# Title Page

**Heinemann Book Project**

Figure : Heinemann logo.

# Record of Revisions

Table : Record of manual revisions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Revision** | **Date** | **Pages Affected** | **Revisions** | **Author** | **Check** | **Approved** |
| 1 | 07/19/17 | All | Created document | Christopher Lum | Christopher Lum | Christopher Lum |
| 2 | 08/11/17 | All | Updated responses | Christopher Lum | Christopher Lum | Christopher Lum |
| 3 | 09/05/17 | 7, 8 | Added response regarding software/hardware teams | Christopher Lum | Christopher Lum | Christopher Lum |
| 4 | 09/13/17 | 9 | Added workflow response | Hannah Rotta/Ryan Grimes |  |  |
| 5 | 12/15/17 | All | Added responses for Sarah Brockett | Hannah Rotta | Christopher Lum | Christopher Lum |
| 6 | 12/16/17 | 4 ,14, 15 | Added link to project vision block diagram. Also added some additions to HR comments. | Christopher Lum |  |  |

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# Nomenclature & Glossary

Table : Nomenclature and glossary of terms

|  |  |  |
| --- | --- | --- |
| **Term** | **Definition** | **Comment** |
| AFSL | Autonomous Flight Systems Laboratory |  |
| C2 | Command and Control |  |
| ESC | Electronic Speed Control | Component used to connect a battery to a motor and to simultaneously transform battery voltage to lower levels to be used by other components. |
| FPV | First Person View | Typically used in the context of a video signal that is transmitted from the UAV to the GCS to allow a bystander to view video from the aircraft in real time. |
| GCS | Ground Control Station | Computer and associated support and communication equipment necessary for the PIC to control that UAV from the ground |
| GCP | Ground Control Point | A known landmark which can be used for referencing (particularly w.r.t. photogrammetry) |
| GPS | Global Positioning System |  |
| LOS | Line of Sight |  |
| NOTAM | Notice to Airmen |  |
| PIC | Pilot in Command |  |
| RC | Radio Controlled |  |
| RTL/RTH | Return to Launch/Return to Home |  |
| Rx | Receiver | This is typically used in the context of a radio transmitter (Tx) and receiver (Rx) |
| SD Card | Secure Digital card |  |
| SM | Statute Mile | 5280 ft |
| TFR | Temporary Flight Restriction |  |
| Tx | Transmitter | This is typically used in the context of a radio transmitter (Tx) and receiver (Rx) |
| UAV | Unmanned Aerial Vehicle | The aircraft and systems carried onboard the aircraft only. This is one component of the entire UAS. |
| UAS | Unmanned Aerial System | The entire system of UAV, GCS, and other associated equipment/entities necessary to operate the aircraft. |
| UPS | Uninterruptable Power Supply | Essentially a large battery used to power computer when the generator is being refueled. |
| UW | University of Washington |  |
| VO | Visual Observer |  |
| WX | Weather Report/Forecast |  |

# Additional Resources

1. Autonomous Flight Systems Laboratory (AFSL) website ([URL](https://www.aa.washington.edu/research/afsl/)).
2. Various photos and media ([URL](https://1drv.ms/f/s!AiTozuZSklGQi6wEltLOtW6taDe7EQ)).
3. AFSL Facebook page ([URL](https://www.facebook.com/uwafsl/)).
4. YouTube video of project with an industry partner ([URL](https://www.youtube.com/watch?v=L62_OWk1elI)).
5. PowerPoint block diagram showing project vision and outline ([link](https://1drv.ms/p/s!AiTozuZSklGQjIJ1yUfhBwQrbaHLXw))

# Questions from Heather Anderson

Send to Chris Lum on 07/05/17.

Respondents

CL – Christopher Lum

HR – Hannah Rotta

CK – Connor Kafka

KC – Karine Chen

RG – Ryan Grimes

**Drones 101 . . . .**

1. How would you explain a drone (and how it works) to a 12-year-old student? (I think I can do a decent job of this, but I’m curious of you have any analogies or specific language that might be helpful.)
   1. CL – A drone is sometimes referred to as an ‘Unmanned Aerial System’ or UAS. UAS vary from tiny aircraft that fit in your palm to enormous aircraft as big as an airliner but they all operate on the fundamental idea that there is no pilot in the aircraft. Instead, the pilot (or operator) is located away from the vehicle and is in communication with the aircraft. This is similar to how a remote control (RC) aircraft operates. The difference between an RC aircraft and a drone is that the drone typically has some ability to fly itself with minimal or no input from the pilot/operator using an autopilot system. The operator is able to issue commands to the autopilot and the system can execute these commands. This is similar to adding cruise control to your car – now instead of constantly having to manipulate the gas pedal, the operator can issue higher level commands to the control system (the cruise control) and it will maintain the vehicle’s speed automatically.
2. What are the current applications for drones?
   1. CL – There are many different applications for UAS. As is the case with a lot of technology, the oldest applications are military. In the commercial and civilian space, some applications include precision agriculture (farming) [1], mapping, surveillance/reconnaissance, search-and-rescue [2], communications, cargo delivery, and many more.
   2. CK – As an emerging technology, drones are being tested and used in many industries. UAVs have the potential to improve previously expensive, difficult, or unsafe jobs such as inspecting hard to see areas of bridges or construction projects, surveying disaster sites, assisting with humanitarian aid, or delivering medical supplies to remote areas.
3. How is this technology changing and how might it be used in the future?
   1. CL – UAS are one of the most rapidly changing technologies in engineering. The capabilities are growing at an exponential rate. Some of these new features include automatic collision avoidance, formation flight [3], collaborative multi-vehicle operations [4], GPS-denied operation [5], and intelligent decision-making. In addition to these algorithmic/software changes, these systems are experiencing hardware and design changes – for example heavy lift octocopters, hybrid VTOL/fixed-wing aircraft, and non-conventional aircraft configurations. Perhaps most importantly is the changes in how these systems are being used. We already discussed some of the current applications for drones but people are constantly thinking up new applications that in turn will drive the change/innovation in the technology. In addition, the regulations related to the technology are rapidly changing and will lead to more

**AFSL at UW and personal motivation . . . .**

1. What are the hallmarks of the UW Autonomous Flight Systems Lab? Why is it successful and innovative?
   1. CL – There are many labs and research groups at the UW and other universities that focus on UAS. What makes the AFSL different is the fact that we focus on demonstrating technologies and ideas on actual aircraft and flight demonstrations. Many groups focus on theory, algorithm development, or simulation. Many ideas are only developed on paper with the end goal of these ideas being published in a journal article. While this is useful for some parts of the scientific community, it is hard for a technology to help society if it is sitting on a shelf in a library. We think it is more useful if you can demonstrate your idea in a flight test. In addition, flight testing often highlights bugs that were not taken into account in simulation.
   2. HR – The AFSL provides an open door to any undergraduates at UW who have an interest in autonomous systems, or simply the goal of applying and growing the skills they learned in their classes. Most students who join the lab have never worked on UAS and come with the desire to learn. Researchers range from freshman through graduate students and also come from a vast variety of engineering disciplines. This diversity in experience brings with it a diversity of ideas and skills which allows for new and innovative approaches to problems that wouldn’t be possible if everyone came from the same background.
2. Why are you working at the lab? What inspires or motivates you to design autonomous systems? What do you hope to accomplish?
   1. CL – I work in the field of autonomous systems because it is an opportunity to work in a highly dynamic and changing field. In addition, autonomous systems and UAS pulls from a wide range of disciplines and sub-topics. In order to understand and build UAS, one needs to understand aerodynamics, propulsion, communication, electronics, computer science, field experimentation, regulations, and many other disparate topics. UAS gives me an opportunity to understand and see how all these different pieces work together to generate a complicated system. In some sense, this is akin to Lego blocks for adults, you take lots of little parts, put them together, and build something greater than the sum of the parts.
   2. CK – I work at the lab because I find UAVs and autonomous systems in general incredibly interesting and fun to work with. The lab is a challenging and dynamic environment that provides a lot of opportunity to work with applications of UAVs in disciplines I might not otherwise get involved with. For example, in the time I have been at AFSL, I have had the chance to work with planning flight operations, flying, constructing, and repairing UAVs, and software development for the autopilot hardware and ground control station software. UAVs will have an enormous impact in future and it is exciting to apply what I learn in class in a field that I am passionate about.
   3. HR – The lab provides an amazing opportunity to demonstrate and develop our own creative ideas as well as work side by side with industry partners. We have the ability to take our ideas, develop them and integrate them into autonomous systems, often taking projects from the conceptual stage all the way through to the completion of testing and integration. For me personally, as a licensed private pilot, it is intriguing to be directly involved in this very different side of aviation, researching and advancing the technologies that inevitably will replace the pilots sitting in the cockpit. To me, it is important to be part of this rapidly growing industry, rather than oppose it, helping to guide it in a direction that will improve our lives. I try to act as a liaison, helping our researchers better understand manned aviation and other pilots better understand the benefits of autonomous flight systems.
   4. KC – I enjoy working in the laboratory because we have a lot of hands on work and freedom to provide innovative ideas to the projects. The lab also allows us to step into the industrial perspective, working with partnered companies, and collaborate in our findings. Personally, I enjoy hardware integration and this allows me to help in designing efficient autonomous systems through trial and error. I hope to contribute new discoveries to strengthen the field of flight, as well as create an environment for people of similar interest to be able to work side by side.
3. What was your most successful design? And why? (Question from my 8-year-old son)
   1. CL – We recently completed a project that integrated an ADS-B transponder onto a small UAS. This transponder allowed the aircraft to be visible to all other air traffic in the area. The FAA has mandated that these transponders will be mandatory for virtually all aircraft by 2020. Currently, these types of systems are carried by larger, manned aircraft. The aircraft we flew weighed approximately 7 pounds and has a wingspan of less than 2 meters. To our knowledge, this is the smallest, lightest ADS-B equipped aircraft in the world. This project was also successful because it involved coordinating with manned aircraft and other aviation stakeholders to perform a complicated demonstration using many technologies and participants [5]. The team traveled to Southern Washington with a mobile flight operations center to execute this mission.

**Future engineers. . . .**

1. What skills, experiences, or interests would students need to succeed in this arena?
   1. CL – While intellect and intelligence are valuable skills in this arena, a large part of engineering is about dedication and determination. Research and innovation requires a willingness to try many different approaches to a problem. Often times these approaches end in failure and it is the ability to get up and try again with a different technique that makes a good engineer.
   2. KC – Don’t be afraid to get back up when you fall. If you have the passion for this field, the ambition to succeed, and the ability to resolve problems through different perspectives, you will succeed. Not saying it will be easy, but this will help you to persevere through the harder pieces of the puzzle. Sometimes, problems can be solved without using complex measures, be open minded about what it could be.

1. What advice would you give to a child interested in pursuing a career in aeronautics or engineering?
   1. CL – Keep an open mind and maintain a willingness to work on problems that might not be exactly aligned with your interests. For example, many people would love to be an astronaut but realistically, not many people will be able to realize this dream since it is such a competitive occupation. However, if you’re able to find joy and a sense of meaningfulness by working on related areas, you’ll have a higher probability of success. Aeronautics is a wide field that encompasses many different disciplines so take some time to explore many of them before settling on a topic that you really enjoy.
   2. CK – Explore what interests you and be curious about the way things work. A good engineer is creative, enjoys learning new things, and is willing to work hard—even when it is difficult, confusing, or dull.
   3. HR – I would highly recommend that they just go get involved with what they enjoy early on. It could be anything from a robotics club to playing around with basic programming or hardware projects at home. I have had a lot of opportunities open up for me in engineering and otherwise simply because I went out and pursued a pilot certificate for fun. If they don’t know what they enjoy, then try lots of things. Having a variety of experiences under their belt will do nothing but help them have a better, well rounded understanding of everything, even if on the surface it doesn’t seem like it has anything to do with engineering. Something as crazy as origami can, and has turned into an important engineering tool for things like developing new, resilient structures.
   4. KC – Start early, try things out, there are plenty of opportunities to discover what you are really interested in. Get curious and ask questions, you might just might discover something in uncharted territories.

# Additional Questions from Heather Anderson

1. Can you describe how there are usually two teams working simultaneously. One team is developing algorithms and designing software and the other team is building the actual vehicle to support the software. Then you bring it together for the test flight to demonstrate that it all works and collect data. Do you think you could describe this and each of your roles in the process?
   1. CL – Developing new technologies for a UAS and executing proof-of-concept demonstrations of this technology typically involves a large team of researchers. There are many tasks that need to be accomplished in order to get a UAS flying with a new technology or algorithm.

Often, a major set of tasks involve development of algorithms or software to support the new technology. These software tasks are typically handled by a team that focuses on working with computers or code in an office environment. This team handles writing custom software or integrating other software or related computational technologies into the system. This team does not need to “get their hands dirty” in the traditional sense because the majority of their tasks revolve around planning and software.

While the first team is developing the required software infrastructure, a second team is usually focused on the hardware development and integration aspects of the project. Often, integrating a new technology or sensor onto a UAS involves hardware

customization or modifications to an existing airframe. Therefore, this hardware team must focus on designing parts, modifying aircraft, and building the associated hardware infrastructure necessary to support the mission. This may involve integrating custom electronics or components onto the system. In short, this hardware team must ensure that the UAS is airworthy for the desired operation.

Both the software and hardware teams need to work in unison and are in constant communication with one another from the inception of the project all the way through the flight test. In fact, many researchers wear both hats and are involved in both software and hardware tasks throughout the project lifecycle.

At the actual flight test, members from both teams are present and work closely to collect data and ensure that the flight test can be executed in a safe and efficient manner.

1. What steps were involved to take the Visual Anchoring Project from a problem statement about navigation in GPS denied environments, to an integrated drone with hardware and software that could solve the problem statement? (note to Heather: As we discussed previously, feel free to use this information in your own words, but please do not direct quote me (RG – Ryan Grimes) until I receive the proper approvals. Thank you!)
   1. RG – The first step in the process was to look at the past similar research and understand what we could try to use from their work. Then we had to figure out what new ideas we would have to incorporate to solve our specific problem statement. This involved figuring out the controller design and range estimation calculation, researching gimbals that would suit our needs, and figuring out a way to send information from Matlab (Matrix Laboratory) to the ArduPlane firmware on the PixHawk.

After the initial brainstorming, the next step was to acquire all the hardware necessary for the project and begin hardware integration so that we would have a testable drone. This involved buying and calibrating the gimbal and camera, building and configuring the Skywalker 1900 drone, and integrating the gimbal and camera onto the drone. It also involved implementing the data transfer between Matlab and ArduPlane.

After configuring most of the hardware, the next step was to develop and begin testing the software (orbit controllers). Truthfully, the hardware integration and software development steps of my project were taking place at the same time, but the hardware integration started and was completed before the software side. This involved making custom changes to the ArduPlane firmware so that we could create custom flight modes that would stabilize an orbit using our range estimation calculations from the gimbal. Once the orbit controllers were created, they were tested using SITL (software in the loop) simulation of an aircraft to make sure they worked as expected.

After the hardware and software were integrated (integrating the software just required us to load our custom firmware onto the Pixhawk), we began the flight testing process of the project. The real test environment is different from our simulated environment in several ways. First, the plane we simulate does not have the same specifications as the Skywalker 1900 aircraft. The simulated plane has a more powerful engine and is much larger. We use this simulation because it is readily available and gives us an idea of how the controllers will perform on an aircraft. However, since there are many differences between the aircraft, the controllers must be re-tuned for the flight test environment.

* 1. HR – The process of working through a project typically follows a fairly standard progression, although there are often twists and turns along the way. Below is a general description of our process, not specific to Visual Anchoring.

We always start with some sort of problem statement. This could be an idea that someone in the lab came up with, it could be taking a previous project and finding some other application for it or just taking it in a new direction, or it could be something proposed by an outside group, such as another research lab on campus, or an industry partner. The problem statement is what drives the direction of the research, essentially identifying what the goal of the project is and why it’s important.

From there a team is developed. There are usually one or two students leading the project – taking it from start to finish – with a team of undergrads assisting. The undergrads sometimes are also heavily involved with the project and work on it until it’s completed, but more often due to time and availability, they usually are helping out with specific aspects of it based on their skills and interests. This means some students primarily help out with the flight testing, others focus on coding when needed, and maybe others work on the hardware such constructing mounting systems to attach the equipment to the UAS, etc.

To get started there is usually quite a bit of time brainstorming ideas of how to attack the problem. From there, the hardware and software are developed, usually simultaneously. Depending on the nature of the project we might be able to use pre-existing hardware or software, as some projects are more software intensive while others the main goal is just integrating certain hardware. As stated before, this could be done by one of the project leaders, or it could be done by any number of undergrads assisting with the project.

Once everything is integrated, we always do “bench” testing – testing as much of the equipment and programming on the ground as possible. This could be done on the computer using simulators, running test data through codes, physically spinning up airplane motors, or doing whatever is relevant for the project. From there we take it out in the field and actually test the project in the air. Some projects are good to go after one or two flights, while others – such as visual anchoring – requiring repeated, ongoing testing to collect all the required data. Depending on how the testing goes, more hardware/software work may be required before continued testing. A majority of flight testing takes place out at Carnation. Some projects require conditions that can’t be met there, for example going to the mountains to do flights over snow, or going down to Dallesport along the Columbia River in order to utilize a ground antenna array stationed down there.

# Questions from Heather and Sarah

**Would you be able to write up a short (one or two page) description of the project that would make sense to middle school kids? Any diagrams that would help illustrate the concepts would be great. Could you also explain the process – what info did you start with, how did you modify existing drones and develop the software, what problems did you encounter and how did you fix them?**

1. HR – Unmanned Aerial Vehicles (UAVs) rely heavily on GPS to navigate, and unfortunately, it’s really easy to lose the GPS signal for a variety of reasons, intentional jamming being one of those. Our goal is to make it so that the UAV can continue to operate and navigate even if it loses GPS. Our research is using a fixed wing (traditional airplane style, ~6 ft wingspan ) UAV, however the same principles would apply to other UAVs, like quadcopters.

To accomplish our goal, we are installing an ADS-B (Automatic Dependent Surveillance – Broadcast) transponder onto our UAV. An ADS-B transponder is a small piece of equipment that is installed on many manned aircraft and will be required on most aircraft by 2020. It uses its onboard GPS information to automatically broadcast its position and altitude. This information can then be picked up by air traffic controllers, or anyone else who has the proper reception equipment to listen to it.

We are partnering with a company that has created a special antenna array system (LAMS - Local Area Multilateration System)  that can listen to these transponder signals and from that, very accurately determine the position of the aircraft. Instead of listening to the broadcast GPS position, it essentially uses triangulation - it measures the time difference between when each signal arrives at the different antennas in the array and converts that to a position relative to the LAMS. Then, using software developed by AFSL, this position information can be converted into a GPS position that can be displayed on a digital map, like Google Maps. Even when the transponder doesn’t have a GPS signal, it continues to transmit a signal that can be picked up by the LAMS on the ground.

Previous work in the lab on this project in past years got this far. A UAV equipped with an ADS-B transponder, could fly near the LAMS with its GPS signal blocked, the LAMS could triangulate its location, and the software on the ground could convert this into a usable GPS position displayed on a map as it flew around.

What we are doing now is taking that GPS position, and sending it up to the plane via a radio connection. We are then processing that with the onboard flight computer so that it can continue to fly and navigate as if that GPS position had been received the normal way, from the GPS satellites. So far we haven’t conducted any flight tests on the current phase of the project. We are currently developing the software and hardware necessary for the project as discussed below.

**When and why did you get your pilot’s license?**

1. HR – I started my training toward the end of my freshman year at UW (2013) and received my private pilot license in 2014. I then went on to do further training and got my instrument rating in 2015.

Flying has always seemed like a really fun and exciting thing to do, and I actually started with aspirations to fly in the military. The practical factor that got me into it initially was that I have a number of family members who are pilots (professionally and for fun) and Boeing engineers. Through them, I have had a lot of exposure to airplanes and aviation as well as simply a lot support and encouragement from them. Once I got started training, it proved to be just as fun as I expected, but also very challenging which gave me more motivation to continue and do my best. The uniqueness of it was another factor. Ultimately, a small percentage of the population has ever even been in a small plane, let alone received their license, so I’ve really enjoyed being part of that community.

Unfortunately due to time and resources, I haven’t been able to keep up with the manned flying much over the past year or two, but having that experience allowed me to easily get my FAA Part 107 Remote Pilot Certificate which allows me to fly unmanned aerial vehicles (UAVs) which I now do at AFSL for research.

If you already have a Part 61 pilot license all you need to do is a quick online course to get your remote pilot certificate. If you aren’t already pilot, you have to take a knowledge test to get certified. Neither route requires a practical exam (i.e. you can get certified to commercially fly UAS without ever actually flying one), because the purpose of the certification is to make sure you know the relevant rules and regulations.

**What got her in the door, experiences at the beginning (expectations for the experience)**

1. HR – My aviation background and experience with piloting manned aircraft is what got me involved in the lab in the first place. A lot of that knowledge translates directly into unmanned operations and has allowed me to lead the flight operations for the lab. This position has allowed me to be involved in at least some capacity with all the projects in the lab over the last year and a half.

I wanted to get involved in the lab to get practical engineering experience, so I could actually apply what I learned in my classes. This has definitely been the case (engineering classes are totally different than doing work for an actual application), but I’ve also gotten a lot of insight into the administrative side of research and coordinating with outside groups (industry partners, securing flight locations, etc).

On projects, including this one, the initial goal and preliminary steps always seem straight forward enough. But it’s amazing how once you start digging into it and working on the steps, the necessary work always seems to multiply. You work on one step and soon it becomes apparent that you first need to complete a number of sub steps. For example, we want to send the position information from the LAMS to the aircraft. To do this we have to set up a wireless connection to send this info to a laptop. This info must then be formatted in such a way that it can wirelessly be sent via a radio connection up to the aircraft. It must then be fed into the flight computer in a format that it can interpret and finally we have to create custom flight controllers that can navigate with this custom position info. Each of these steps are very involved in and of themselves.

**The problem and how it came to them (their problem statement)**

1. HR – GPS is an integral part of unmanned aerial systems (UAS). But because they are so susceptible to GPS loss, it is important to find alternative methods to navigate and keep the planes from crashing. Our goal is to provide one possible option that should have widespread application, to allow UAS to continue to operate without GPS. Projects are always developed due to some sort of need. In this case, several years ago, when the project first kicked off, it had become obvious that 1) UAV technology was going to continue to rapidly grow and 2) GPS-denied environments are a very real possibility, so it is important plan for them.

**Some ideas they brainstormed, how they chose their solution/approach**

1. HR – So far most of the work done has been on the coding side. Typically we start with one idea and attempt to make it work. Usually along the way another idea manifests itself so we explore that one to decide if it is better or worse or maybe just a backup option to the first idea.

I foresee changing approaches a number of times when it comes to our custom flight mode, which we are just beginning to create. Flight modes dictate how the aircraft flies - there are manual flight modes (the pilot flies it like a remote control plane without any computer aid), there are autonomous flight modes (the plane flies itself without any pilot input) and there are hybrid modes in between the two. Another project (Ryan’s Visual Anchoring project, which Heather is familiar with) required us to create a different custom flight mode, so we are building off the ideas and solutions we learned from that process. But the the two modes need to do different things, so while some parts of it we can probably copy directly (ex the coding that tells the plane to maintain altitude and maintain level wings, etc) others will probably require some educated trial and error. This can be accomplished first through simulation, then once we are confident in its simulation behavior, we will try it during an actual flight test.

The first time we test a new flight mode is always nerve wracking. No matter how much you simulate something, there’s a good chance it will behave differently in real life, simply because you can never perfectly simulate actual conditions. One example where this went wrong was during the Visual Anchoring testing when we switched the UAV into our custom mode, and instead of telling it to orbit a point in the field we were in, we unintentionally told the plane to fly to the 0 latitude, 0 longitude point, which is over near Africa. The plane essentially tried to get to Africa as fast as it could which resulted in it instantaneously rolling over in the air and plummeting to the ground.

**What exactly did each team (hardware/software) do--so a few tangible examples like writing code or designing the drone body**

1. HR – There are a number of teams working on this project. Some students are involved in only one team, while others are on multiple. This project definitely isn’t the work of a single person, but rather a cooperation of all the teams.

Hardware - one team is focusing on constructing the aircraft. We buy our styrofoam airframes premade off the internet, then assemble them in the lab, and integrate avionics/electronics which include a flight controller (onboard computer which runs the autopilot...the brains of the plane), GPS receiver, radios to connect to the ground, servos to control the flight surfaces (ailerons, elevator, rudder, flaps), motor and propeller. This team is also in charge of configuring the autopilot, and ensuring the system functions both on the ground and in the air.

Hardware - another team is designing and integrating the payload. This consists of designing and 3D printing a case to house the transponder, an arduino and a few other sensors that need to be in the aircraft and are specific to this mission.

Software - one group is creating a custom flight mode to control the aircraft when it is receiving its position information from the ground rather than from a GPS unit. This involves coding flight controllers to customize how the aircraft will behave in certain situations.

Software - another team is working on processing the position information output by the ground based antenna system, converting that into a format that can be sent via radio connection up the aircraft in the air. This also needs to be received by the plane in a format that can be fed into its flight controller to be used for navigation.

**An example or two of integrating or bench testing**

1. HR – We have done some testing with the transponder, basically to verify that the setup the students had for the previous phases of the project still work and we understand how it works. We turned it on and connected it to our software and verified that when we walked around with the transponder outside, the software also showed that we were moving on the map.

We have a simulator that simulates the UAV flying around a specific location and sending out its ADS-B position information or “packets.” This allows us to simulate certain flight paths, and run that simulated position information through our software to verify that the software is doing what it should do. This is a lot quicker way to troubleshoot than going out and setting up and conducting a full flight test, just to find out something isn’t working quite right in the code.

**What they tested in a field test**

1. HR – We haven’t conducted field tests for this phase of the project yet. We are aiming to start testing later in the winter/spring (see CL response below)
2. CL – While we have not conducted full flight tests of the current phase of the system, we’ve conducted extensive and successful flight tests of other parts of this system in previous campaigns as referenced in [5], [6], and [7].

**What happened during the test (play by play)**

1. CL – We had several tests of increasing complexity/risk for this project
   1. We conducted MANY flight tests and trials both in simulation as well as at our local flight testing facility before conducting this actual mission. The following tests are ones that were conducted away from Seattle.
   2. During initial ground testing in Seattle, we identified some bugs and shortcomings, particularly with respect to the software communication.
   3. During ground testing at KDLS (the airport in the Dalles) we discovered additional difficulties with respect to the transponder payload (the proximity to the antenna appeared to be overwhelming the electronics and necessitated the development of some electro-magnetic shielding).
   4. During the subsequent flight test demo, we encountered severe environmental conditions (high winds and gusts) which required modifications to the flight plan.

**What they learned from it, what they changed**

1. CL – Every time we conduct a test, we make change and improvements for future excursions and experiments. NOTHING is a substitute for experience and these flight tests serve as a change to expose shortcoming in the system and make changes to make future experiments more productive. Our current flight operations program is the result of 3 years of experiments and experience.

**What happened when they tested again (play by play)**

1. CL – We conducted a successful flight experiment and demonstration. Success is often at the end of a long road of failures and learning experiences.

**A real world application coming out of the project/next steps in a broad sense**

1. HR – There will always be military applications for just about any UAV technology. This will help allow UAS operation/navigation in hostile environments. It will also help in the process of further integrating UAS into the National Airspace System here in America. It allows for better UAS tracking, and as UAVs become more integrated into the airspace above us, it can potentially provide navigational redundancy so that if their GPS is jammed or interfered with they can continue to function, rather than crashing or flying away and getting lost.

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