Final Report

The Sky's the Limit: An Unmanned Aircraft Laboratory Module

Project Goals and Objectives

The goal of the *Sky's the Limit* project is to create, evaluate, and then disseminate new learning material that reflects advances both in unmanned aerospace systems and in what is known about the impact of active learning on engineering education. The creation of an unmanned aircraft system that is simple enough for students to program, yet safe enough to withstand the inevitable errors that occur during the active learning process, is possible with current advances in embedded computing, miniature sensor devices, wireless networking, and automatic control. The *Sky's the Limit* project envisions the creation of such a system as the cornerstone of material that provides a new hands-on learning opportunity that can be incorporated into the curriculum of the College of Engineering and Applied Science at the University of Colorado in a variety of ways.

The *Sky's the Limit* project has three main goals:

Goal 1: Creation of an avionics system that reflects advances in unmanned aerospace systems

- Design a low-cost avionics system that allows programming of control laws and sensor fusion algorithms
- Create a friendly interface that can be used by students with little computer programming experience
- Provide seamless envelope protection such that default algorithms override student implementations when the system approaches pre-defined unsafe states
- Create a complete Unmanned Aircraft Laboratory Module (UALM) that combines the aforementioned avionics system with radio-controlled model aircraft

Goal 2: Assessment of the introduction of the UALM into the curriculum of the Aerospace Engineering Sciences Department at the University of Colorado

- Introduce the UALM into the junior-level ASEN 3128 Aircraft Dynamics course in Spring 2011.
- Develop assessment material to study the impact of UALM in ASEN 3128 Aircraft Dynamics and in ASEN 4028/4128 Senior Design Practicum.
- Provide baseline data by deploying assessment tools in Spring 2010 before the UALM is introduced.

Goal 3: Dissemination of the UALM and additional learning materials focused on the societal benefits of unmanned systems

- Expand UALM for use in other courses in the College of Engineering curriculum and create web-based service to disseminate instructions for module construction.
- Create 6-8 grade learning materials and disseminate through the TeachEngineering digital library.
- Host outreach activities based activities for K-12 students using UALM, specifically

leveraging existing programs at the University of Colorado.

iSTEM support specifically addresses Goal 1 of the *Sky's the Limit* project. The PI taught ASEN 3128 in Spring 2010 and has already committed to teach ASEN 3128 in the Spring 2011 and will be able to implement the assessment tools in order to satisfy Goal 2. Creation of the assessment tools and dissemination of the learning material for Goal 3 are supported as outreach components of existing grants from the National Science Foundation (IIS-0845835, IIS-0713525 and ATM-0824160) .

Avionics System and Airframe

The centerpiece of this effort is the creation of a complete unmanned aircraft laboratory module. The aircraft chosen for this effort is the Hobico NexSTAR EP radio controlled aircraft. The NexSTAR platform has been used extensively by RECUV for other unmanned aircraft projects.After surveying the existing market of small autopilot systems and considering the tradeoffs associated with designing and building our own system, we determined that the open-source Santa Cruz Low-cost UAV GNC System (SLUGS) autopilot developed at the University of California Santa Cruz was the best choice for the UALM.

Figure 1. Hobbico NexSTAR aircraft.

The Hobbico NexSTAR EP aircraft is an electric powered, almost-ready-to-fly (ARF), radio-controlled aircraft. Electric propulsion simplifies operation of the aircraft, sacrificing extended endurance for ease of use. UALM flights will be short and are not affected by the reduced endurance of the aircraft. RECUV has performed over 100 flights of a variation of the NexSTAR platform to investigate atmospheric sensing, cooperative control of UA teams, catapult launch and parachute recovery, autonomous take-off and landing, optimal communication.

Figure 2. SLUGS autopilot used for UALM.

The SLUGS autopilot (Figure 2) is heavily geared towards use on small to miniature sized UAVs. Great care has been taken to assure that it has enough processing power for moderately complicated control tasks and at the same time is easily reprogrammable via Simulink. This allows for rapid iterate from simulation to implementation, particularly by students with limited computer programming skills.

Key features of the SLUGS system (Figure 3) that make it suitable for the UALM include:

- **Easy programmability:** All software is written using Mathworks' Simulink and The Real Time Workshop Embedded Coder, allowing implementation by students with limited programming skills.
- **Fast execution time:** The main processing cycles are executed at 100Hz, allowing telemetry reports of attitude and position at 100 Hz with the rest of the messages scheduled at 10 Hz.
- **Modularity:** SLUGS is powered by two dsPICs DSCs; one for sensor fusion and

attitude estimation from a rich sensor suite and the other for control and communications tasks, providing enough processing power for complex algorithms.

- **Small size:** SLUGS is small enough to fit in a miniature UAS but able to drive up to ten different servos. It also includes a multiplexor to choose between pilot and automatic control.
- **User-friendly interface:** Control software is fully integrated with Google Earth to allow the Ground Station operator to create flight way points and display the UAS flight trajectory in 3D. Full featured Gound Station software provides graphical displays for all of the UAS telemetry.
- **Low Power:** Very low power allows the autopilot to run on a typical RC battery for extended time. Users can select to power the receiver and MUX from the same battery, or use an additional battery via configuration jumpers.
- **Simulation:** Complete Hardware-In-the-Loop simulator allows testing of new algorithms directly in the auto pilot from the desktop.
- **Open:** Hardware schematics, layout, and software source code are available via a GIT repository with an MIT Open Source License.

Figure 3. Modular SLUGS avionics architectures. Two DSPs allow decoupling of sensor fusion and control law implementation.

Budget

Table 1. UALM Equipment Budget

Sensor Type	Unit Cost	Quantity	Total Cost
Hobbico NexSTAR Select Brushless EP Trainer ARF	578	5	2890
SLUGS circuit board	380	5	1900
ADIS16400BMLZ inertial measurement unit	294	5	1470
San Jose Navigation 5Hz GPS receiver	100	5	500
XTEND Zigbee Radio	212	5	1060
Ground Station Laptop	1455	1	1455
Spare servos, wires, nuts, bolts, etc	24582	1	245
Other	82	1	82
		Total	**$9600**

Assessment and Next Steps

All hardware and electronics have been acquired for the UALM. Aerospace Engineering Sciences Department Senior Instructor Trudy Schwartz and several student employees have been engaged to help construct the SLUGS autopilots. RECUV staff member Tom Aune has acquired the NexSTAR EP aircraft and begun preparing them for flight. Undergraduate student Jacob Hayes is being supported by an NSF Research Experiences for Undergraduate (REU) Supplement and will devote partial time to helping integrate the autopilot system into the NexSTAR EP.

The goal for Summer 2010 is completion of the SLUGS autopilot and initial checkout flights of the system. The Fall 2010 semester will be devoted to additional software development in preparation for deployment during the Spring 2011 semester.