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Teaching Engineering Through the use of a Student UAS Competition

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Teaching Engineering Through the use of a Student UAS Design Team

Abstract

For the past thirteen years, Mississippi State University has used a student unmanned aircraft systems competition as an approach for teaching students system design, systems integration, prototype development, and testing. The design team competes in the annual international student unmanned aircraft system competition hosted by the Association for Unmanned Vehicle Systems International. The concepts introduced to the students allow them to engage in real-world engineering activities including designing a system based upon the requirements given in a request-for-proposal, integrating various sensors and electronics into their air vehicle, writing test plans to evaluate system components, and conducting ground and flight tests for the system.

1 Background

In January 2003, the Association for Unmanned Vehicle System International (AUVSI) established the student unmanned aircraft systems (SUAS) competition "aimed at stimulating and fostering interest in this innovative technology and encouraging careers in the field, the competition challenges the students to design, fabricate, and demonstrate a system capable of completing a specific and independent aerial operation."[1] The Seafarer Chapter of AUVSI hosts the annual competition during June at Webster Naval Outlying Field (Webster Field) in St. Inigoes, MD. Webster Field is an auxiliary field of Naval Air Station Patuxent River, home of naval flight testing.

After hearing about the competition at the AUVSI conference in 2003, it was decided Mississippi State University should form a team to compete in the 2004 AUVSI SUAS competition. From the early stages of consideration, it was understood the team would greatly benefit from being multidisciplinary. Although based in the aerospace engineering department, team membership was opened to all engineering disciplines with an emphasis on electrical engineering, mechanical engineering, and computer science or software engineering.

There are many names used to describe an unmanned aircraft system including unmanned aerial vehicle (UAV), remotely-piloted aircraft (RPA), unmanned aircraft system (UAS), and drone. In terms of the air vehicle, UAV, unmanned aircraft (UA), RPA, or drone can be used. The most common nomenclature within the unmanned community is UAV, which as defined in the Department of Defense Joint Publication 1-02, "DOD Dictionary of Military and Associated Terms," as follows:

> "*A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic*

vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles. Also called UAV."[2]

The terms UAV, UA, or RPA emphasizes the air vehicle. However, since 2005, the Department of Defense (DoD)[3] and the Federal Aviation Administration (FAA) have used the term UAS, which not only includes the unmanned aircraft, but also includes the associated ground control station (GCS), telemetry/data link, communication and navigation, and sensor package.

1.1 Competition Overview

The competition, aimed at performing an intelligence, surveillance, and reconnaissance (ISR) mission for a small marine reconnaissance team, was scored based on three parts: a journal paper, a flight readiness review, and the mission performance. Over the years, the competition has expanded to include tasks such as locating infrared (IR) targets, sensing and avoiding (SAA), air dropping, cyber-security tasks, and others. Overall, the objective was to provide real-time or near real-time intelligence of various targets and actionable intelligence for at least one target in a designated search area. The UA must navigate the search area autonomously while searching for targets (geometric shapes cut from plywood) as illustrated in Figure 1.1 The sizes of the targets range from four feet (width and length) up to eight feet. The number of targets located in the search area can range from four to 14 targets. The characteristics of the targets that the competitors must identify are the location (latitude and longitude), orientation, shape, color, and alphanumeric character on the target. Locating the targets can be accomplished either manually by the students identifying a target in their pictures or automatically with the use of auto-targeting recognition and location (ATARL) software. While in the search area, the UA must fly autonomously. This is achieved by an onboard autopilot or GPS-capable flight control computer. The UA can perform a conventional takeoff and landing (CTOL) or automatic takeoff and landing (ATOL).

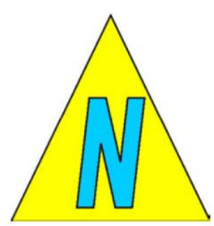

Figure 1.1

The UAS must also have the capability to be dynamically re-tasked while inflight. To do this, new latitude/longitude coordinates have to be uploaded to the UA, which will send the UA to a new location within the search area to look for what is known as an emergent target (otherwise called "pop-up" target). The students have to identify the emergent target as well as provide its location. The emergent target, over the years, can be nearly anything from a downed firefighter to a lost airplane as shown in Figure 1.2.

Figure 1.2

Since the targets have alphanumeric characters written on them, they can be combined to spell out a secret message. After finding the targets, presumably all of the targets, then the students have to rearrange the letters, either manually or automatically, to determine what the secret message is, Figure 1.3[1].

Figure 1.3

Another task is known as the simulated remote information center (SRIC). This simulates communicating with a remote target and receiving a coded message from the information center. The UA must autonomously fly over the SRIC, enter a holding pattern, and establish communication with the SRIC to receive the coded message. Then, that message must be transmitted to the GCS.

The competition releases rules or request-for-proposal (RFP) outlining the specifics for the competition to participating schools in early fall. The rules outline the primary tasks (autonomous flight and ISR) and the secondary tasks (ATOL, ATARL, emergent target, SRIC, etc.). The rules also include specific deadlines as to when items are submitted for the competition, the amount of registration fees, documents for base access, and other required items (proof of flight video and journal paper). After the rules are released, the participating schools have two and a half weeks to review the RFP and submit comments. After the comments have been submitted, the schools are asked to participate in what is called "University Day." This is a conference call with the competition officials and judges to discuss the rules and submitted questions or comments. Two weeks after the University Day, the final revision of the rules is released and registration opened.

Registration is open for about one and a half months. Three months prior to the competition, the students must submit a team composition form, design fact sheet, and tasking order plan (flight plan) followed by base access form. One month prior to the competition, the journal paper and proof-of-flight video must be submitted.

1.2 Competition Scoring

As previously stated, the competition is divided into three phases: journal paper, flight readiness review, and mission performance. The journal paper, which is submitted prior to the flight phase of the competition, describes the concept, system design, and system testing completed during the technology development phase (student design, build, test phase after the rules are release) of the competition. The paper is limited to 20-pages and must describe team coordination and systems engineering, which includes the design of the UAS including details on test and evaluation completed during the technology development phase, ground and flight testing, and tradeoff studies. The paper is 25% of total scoring. The flight readiness review (FRR) is to assess the readiness to conduct flight operations at the competition. The FRR is not a restatement of the journal paper, but an oral presentation of prior flight data and ground test data to the judges where students convince the judges that the UAS is ready for flight and can perform the mission. During the FRR, the students will go through their mission briefings and procedures. The FRR is 25 % of total scoring. The mission performance, which is 50% of scoring, is the portion of the competition where the students fly the UAS and perform various tasks. The UA must fly autonomously through the search with manual takeoff and landing or ATOL. The mission is limited to 40 minutes with the flying portion limited to 30 minutes and 10 minutes for post processing. However, the goal is to find the targets and present the data to the judges in 30 minutes. The competition ends with an awards banquet on the night of the last day of flying.

When the competition started in 2003, only two universities participated. Now the competition has grown to upwards of 48 schools from different states and countries including Canada, Israel, India, Turkey, and Germany. The competition has also been expanded to high schools. The competition is a great place for students to network with other universities and with the various industry partners that volunteer and display at the competition including Naval Air Systems Command (NAVAIR).

2 Team Description

Throughout the course of the technical development phase, the students from various engineering disciplines and classifications set out to design, build, and test a UAS to meet the criteria outline in the rules of the competition. The team lead, responsible for the overall management of the team, sets the schedule, and is chief liaison and designer for the team. Under the team lead, the airframe group and avionics group are responsible for focused areas pertaining to each group’s expertise, Figure 2.1. The airframe group, headed by the airframe group lead, is responsible for the fabrication of the airframe including the structural components and propulsion system. The avionics group, headed by the avionics group lead, is responsible for the electrical system, electronics, flight control system, and sensors. The avionics group lead is also responsible for the software of the UAS. Throughout the build phase, the three leads work closely to ensure a smooth integration of the avionics and airframe. To accomplish this endeavor, the team has decided to custom build the airframe to house the avionics. This way they are sure that everything will fit properly rather than try to customize an off-the-shelf aircraft to fit the avionics.

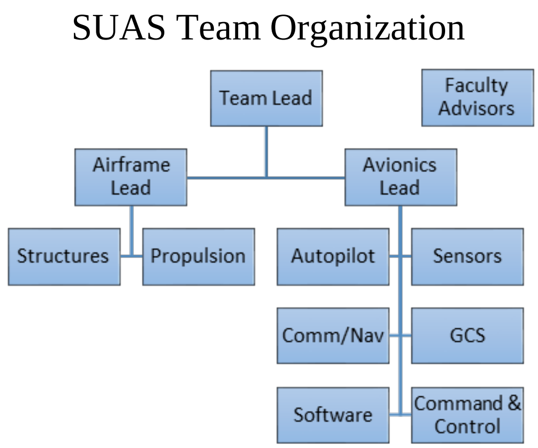

Figure 2.1

At the inception of the team in 2003, it was decided that the team should be a multidisciplinary (an ABET outcome[4]), multi-classification team. This was done for two reasons: a. an unmanned aircraft system is a system of systems requiring many disciplines to design, build, and operate, and b. having students from freshman up to seniors ensures "tribal knowledge" is passed on from year-to-year. The team consists of students from various engineering disciplines in the college of engineering such as aerospace engineering (AE), electrical and computer engineering (ECE), mechanical engineering (ME), computer science and engineering (CSE), industrial and systems engineering (ISE), and agricultural and biological engineering (ABE). Over the years, however, there have been students from marketing, accounting, kinesiology, geography, and elementary education. The first team included two high school students.

Although housed in the aerospace engineering department, the membership was opened to all engineering disciplines as stated above. The faculty advisors for the team came from the aerospace engineering and electrical and computer engineering departments. The aerospace engineering advisor's background was aircraft design, flight test engineering, and composite manufacturing, while the electrical and computer engineering faculty's background was control systems. The background of the advisors gave valuable insight to the students on aircraft design, manufacturing, controls, and testing.

Although considered as an extracurricular activity, the aerospace department created a design team course, where the students receive 1-hour credit. This credit does not count towards graduation. However, it is listed on the students' transcripts and can be used as a talking point when the students are interviewing for a job. Because of the success of this course, the Bagley College of Engineering at Mississippi State University just recently stood up a college-wide design team course based upon the format created by the aerospace engineering department.

Many students stay with the team all four years that they are at university, which is evident in Figure 2.2. Here you can see some of the student remaining with the team for three or four years. Most freshmen that join the team generally have very little knowledge working with tools, let alone composites, nor understand the design process of a system such as an unmanned aircraft system. Therefore, it is the job of the seasoned team members to instruct and guide the younger students. Starting in their junior year (sometimes sophomore year), depending on a student's aptitude, some members are elevated to the level of task leader. Their primary job is the assist the airframe and avionics leads in the fabrication of the system and instruct the younger students. In addition, these very students can be elected to the position of airframe lead, avionics lead, or team lead. There have be occasions where a junior is elected to team lead. By accepting freshmen who participate in the team for multiple years, 'tribal knowledge' is passed on from year-to-year, member-to-member. Even with written documentation, having someone with intimate knowledge and experience aids in the then-year design process.

Figure 2.2

It is in the team environment that the students learn to interact with other students outside their disciplines and deal with personality differences. It is hard to assess how students interact with one another, but they managed to design, fabricate, and operate a competitive UAS since the inception of the team. As with any organization, there are conflicts and misunderstandings; however, the team lead and team member manage to overcome those difference to create a working UAS.

From the main team, a 10-person alpha team is stood up. This is normally the flight operations team (Figure 2.3) and is the group that travels to Maryland for the competition. The alpha team consists of the three leads, the UA pilot, safety officer, ground crew, and sensor operators. The team lead assumes the role of mission commander, airframe lead is the ground crew chief, and avionics lead is guidance, navigation, and control (GNC) officer. The mission commander is in charge of overall operation of the flight mission. At competition, the mission commander interfaces with the judges and competition director. The ground crew chief is in charge of transportation and assembly of the UA and is responsible for the airplane handlers. The GNC officer ensures all electrical components and avionics are installed on the airplane and in good order. The GNC officer is responsible of assembling and operating the GCS. The ground crew normally consists of airplane handlers for assembling and transporting the UA. Launch/recovery officer and personnel are responsible for launching and recovering the UA if the UA performs ATOL. The launch/recovery officer reports to the mission commander. The sensor operators are responsible for monitoring the ISR screen, operating the camera, and gathering the mission data (targets, target characteristics, SRIC, etc.) The sensor operators report to the GNC officer. At the completion of the flight mission, the mission commander submits the collected ISR data to the judges. The UA pilot acts as safety pilot in the event there is an issue with the autopilot. If the UA is not going to perform ATOL, then it is the responsibility of the UA pilot to takeoff and land the UA. The safety officer monitors the weather and makes sure that the mission operating safely. The safety officer has the final call on whether the mission can start or continue. The safety officer can terminate flight operations if a safety issue arises.

Flight Operations (Alpha Team) Organization

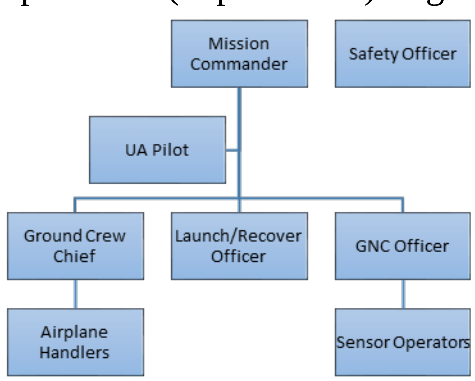

Figure 2.3

3 System Design

The students start the design process upon receiving the draft rules in early September. They follow the V-model[5] from systems engineering, Figure 3.1. During the decomposition phase, the students perform various trade studies to determine items needed to fulfil the mission. They compared various criteria such as price, size, weight, and capabilities and down select the best equipment. From there, they are able to size the airframe to fit the various electronic component and meet the endurance dictated by the rules and team lead. They perform a requirements analysis for the system. At this point, the students decide what tasks (including the primary ISR task plus the secondary tasks) they can accomplish in the time allotted for the mission.

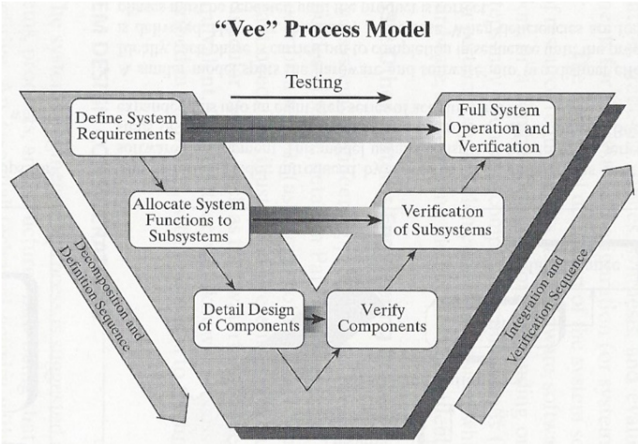

Figure 3.1

3.1 Airframe Design

The airframe is designed around the avionics required to complete the mission. The methodology the students used to design the first airframe in 2004 was that outlined in Reference 6. The first student-design airframe had a design weight of 35 pounds and a wing loading of W/S = 2.92 pounds per square foot, the wing area of the wing was 12 square feet. The aspect ratio was AR = 6.75. This aspect ratio yields nearly an elliptical lift distribution, which is the most efficient lift distribution that can be attained. The wingspan was determined to be 108 inches. The configuration was a conventional tractor type, Figure 3.2.

Figure 3.2

The students know the primary ISR mission requires some type of imaging device plus its power and control source. Because of issues with the first design of residue affecting the camera dome, which is under the fuselage, the next design featured a twin-boom, pusher configuration, Figure 3.3. This configuration would remain with the students until the 13th competition. This design started with a box shape with a 9-inch-by-9-inch cross section fuselage and 40 inches in length. In later designs, the wingspan increased to 128 inches and the fuselage length increased to 55 inches. This configuration ensured that all the avionics (autopilot, power distribution board, camera, and onboard computer) could easily be housed. The UA utilized a 12-horsepower, two-stroke engine, a three-bladed propeller, and carried 0.563 gallon of fuel for a 50-minute flight. The main landing gear was a spring-leaf configuration and the nose landing gear was a trailing-link type. The UA was fabricated using pre-impregnated (prepreg) carbon fiber with Nomex© honeycomb core. The fuselage, wings, and empennage was a sandwich core with the carbon and honeycomb. Both the main and nose landing gears were solid laminate. The entire structure, except for the carbon-tube booms, was fabricated by the students.

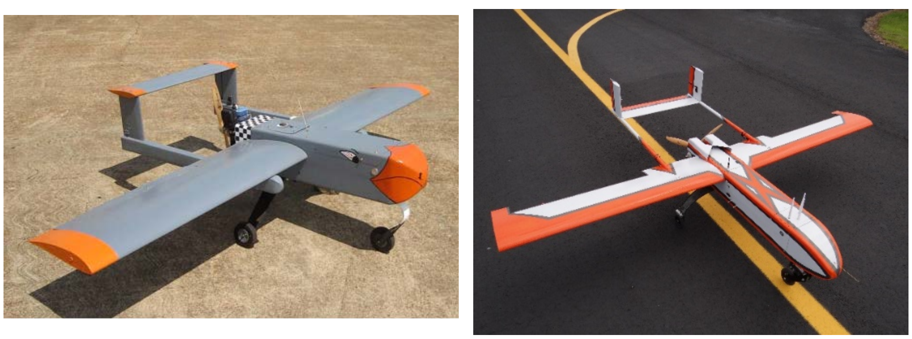

Figure 3.3

After competing with the large vehicle since 2005, last year the students elected to go to the other end of the size spectrum. The main reasoning for this was logistics. Transporting the larger UAS had become burdensome with limited flying airspace at our local field. Therefore, the team leadership called for a design change. This change resulted in a 20-pound UA, Figure 3.4 with a two-meter wing span and used an electric propulsion system. Instead of a built-up structure for the wings, the wings of the new UA were solid foam core with a layer of medium-weight fiberglass. Rather than using prepreg fiberglass, the students used dry fibers wetted out with epoxy resin. The fuselage was a payload pod with a keel tube of carbon fiber. The payload pod used four layers of fiberglass and the keel tube was a commercial-off-the-shelf (COTS) item.

Figure 3.4

3.2 Avionics Design

One of the requirements for the competition is that the UA must navigate the search area autonomously. Hence, this means the aircraft requires an autopilot. For the first three years, the team used a Micropilot 2028g autopilot. Then the team was able to purchase a Cloud Cap Technology Piccolo autopilot. This autopilot served the team well, even allowing to team to finish in the top three rankings for two years, including a first-place finish in 2008. When the size of the UA changed, the team switched to a 3DR Pixhawk autopilot. This autopilot and its accompanying software (Mission Planner) are open source allowing it to be customized for the student's needs. It allows the students to do the dynamic retasking and can control the camera gimbal to add camera stabilization. Figure 3.5 shows the three autopilots used throughout the team's existence.

Figure 3.5

The students have chosen different type of cameras over the years. The selection ranged from a Sony EVI-D70 to Imperx IGV-B4820 to Point Grey Flea3, Figure 3.6. Each camera has its merits. The Sony EVI-D70 was a full pan/tilt/zoom camera in one unit. The Imperx what a 16 megapixel camera. The Point Grey Flea3 was an USB3, 8 megapixel camera. The switch to the Point Grey was because it was small enough to fit the new airframe.

Figure 3.6

3.3 System Integration

The proceeding sections highlight and describe the team's UAS and the process that the students must achieve to design a viable unmanned aircraft system. The design process used by the students is similar to the design and integration techniques they will encounter in the UAS industry[7]. The students are given a set of requirements from the competition and have to decompose those requirements, decide what components would meet the requirements, and then reconstruct the components (perform system integration) into a viable system that meets the initial requirements. This allows the students to experience real-world engineering outside of the classroom.

4 Student Performance and Evaluation

The primary objective for the team was to learn how to design and build a complete unmanned aircraft system based upon requirements that could compete in the AUVSI student UAS competition. An airplane in and of itself is a system of systems. Added to that are the systems that make up an UAS: flight controls, GCS, data link, command and control, sensors, etc. The ECE students might not understand the concept of flight or aerodynamics, but it is the job of the AE student to educate the ECE student. And the AE student might not understand the need for a certain gauge wire to carry the proper current from the battery to the electronics, but the ECE student handedly educated his AE brethren. What is sometimes amazing is that the students don't fully realize in the beginning that they are being taught by each other. In essence, being on the team is group learning[7] or team learing. At the same time, the students are able to apply what they learn in class to a real-world engineering problems. From a systems engineering point of view, the students are decomposing the requirements (competition rules) into small manageable pieces and designing the system to the requirements. As the components are received or fabricated, the students conduct bench and ground testing on a component level followed by subsystem level testing. As they verify that the components and subsystems perform as design, they continue with assembly to reach system level testing. They are following the V-model[5] introduced previously with Figure 3.1.

A survey was taken of the students at the conclusion of each competition year, Figure 4.1. The students consistently rank the competition class good or very good. The survey was taken of each student with a ranking from 0 = very poor to 5 = excellent. The number of students each year varied from eight to twenty. The overall response from the students is that participating on the team allow them to use their classroom knowledge on real-world challenges and issues.

The team has ranked as high as first place in 2008 and as low as 27th in 2015. Obviously, winning is what the students want to achieve. However, the educational value and engineering insight are highly important along with learning to work in a team environment with diverse team members outside of their areas of study. This is reflected in a survey conducted with former students who are now working as engineers in various engineering fields from defense analyst to designer and flight test engineer. Two former students are working in the UAS field, although at the time of this writing they had not responded. These former students are either in the private sector, government contractor, or direct governement employee. One response to the survey is given in Figure 4.2

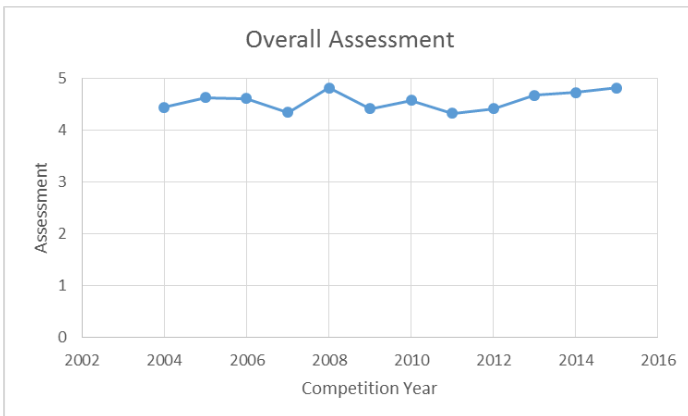

Figure 4.1

Selected quotes from other former students concerning their assessment of the competition:

"Being on the team taught me what it meant to be an actual engineer and how to approach real world problems. Unlike problems I was given in class that always had correct answers, in the real world there are constant tradeoffs and it is being able to figure out the best balance of tradeoffs that produces the best design. If it weren't for the team, I don't think I would have continued with my major as an aerospace engineer."

"Yes. Class teaches you all the theory but not how to apply it in a practical manner. Things that sound great in theory don't always work in practical application."

"It has aided in providing a goal-oriented, multidisciplinary, team environment. A traditional school education often lacks in teaching students that problems are often multi-disciplinary and that such problems require constant communication and a level of understanding between subteams to accomplish the task."

1. What was your major when you joined the team?

Electrical Engineering

2. How long were you on the team?

4 years

3. How did you hear about the team and why did you join?

Heard about the team from a classmate. It sounded like a fun project.

4. What was your role(s) on the team?

I was a systems guy the first year, Team Lead the 2^{nd} year, and Avionics/Airframe worker 3^{rd} and 4^{th} year.

5. Did participating on the team helped you in your engineering education? Please explain if so.

Being on the team helped my education in so many ways. For one, it gave me the hands on environment to take concepts learned in the classroom and translate those to practical applications, after all, that is the essence of engineering. It gave me invaluable experience I couldn't have gotten from a strictly academic curriculum. It prepared me for my current job by exposing me to many more applications than learned in the classroom and also taught me how to work as a cohesive unit with my teammates.

6. Did participating on the team helped you to gain employment in an engineering field?

Yes it did. The experience I had on the team directly helped me get my current job.

7. How has participating on the team helped you in your engineering career?

I have learned many unique skills and concepts from my time on the team. I do genuinely feel that my experience on the team sets my apart from other engineers.

8. Are you employed in the UAS field? If so, what is your role?

No

9. What was your overall experience on the team?

Being involved with the team was one of the highlights of my higher education experience. I had the most fun and gained the most the last 3 years I was on the team, but that was because I was much more involved with the team during that time.

10. What would you changes would you make to the team?

It might be good if each member of the team had generic goals for each semester or the year and had to write up a short paragraph or two addressing their performance against their goals.

Comments

I think that Team Xipiter was an amazing, one of a kind educational opportunity that helped shape not only my college career, but my career after graduation. The team definitely has had a lasting impact on me. I hope as many students as possible can take advantage of this sort of learning!

Figure 4.2

5 Conclusion

The competition allows the students to participate in a systems engineering challenge. In the classroom, the students are generally given close-ended problems where there is always a correct answer[9]. The competition allows the students to design a system where there is not a correct answer but a better answer. We see this a very positive aspect of the competition and the student UAS design team. In addition, the students of one discipline get to interact with students of other disciplines and in some cases, become close friends throughout the process. Furthermore, the students get to network and interact with other teams at the competition. At competition, they are able to exchange ideas and in some cases lend a helping hand to other teams, if needed. This allows the students, whether they understand it or not, to be good ambassadors for the university.

A major drawback is scarce financial resources to operate the team. The team does get some support from the aerospace and electrical engineering departments. However, due to travel and general operating expenses of the team, the advisors are constantly looking for financial support. The team has managed over the years, but at times, it has been difficult.

If one would put together a design competition team, especially unmanned aircraft system, make sure that it is a multidisciplinary team. In the author's opinion, that is a key trait in producing a successful and well-rounded team. In addition, make sure that the team is also a multi-classification team that accepts freshman up to seniors. Tribal knowledge, experience, and continuity is a major plus. Furthermore, give the students guidelines and then step back. Honestly, students know more than one would think. With a little guidance, they can create some excellent designs.

The use of the SUAS competition has been a valuable teaching tool for the students as well as the advisors. The students understand the need to work in a team environment and among fellow engineers, albeit, in different areas. They understand the need to design and build to requirements in which they can achieve an optimal design for a specific need. It gives them an opportunity to apply classroom education to a practical, real-work situation. They gain an invaluable hands-on experience that they can use in the industry and beyond. The design team has been a positive teaching tool that will, hopefully, continue for years to come.

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