aerial vehicle (UAV) with real-time video surveillance capabilities. The project was a capstone project within the Mechanical Engineering Technology at Arizona State University. The student team was composed of seven students. So, the work presented below was accomplished by a relatively small group of students and stretched their skill set in a number of ways.

Within the College of Technology and Innovation at Arizona State University, the senior capstone project is a two semester, six credits total, experience for the engineering and engineering technology students. In these capstone projects, the students are assembled into a team staffed for a specific project and are supported by a faculty and industry adviser. The students tackle a design process in the first semester and then complete a detailed design and prototype realization in the second semester. The curriculum is organized so students can apply their technical and non-technical skills in solving their capstone problem and gain knowledge via a culminating major design-build project. The capstone projects are intended to provide students with hands-on learning, continuous practice of a broad set of technical, management, and professional skills, ideally in a cross-disciplinary setting.

In this project, the students designed a UAV capable of flying under direct manual control and indirect automatic control. A ground control station (GCS), consisting of a laptop computer and a 2.4GHz receiver, sends and receives telemetry from a 2.4GHz modem located in the UAV. The GCS utilized Paparazzi, an open-source hardware and software autopilot platform, which allows mission specific flight plans to be created, uploaded, and executed and monitored during the UAV's flight. Real-time video surveillance is accomplished via a color CCD video camera mounted in a movable turret, allowing the camera to survey sixty degrees left or right from its center position of the UAV. Real-time video from the UAV is transmitted to the GCS via a receiver antenna and receiver. The receiver is connected to a USB video capture device connected to a designated video processing laptop.

The UAV is comprised of two primary systems: the autopilot and the airframe. Both systems must function together as a whole, which makes it very important that the flight control system is compatible with the autopilot system. The propulsion system is coupled with the airframe assembly to provide not only thrust but also acts as part of the control system. The autopilot system is comprised of the aircraft, on-board hardware, communication links, and ground station.



```
16:56:53 MYAC, AUTO2
16:56:53 MYAC, mayday, kill mode
16:56:53 MYAC, Geo init
16:56:56 MYAC, Takeoff
16:56:59 MYAC, Standby
16:57:00 MYAC, Oval 1-2
16:58:02 MYAC, approaching
```

Figure 1. Ground Control Station Screenshot of Paparazzi System.

Autopilot System

Due to size, weight and project funding, the autopilot system needed to be lightweight, inexpensive and highly adaptable. These criteria led to the selection of the Paparazzi software and the Tiny 2.11 autopilot board, adapted from an off-the-shelf Wi-Fi network board. The Tiny

2.11 Autopilot board uses a Philips LPC2148 ARM7 based microcontroller, which is a low-power 32-bit RISC processor. The chip has 512KB on-chip Flash ROM, 40KB RAM and can be clocked at 60MHz. The Tiny 2.11 board also has an integrated LEA-5H GPS receiver with a 0.71 in × 0.16 in patch antenna.

The Paparazzi Project[2] is an open source endeavor created at ENAC, the National Civil Aviation University in Toulouse, France. One of the main advantages of the Paparazzi autopilot system is that it is fully open source, which means that the software has been developed under a General Public License (GPL) making it available and free to any user, and it can be modified by the user to suit whatever performance aspect that is required. This allows for modifications that make the software compatible to the current project objective. The Paparazzi autopilot software provides a ground control station (GCS). The GCS is the graphical interface allowing the user to perform functions such as programming the planned flight path, flight status monitoring, , and receiving telemetry from the UAV. A screenshot of the Paparazzi GCS during UAV testing is shown in Figure 1.

The GCS presents an overhead map of the location where the UAV will be flying. The map is generated from satellite images and downloaded from Google Earth™. The flight path, waypoints, and aircraft location are superimposed onto the map, so any deviations from the flight plan can be viewed in real-time. The Strips display, located in the lower left corner of the GCS, displays information about the aircraft, such as battery pack voltage, airspeed, and throttle setting. Common commands located here include launch, take-off/landing, and surveying. Different aircraft may have different associated commands, so the strip layout can be modified to suit the aircraft.

Tiny autopilot board utilizes infrared thermopile sensors as an alternative form of flight stability. While not as precise as a gyroscope, these sensors work in a similar fashion. The theory behind the sensors is that temperature fluctuates according to aircraft attitude. When opposite facing sensors are connected by way of an electrical network, the difference in temperature readings will zero out. This works in both the vertical and horizontal axes. Calibration is required to ensure that the temperature difference has been neutralized. For example, in the vertical axis, the sensor facing the ground will register a temperature much higher than the sensor facing the sky. This is how the autopilot system determines which direction is up.

The communication between the autopilot board and the GCS is carried out by a set of 2.4 GHz wireless modems. The 2.4 GHz band was selected to allow use of a wireless video camera transmitting at 900 MHz.

UAV Aerodynamic Design and Longitudinal Stability

The primary mission of the UAV was to prove the feasibility of creating a semi-autonomous UAV with real time video capability in a University student project setting. The first step in the aircraft design was to establish design criteria based on the mission objective of the UAV. These criteria were as follows.

- The aircraft should produce enough lift to support the autopilot system, avionics, and wireless video system.
- The wingspan of the aircraft should be less than five feet and the fuselage section should be able to accommodate the autopilot hardware, avionics, and wireless video system.

- Cruising speed for the aircraft should be in the range of 35 ft/s ~ 40 ft/s, slow enough to allow the wireless video system to stream video.
- The aircraft should have good dynamic stability in all axes, and the neutral point should be far enough aft of the CG to facilitate a large static margin for good longitudinal static stability.

The students decided that a flying wing configuration would satisfy these basic design criteria. The flying wing configuration allowed simplified analysis, design and fabrication as well as providing a lightweight and aerodynamically efficient platform. A flying wing produces lift more efficiently than a conventional aircraft configuration of wings, fuselage, and tail. Since weight is one of the primary concerns in the aircraft design, the flying wing was also chosen to obtain a higher lift-to-weight ratio by eliminating the fuselage and tail structures. This configuration has the added benefit of the entire surface area generates lift, which is ideal during low speed flight. A flying wing is also an ideal candidate for an autopilot system since it is inherently unstable, unless augmented with some type of computer control system.

A base weight of the autopilot hardware, avionics, and wireless video system was calculated by weighing the individual components (shown in Table 1).

Table 1. Avionics and Video System Weight.

Component	Weight (lb)
Avionics Battery	0.870
Wireless Video Camera Battery	0.370
Tiny 2.11 Autopilot	0.059
Vertical IR Sensors	0.010
Horizontal IR Sensors	0.010
Wireless Modem	0.030
RC Receiver	0.010
Wireless Video Camera	0.070
Wireless Video Camera Transmitter	0.050
Engine Speed Controller	0.054
Servo × 2	0.060
Total Weight	1.593

Table 2. Estimated UAV Empty Weight.

Component	Weight (lb
EPP Foam	1.000
Fuselage Box Structure	0.500
Spars	0.200
Winglets /Control Surfaces	0.250
Motor/Propeller	0.244
Glue/Hardware	0.250
Total Weight	2.444

Using a maximum wing length of five feet and an estimated wing area of 5.0 feet^2, the projected volume of the aircraft was estimated and the weight was calculated based on the density of expanded polypropylene (EPP Foam)[3] of 1.33 lb/ft^3. An estimated weight of the structural components was then calculated[4,5] and is shown in Table 2 below. With the calculated weight of the avionics, wireless video system, and the estimated weight of the structural components, the UAV had a projected weight of four pounds.

Using this estimated design weight of the UAV, the required lift coefficient for a cruising speed of 35 ft/s is 0.5442. The airfoil and wing design/analysis program XFLR5[6] which is public-domain software was used to design the candidate UAVs. A total of five different wing configurations were considered by the students for this design. For each airfoil analyzed, aerodynamic coefficients were calculated for Reynolds numbers ranging from 2,000 to 3,000,000 and for angles of attack ranging from 6° to 15°. The resulting calculated airfoil aerodynamic data were used to estimate the finite wing characteristics and performance, such as lift curve slope and trim angles of the UAVs (shown in Table 3).

Table 3. Candidate Design Characteristics.

	Design 1	Design 2	Design 3	Design 4	Design 5
Fuselage Airfoil(s)	NACA0020 E230	NACA0024 E186	NACA0020 E230	NACA0020 E230	NACA0024 E230
Fuselage Dihedral	5.0°	0.0°	4.0°	0.0°	0.0°
Fuselage Twist	5.5°	5.0°	7.0°	7.0°	7.0°
Wing Airfoil	E230	E230	E230	E230	E230
Wing Dihedral	5.0°	4.0°	4.0°	4.0°	4.0°
Wing Twist	5.5°	5.0°	2.0°	2.0°	2.0°
Wing Span (ft)	7.47	4.90	5.99	3.99	4.54
Wing Area (ft^2)	6.16	6.52	7.34	5.33	5.03
CG (in)	8.20	8.37	7.50	6.50	6.15
NP (in)	8.90	9.75	9.00	8.10	7.75
Cruising Speed (ft/s)	29.0	34.1	30.0	39.0	37.5
A/C Trim Angle	5.0°	4.0°	4.0°	4.0°	4.0°
C_L	0.6444	0.4410	0.5046	0.4057	0.4727
C_m	0.0190	-0.0002	0.0016	0.0008	0.0000
Static Margin (%)	5.00	7.66	7.80	8.00	11.00

Figure 2 shows a sample aerodynamic grid created for the analysis of the UAVs using the XFLR5 program and the pressure distribution at an angle of attack of four degrees. Once the analyses of the candidate design configurations were completed, the longitudinal stability analysis was conducted using XFRL5.

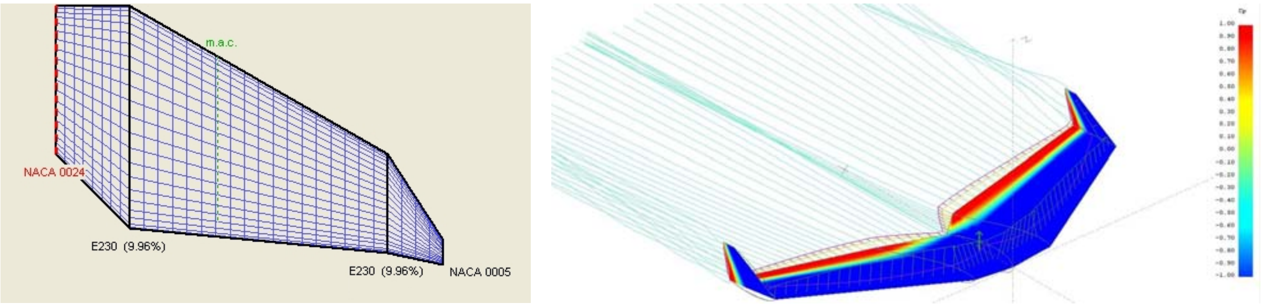


Figure 2. Aerodynamic Panel and Pressure Distribution at α = 4°.

Based on the design criteria, students decided that "Design 5" provided the needed payload capability, lift, and the desired cruising speed. The characteristics of the selected design are found in Table 3. "Design 5" provides the high thickness to chord ratio of the NACA 0024 airfoil and the high lift of the Eppler 230 airfoil. This combination of the airfoils achieves a relatively high aspect ratio wing, which is recommended for slower aircraft[7]. The Eppler 230 airfoil (used at the tip), is generally used on swept wings and provides good stability. The span of the UAV is 54.5 inches, including a midsection length of 12 inches and a chord length of 16 inches. The midsection between the two wings provided a pseudo fuselage to house all the systems (autopilot, wireless video camera, batteries, etc). The fuselage cross-section is a NACA 0024 airfoil blending to an Eppler 230 airfoil, attached to the wing sections by two carbon fiber spars running through the fuselage and into the wings.

Figure 3 shows the longitudinal stability analysis of the "Design 5" UAV model. The neutral point of the aircraft is located 7.75 inches from the leading edge of the fuselage section. The CG is located 6.15 inches from the leading edge of the fuselage, yielding a static margin of 1.6 inches. This static margin provided the desired longitudinal static stability and short-period dynamic pitch stability.

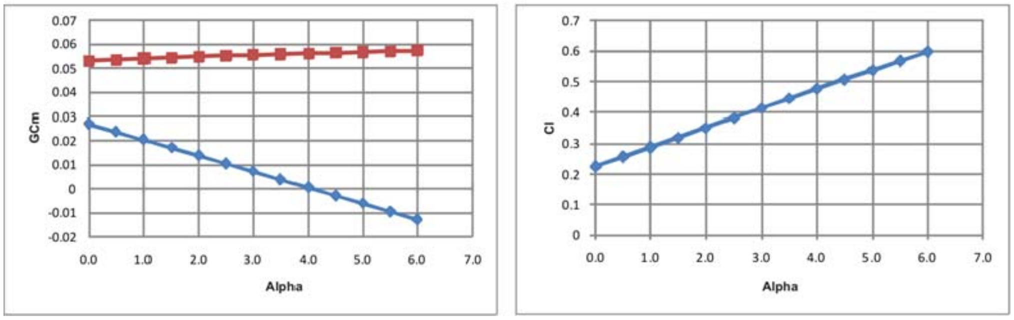


Figure 3. Longitudinal Stability Analysis Results for the Selected UAV Design.

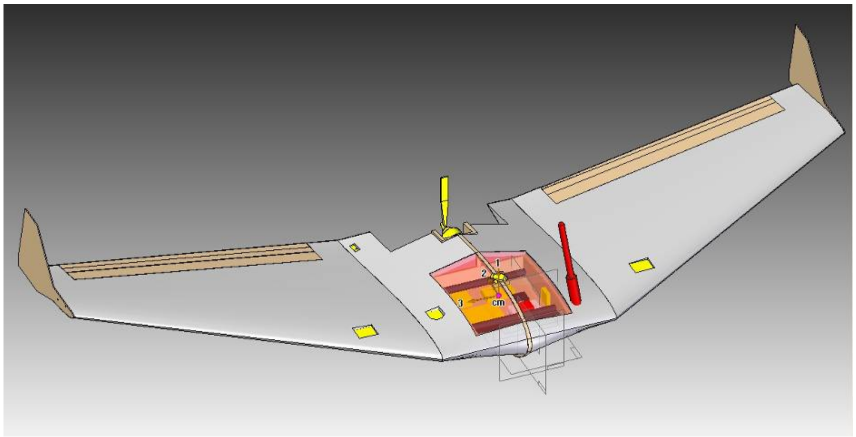


Figure 4. Solid Edge™ Model of the UAV.

During the design phase, students proposed that the UAV be a modular configuration. A modular configuration allowed for various size airfoils to be added to the fuselage for different missions. A larger set would allow the UAV to carry a larger payload while having a lower cruising speed. Adversely, a smaller set of wings would allow for portability of the UAV while enabling a higher cruising speed. Modularity of the UAV was accomplished by friction fitting the wings to the fuselage spars and taping the wings to the outer surface of the fuselage. This allowed the same fuselage to be used for various wing configurations. The aircraft pitch and roll attitude is controlled by elevons located at the trailing edge of each swept section of the wing. The width of the elevons (forward to aft) was set as 15% of the root chord length of the wing[8]. The length of the elevons was chosen to be 16.8 inches, 80% of the span of a single wing[8]. Because a flying wing does not utilize a vertical tail, it was necessary to attach winglets to the tips of each wing to provide directional stability. Winglets also reduce drag resulting from wingtip vortices, and help to reduce lift-induced drag. The winglet length was fixed as 20% of a single wing's span.

With the information for the selected design obtained with XFLR5, a digital model was created using SolidEdge™ software[9] (Figure 4). The model contains all of the systems. This compete digital model allowed fine-tuning of the CG location to conform to the desired trim CG obtained from the XFLR5 analysis, by manipulating the arrangement of various system components within the fuselage. The exact dimensions of the wing were thus established for the final design of the aircraft.

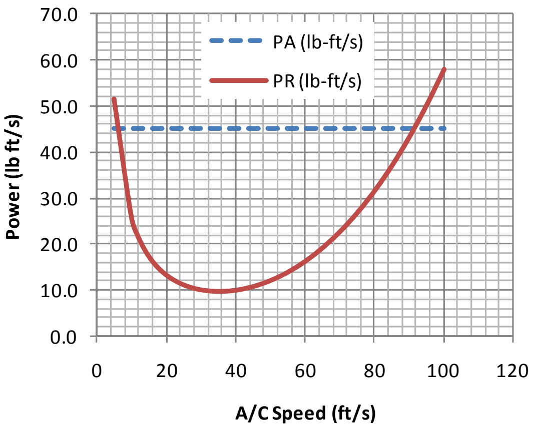


Figure 5. Power Curve.

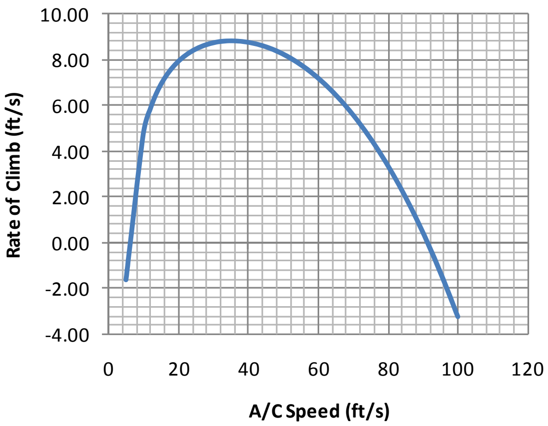


Figure 6. Rate of Climb Curve.

The UAV was propelled by an electric motor. The selection of the electric motor was based on several factors, weight, relatively maintenance free and low cost. The electric motor, AXi Brushless-2814/12[10], was selected with an eight inch, two-bladed propeller. The power available (P_A) was given in the engine specifications of the design criteria as 45 lb-ft/s. Given the weight, airspeed and lift-to-drag ratio in steady state level flight, power required for the UAV was calculated. Figure 5 shows the power required and power available versus airspeed. At a cruising speed of 35 ft/s, the power required (P_R) was found to be 9.8 lb-ft/s. As shown in Figure 5, the estimated maximum speed of the UAV will be approximately 92 ft/s. The rate of climb for the UAV was also estimated from the power data using the following equation, where *W* is the weight[7].

$$R/C = \frac{(P_A - P_R)}{W}$$

Figure 6 shows the rate of climb versus airspeed. At an airspeed of 35 ft/s, the UAV can climb with a rate of 8.8 ft/s.

UAV Fabrication

The construction methods used for the UAV were similar to those used on R/C model airplanes. The major difference between the construction of the UAV and construction of an R/C model airplane was the tight control over tolerances. The main rib was cut to specification from plywood-balsa composite. Upon completion, the two fuselage halves were adhered to the main rib. Elements to construct the avionics compartment were cut out of balsa and affixed to the compartment interior. The motor mount was fabricated by doubling and fastening sheets of 0.25 inch plywood-balsa composite, mounted to the main rib and fuselage. A rectangular cutout in the bottom port side of the avionics compartment was made to house the video camera turret. Figure 7 shows the modular fuselage design layout.

Real-time video surveillance is accomplished using a KX171 color CCD video camera mounted in a movable turret. The turret allows the camera to survey 60 degrees left or right from its center position on the UAV. The camera mount design incorporates a gimbal and turret.

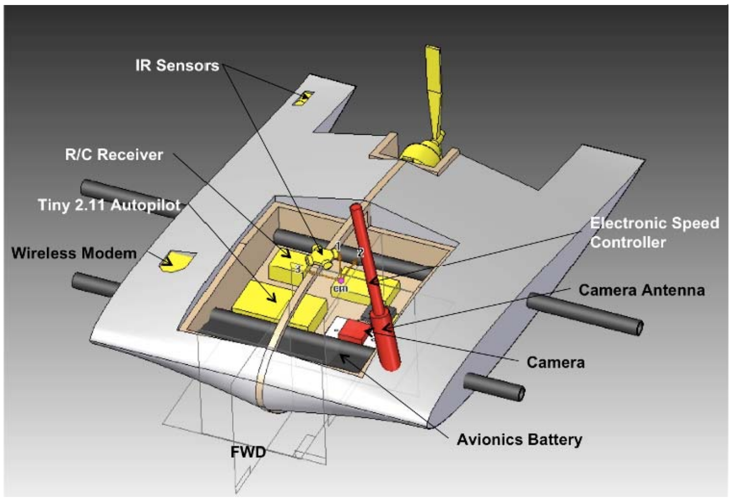


Figure 7. Modular Fuselage of UAV NX-03.

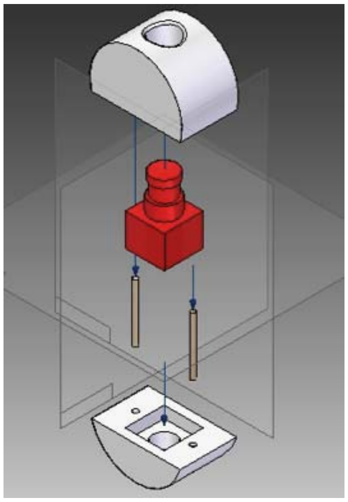


Figure 8. Video Camera Turret.

Figure 9. UAV NX-03 Assembly

The camera was securely fitted into a slot cut into the turret and is encased on five sides by a solid piece of EPP foam, as shown in Figure 8. The cap for the back of the camera completes the "disc" shape of the turret and provides a means of leading the camera wire to its transmitter through a hole in the back. The turret is fixed to a balsa axle and is mounted to a gimbal rack, allowing rotation while keeping its axial orientation stationary. The axle is mounted at a slight angle with respect to the wing's chord line to place the camera's field of vision slightly in front of the wing. The turret movement is from side to side, allowing the UAV to circle an object while keeping the camera fixed on that object.

Carbon fiber stiffeners were slotted and glued into each main wing, one inch from, and parallel to, the leading and trailing edges. Following completion of the servo compartments, servos were embedded into the wing foam for a flush-fit, and the elevons were mounted with hinges to each wing. All electronic components, including the motor, were mounted in their respective locations and the embedded wiring was connected. Wiring was then neatly organized and zip-tied within the avionics compartment. The wings are slid onto the carbon fiber spars, and secured to the fuselage center section with clear packing tape for quick and easy removal or replacement, to accommodate the aircraft's modular design. Figure 9 shows UAV NX-03 assembly.

Flight Testing and Results

Individual testing of components, as well as a series of test flights, were conducted during the course of the project. A brief description of these test flights is given below.

Manual Flight Testing. Manual flight-testing of UAV NX-03 was performed with the aircraft controlled from the ground using the radio transmitter. Trim conditions and calibration of the controls under manual flight were achieved before embarking on autonomous flight. Trim conditions vary based on effective load and center of gravity (weight and balance), and are also influenced by ambient conditions. The primary method for trimming the UAV for steady-state level flight is through fine adjustment of the control surfaces (elevons) and engine thrust during manual flight. Pitch is the primary control for airspeed, and roll is primary for lateral/directional control. There is no yaw control, however, winglets are used at each wing tip to provide directional stability. Engine thrust is controlled and adjusted as needed for climb, decent, and level flight conditions, and is the primary control for altitude.

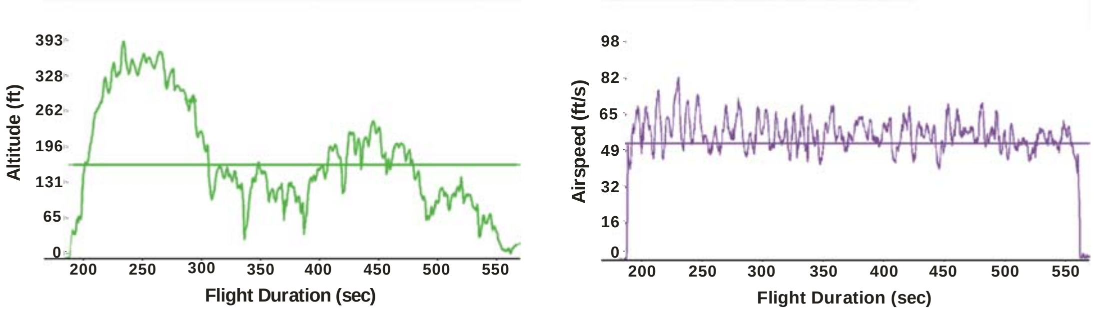
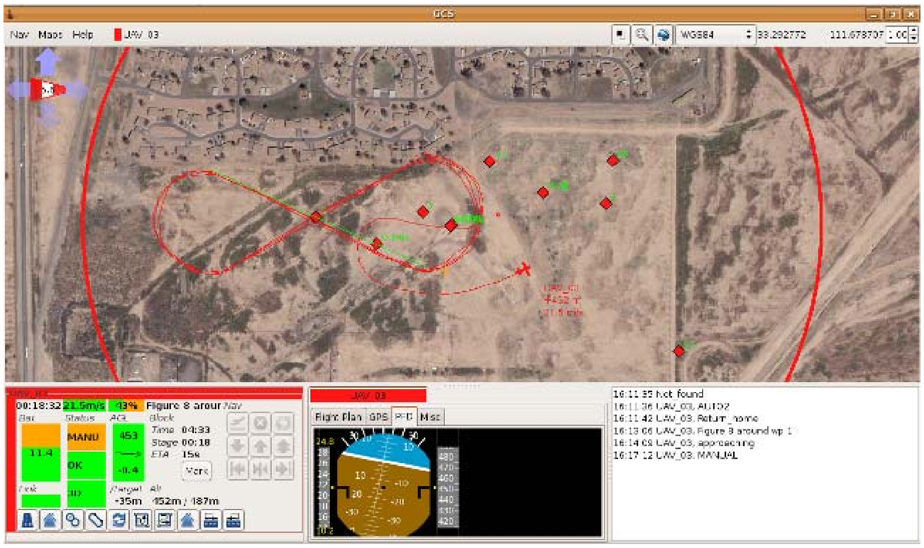


Figure 10. Altitude and Airspeed Histories of UAV NX-03 During Manual Flight.

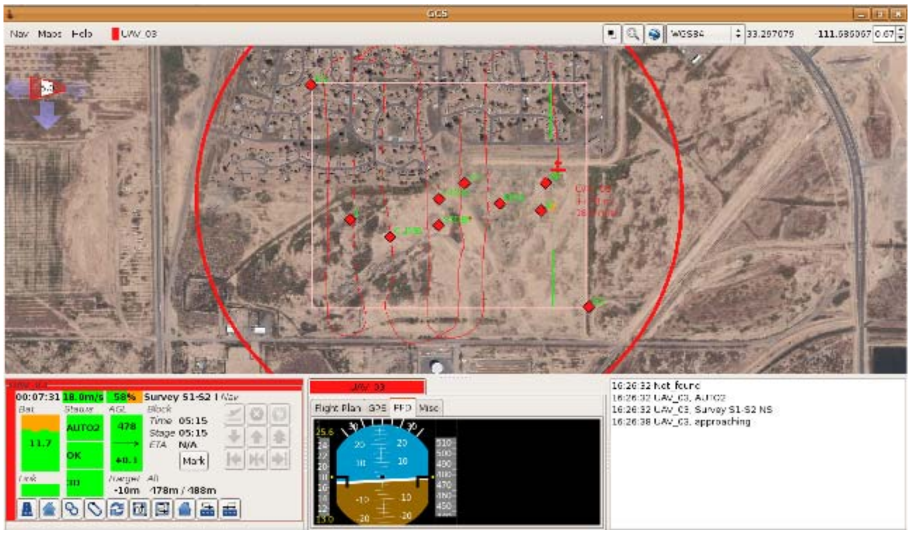
The results of the manual test flights showed that level, un-accelerated flight, could be achieved at 25% engine thrust. The power available was sufficient for launch, and there was plenty of excess power for high rates of climb, a desirable characteristic for the UAV. The UAV was trimmed so that straight and level un-accelerated flight could be achieved with centered control inputs on the RC transmitter. Figures 10 shows flight-test telemetry from the manual flights used to determine basic trim conditions.

Fully Autonomous Flight Testing. For fully autonomous flight-testing, a flight plan was programmed using the Paparazzi software and then uploaded to the autopilot system onboard. The aircraft was manually launched. Once altitude was achieved, the aircraft was transferred to the fully autonomous mode. Several real-time autonomous flight tests were performed to demonstrate the functionality of the UAV. Two of the flight plans used a figure-eight pattern, e.g., Figure 11, and a search and rescue flight path, as shown in Figure 12. The purpose of these tests was to verify the real-time autonomous flight capability with different sets of waypoint scenarios.



```
16:11:35 Not_found
16:11:36 UAV_03, AUTO2
16:11:42 UAV_03, Return_home
16:13:06 UAV_03, Figure 8 around wp 1
16:14:09 UAV_03, approaching
16:17:12 UAV_03, MANUAL
```

Figure 11. Figure-Eight Flight Path Ground Tracks.



```
16:26:32 Not_found
16:26:32 UAV_03, AUTO2
16:26:32 UAV_03, Survey S1-S2 NS
16:26:38 UAV_03, approaching
```

Figure 12. Search and Rescue Flight Path Ground Tracks.

The guidance loop in the autopilot controller uses the uploaded waypoint information to determine the next destination of the UAV. Figure 13 shows the flight test telemetry from the UAV, recorded transitioning from manual to autonomous mode during a test-flight. As shown, the aircraft maintained appropriate altitude, airspeed and heading while consistently navigating to the pre-programmed waypoints during the auto-flight.

Figures 14 relates roll and pitch angles to time throughout the duration of the corresponding flight. It should be noted that during initial test flights, a 2-3 Hz side-to-side oscillation was noticed in the roll history. This was corrected and showed that the UAV was easily controllable and the design process lends itself to making changes to the airframe and other systems in a quick and efficient manner.

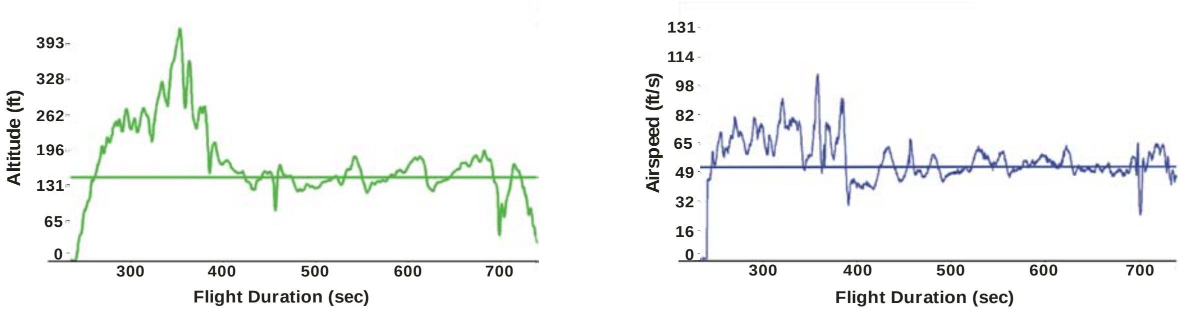


Figure 13. Altitude and Airspeed Histories of UAV NX-03 During Autonomous Flight.

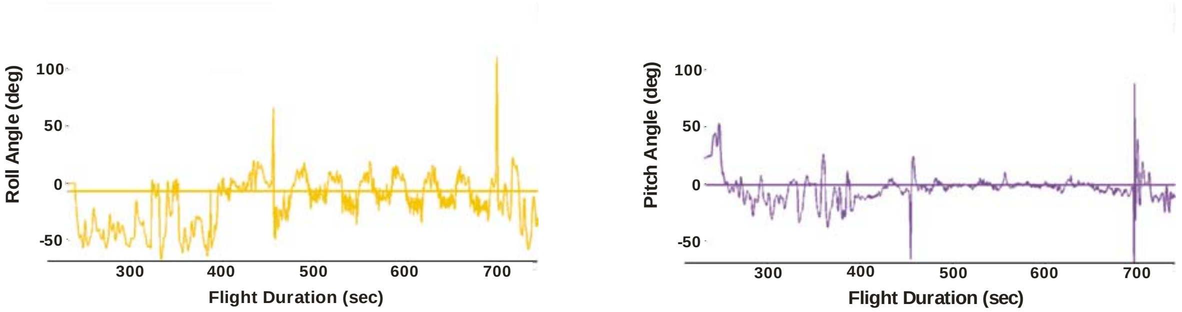


Figure 14. Roll and Pitch Histories of UAV NX-03 During Autonomous Flight.

Figure 15. Real-Time Onboard Video Surveillance.

Testing of the onboard video surveillance system was conducted simultaneously with the autonomous flight testing. Once the video transmitter was powered, the aircraft successfully streamed video to the GCS via the flat patch receiver antenna, dual output receiver and USB video capture device. Figure 15 shows a screen capture taken from the real-time surveillance footage recorded from onboard the aircraft.

Student Learning and Assessment Data

The UAV student design team was composed of seven students within an aeronautical concentration of the Mechanical Engineering Technology program at Arizona State University. The aeronautical concentration students are required to take 18 credit hours of the concentration technical courses in addition to the core requirements of their degree program. These courses are: Aircraft Systems, Aircraft Design I, Aircraft Structures, Gas Dynamics & Propulsion, Wind

Tunnel Testing, and Composites Materials Manufacturing. At the beginning of the semester, the UAV capstone project faculty adviser created two design groups, the structural design/fabrication group and autopilot system design group. The adviser had students identify all necessary project tasks, create a project plan, and report progress via weekly group meetings. Each group team leader was able to accomplish the required schedule. The requirements for the capstone course include a written design/progress report each semester and a formal presentations, including a project showcase for the public and Industrial Advisory Board (IAB). As a related assessment activity, faculty and IAB members were asked to assess student proficiency in multiple outcome areas. The summary results of this assessment are shown in Table 4. As shown in the table, the student outcomes were ranked around 90% or higher for all of the items.

Table 4. Capstone Project Assessment

Outcomes to assess:	1	2	3	4	5	6	**Average Score**
Ability to communicate effectively in written & oral formats (g)		1	12	22			**3.60**
Percentage of attainment		*3%*	*34%*	*63%*			**90%**
Ability to function effectively on teams (e)			6	26	3	1	**3.81**
Percentage of attainment			*19%*	*81%*			**95%**
Ability to apply creativity in the design of systems, components or proecesses (d)			8	27			**3.77**
Percentage of attainment			*23%*	*77%*			**94%**
Understanding of basic machine design elements (program criteria)			13	21	1		**3.62**
Percentage of attainment			*38%*	*62%*			**90%**
Appropriate mastery of the current knowledge, techniques, skills and tolls of their desciplines& an ability to apply knowledge & adapt to emerging applications of mathematics, science, engineering & technology (a)			11	24			**3.69**
Percentage of attainment			*31%*	*69%*			**92%**
Ability to conduct, analyze & interpret experiments & apply experimental results to improve processes/designs & commitment to continuous improvement & the competencies to measure characteristics of quality, to compile data into meaningful report format & to interpret data (c)			12	18	5		**3.60**
Percentage of attainment			*40%*	*60%*			**90%**
Ability to identify, formulate & solve technical problems (f)		1	12	22			**3.60**
Percentage of attainment		*3%*	*34%*	*63%*			**90%**

Scale : 1-Poor, 2-Average, 3-Good, 4-Excellent, 5-Not observed, 6-Did not assess

Since 2008, the Engineering Technology Department has started to incorporate the use of more formal rubrics when evaluating outcomes. This has been a gradual change and the rubrics were edited several times in those years as faculty worked with the rubrics. Tables 5 and 6 below are outcome assessment data evaluated by a group of faculty advisers based on new rubrics.

Table 5. Capstone Project Assessment Results - ABET Outcome b.

ABET OUTCOME – b

Technical Competence–An ability to apply knowledge of mathematics, science, and engineering as well as collect, analyze, and interpret data.

Level 1 Verbally and mathematically communicates the engineering and science principles underlying engineering problems and recognizes own strengths and weakness in their knowledge.

Level 2 Applies learned math, science, engineering and technology principles to engineering problems.

Level 3 Selects and applies appropriate math, science, engineering and technology principles to domain specific engineering problems.

Level 4 Selects and applies appropriate math, science, engineering and technology principles to successfully solve multidisciplinary engineering problems.

Rubric

		Level 1	Level 2	Level 3	Level 4
ABET (b) an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology.	*Mathematics*		1	3	1
	Engineering Analysis		2	3	
	Science		2	2	1
	Product/Project Realization			4	1

Evaluator's comments;
- The team possessed sufficient skills to properly handle all below to a satisfactory level of completion.
- One student used theoretical design data to create a new prop.
- Students designed a complete lower end in solid works & then used CAM software, surfcam to start machining parts.
- Students showed excellent skills to model UAV with solid edge, create all the detailed drawings.
- Demonstrated ability to analyze problems & resolve using creativity & application of current technology.
- Students as a CAD master drawings are professional quality.

Table 6. Capstone Project Assessment Results - ABET Outcomes h and i.

OUTCOMES – h, i

Professionalism–An understanding of professional and ethical responsibility, a commitment to on-going professional competence and possession of basic professional and organizational success skills.

Level 1 Exhibits professionally appropriate behavior patterns, appreciates engineering as a learned profession and possesses daily success skills.

Level 2 Accepts responsibility for their education, understands the major professional and ethical responsibilities of engineers, the major specialties of engineering and basic corporate structures and purposes.

Level 3 Uses common moral theories and concepts to guide them in their ethical decision making and has formulated a probable career path that takes into account current trends technology and society

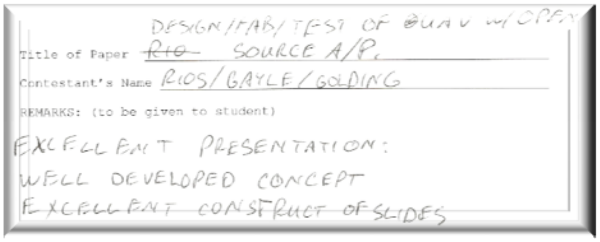
Level 4 Effectively guides their own efforts at gaining and maintaining their professional competence and reputation.

Rubric

		Level 1	Level 2	Level 3	Level 4
ABET (i) an understanding of professional, social and ethical responsibility	*Time management*		1	3	1
	Ethics			5	
	Professional Identity		1	4	
ABET (h) life-long learning	*Lifelong learning*		4	1	

Evaluator's comments;
- This was stressed with the students. Tried to push good habits for students to follow.
- Capstone is an excellent way to see your strengths & weakness. I saw a real growth of maturity in students.
- Created a Gantt chart at beginning of year and used the schedule to check their process.
- Some knew they had weaknesses, however they knew where to get educated answers.
- Student created weekly meeting minutes to keep all the schedules to accomplish the project.
- Students commented on need to stay current with technology especially software.
- During the project post mortem meeting the students had an open discussion focused on desired engineering skills relative to machine building.
- All 4 students discussed plans to increase their knowledge & skills relative to their chosen career path.

Also, the student team attended a competition, where their work was presented at the AIAA (American Institute of Aeronautics and Astronautics) Region VI Student Conference, on March 25~27, 2010. The UAV student team won second place overall in the undergraduate division at this regional student competition. The judges' comments on UAV student's presentation and report are very positive, as shown in Figure 16.



DESIGN/FAB/TEST OF UAV W/OPEN

Title of Paper ~~RIO~~ SOURCE A/P.

Contestant's Name RIOS/GAYLE/GOLDING

REMARKS: (to be given to student)

EXCELLENT PRESENTATION:

WELL DEVELOPED CONCEPT

EXCELLENT CONSTRUCT OF SLIDES

Figure 16. Judges' Comment on the UAV Team Presentation.

Summary

This paper discusses a capstone project whose objective was to design, build and successfully test a small unmanned aerial vehicle (UAV) with real-time video surveillance capabilities. In this project, a seven student team designed a UAV capable of flying under direct manual control and indirect automatic control. Programmable autonomous flight software, utilizing GPS, was used to control the onboard autopilot system. The students utilized Paparazzi, an open-source hardware and software autopilot platform, and were able to develop mission specific flight plans to be created, uploaded, and executed and monitored during the UAV's flight. Real-time video surveillance is accomplished via a color CCD video camera mounted in a movable turret. So, the work presented was accomplished by a relatively small group of students and stretched their skill set in a number of ways. Assessment data indicate that the students performed well.

Bibliography

1 Ren, Wei, "Trajectory Tracking Control For a Miniature Fixed Wing Unmanned Air Vehicle," *International Journal of Systems Science*, Vol. 38, No. 4, April 2007, pp. 361-368.

2 ENAC Civil Aviation University, "Paparazzi, The Free Autopilot", URL: http://paparazzi.enac.fr/wiki/Main_Page [cited 26 February 2009].

3 Luhtanen, Mark (Oct 24, 1996), "Foam Goes From Bumpers to Bike Helmets", *Machine Design;* 68, 19; ABI/INFORM Global pg. 53.

4 Barron, A.R., Khan, M.R., "Carbon Fibers: Opportunities and Challenges", *Advanced Materials & Processes*, Vol. 166, No. 9, September 2008, pp. 47-49.

5 Mott, R.L., *Applied Strength of Materials*, 2nd edition, Prentice Hall, 1989, pp. 56-59.

6 *XFLR5(*http://xflr5.sourceforge.net/xflr5.htm*) - Analysis of Foils and Wings Operating at Low Reynolds Numbers*, V4.17B, André Deperrois, 2009.

7 Brandt, S.A., Stiles, R.J., Bertin, J.J., and Whitford, R., "*Introduction to Aeronautics: A Design Perspective*", 2nd Edition, AIAA Education Series, AIAA, Reston, VA, 2004, pp. 41-260.

8 Raymer, Daniel, P., *Aircraft Design: A Conceptual Approach*, 2nd Edition, AIAA Education Series, AIAA, Washington, DC, 1992, pp. 113-114.

9 Solid Edge, Velocity Series, Software Package, Ver. ST, Siemens PLM Software, Plano, TX, 2009.

10 AXi Model Motors. Retrieved December 4, 2009, from Model Motors website: http://www.modelmotors.cz/ index.php? page=61&product=2814&serie=12&line=GOLD.