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Vertically Integrated Project (VIP) – Design and Development of Unmanned Aerial Systems as Part of Research Course

Dr. Adeel Khalid, Kennesaw State University

Adeel Khalid, Ph.D. Professor Industrial and Systems Engineering Office: 470-578-7241

Design and Development of Unmanned Aerial Systems for Industry Applications – A Case Study

Abstract

In this paper, the design and development of Unmanned Aerial System (UAS) by a team of interdisciplinary undergraduate students is discussed. The on-going project spans over the period of several years. In this working paper, the research goals are discussed, student participations and task breakdown are highlighted. The key emphasis is on the value of this project-based course offered to undergraduate students at all levels and engineering disciplines. Dissemination plan, student tasks and schedules, and student perspectives are discussed. Learning objectives and assessment are reviewed. Student perspectives and the value of this research-based course are highlighted. Additionally, some results obtained from this research are examined.

Introduction:

A new interdisciplinary undergraduate research course is developed and taught at the Kennesaw State University. The objective of the project is to custom design, build and fly a modular Unmanned Aerial Systems (UAS) (aka drone) for specialized industry applications. In its first iterations, the team is designing a UAS for a civil engineering company for surveying mission. In the next years, the team will upgrade the design for bridge and weld inspection mission. In the following year, the mission will include manhole probing, thermal/infrared imaging, and air data collection. The goal is to continue to expand the capabilities of the custom designed UAS while providing research opportunities to undergraduate students.

The first phase of the project is supported by United Consulting (a local Civil Engineering company). They provide funding for the equipment. Design and fabrication of the UAS is done by the research team. The in-house facilities used for this project include 3D printers, CAD software, and other fabrication facilities. These and other required facilities are available in the AERO (Aerospace Education and Research Organization) lab at the host institution. Nine undergraduate students work on this interdisciplinary project under the guidance of one faculty member. Students working on the project are from Mechanical Engineering, Civil Engineering, Mechatronics and Computer Engineering programs. The research team is divided into three main groups: a) Avionics Group, b) Structures Group, and b) Systems Group. The avionics group includes students from Mechatronics and Computer Engineering. The systems groups include students from Mechanical and Civil engineering. The structures group includes students from Mechanical and Civil engineering departments. The avionics group is responsible for selection, design, and integration of all the electronic components including but not limited to flight computers, GPS, accelerometers, gyroscopes, batteries, motors, cameras etc. The systems group is responsible for creating the Computer Aided Design (CAD) models of the UAS. The systems group is also responsible for weight estimation, performing structural analysis and layout design. This group performs weight, power, and stress calculations. They also fabricate the aircraft parts and integrate all the mechanical components. The goal is to continue to recruit students from multiple disciplines. Each student brings a unique perspective to the team.

United Consulting provides expert consulting engineering and geotechnical services for the built environment. There are three basic missions to be accomplished by the UAS: 1) Survey a large area of land to collect topographical data, 2) Bridge inspection and 3) Manhole probing mission. For 1st and 2nd missions, optical cameras are the primary payloads. For the manhole probing mission, a unique module is designed to lower a data collection tube, encased in a rigid telescoping mechanism into a manhole, while the UAS hover overhead. The tube collects air quality data. Key requirements include the ability of the UAS to maintain a minimum flight endurance of 30 minutes for the heaviest (manhole probing) mission, have a flight range of one 1 mile, and the ability to support modular equipment.

Students are enrolled in a research course and get credit for their work. They have the option to use the credits towards technical electives for their degree program. This course is open to all students from all engineering disciplines, including undergraduate freshmen all the way to senior students. They are taught the research methods and processes and apply those techniques on a real-world project. Senior students also serve as mentors to junior students.

Literature Review & Methodology

Research shows that students actively working on hands-on engineering projects learn above and beyond the traditional classroom instruction. Kokotsaki et. al. [1] indicate that active student-centered form of instruction leads to student autonomy, constructive investigation, goal-setting collaboration, and enhanced communication skills. Projects like this also address a wider set of learning styles, promote critical and proactive thinking, and reflection. Mills et. al. [2, 8] argue that the current engineering programs do not provide sufficient design experience to students. Because of this, graduates often lack communication skills and teamwork experience. Engineering programs need to develop more awareness among students of the social, environmental, economic, and legal issues. These issues are better addressed in a project-based learning environment than in any other classroom setting. Mills et. al suggest that they are part of the reality of modern engineering practice and are best addressed in a group project. Shekar [3] suggests that in project-based learning, students are active learners and involved in hands-on activities. Professors are facilitators who provide guidance to students and encourage students to think and work through the problem. This process has been shown to increase student motivation, allowing them to apply the knowledge learned in engineering classes, in an interactive environment. Students get a chance to discuss concepts with each other and collaborate on projects working towards a common goal – this is also representative of a real-world project. Hadim et. al. [4-7] suggest that project-based learning facilitates the development of many of the "soft skills" demanded from engineering graduates.

Research Goals

This research project aligns with the university wide Quality Enhancement Plan (QEP) initiative. The course makes it clear that the undergraduate research experience provides appropriate scaffolding. In other words, students learn some foundational information and gain research experiences. Junior students are paired with more experienced students to learn the technical aspects of design. Short lectures / hands-on instruction is done throughout the semester. The course is structured according to the best practices for collaborative projects. There are frequent opportunities for students to receive feedback from peers and the instructor at different phases of the research. Students get the opportunity to work individually and in teams. The team meets in sub-groups multiple times during the week. There is also a weekly meeting for the entire team to bring together ideas and discuss progress and future direction.

Examples of student activities include but are not limited to the following tasks. Careful research is done on the selection of electronic components to ensure quality, reliability, and compatibility. Calculations for power, weight, and flight endurance are performed to ensure the UAS would perform as intended. Finite Element Analysis (FEA) static simulations are performed to ensure structural stability of key parts. Also, connectivity and compatibility between electronic components is ensured. The team fabricated the aircraft using 3D printing and other fabrication techniques. The team has also performed flight tests.

UAS Conceptual Model

An exploded view of the Computer Aided Design (CAD) model created by students is shown in Figure 1. This model shows various components that are put together to create the assembly.

Figure 1: CAD Model of the Proposed UAS Design

The wiring diagram in Figure *2* shows the connectivity between the flight controller, receiver, transmitter, ESC, motor, battery and other electronic devices.

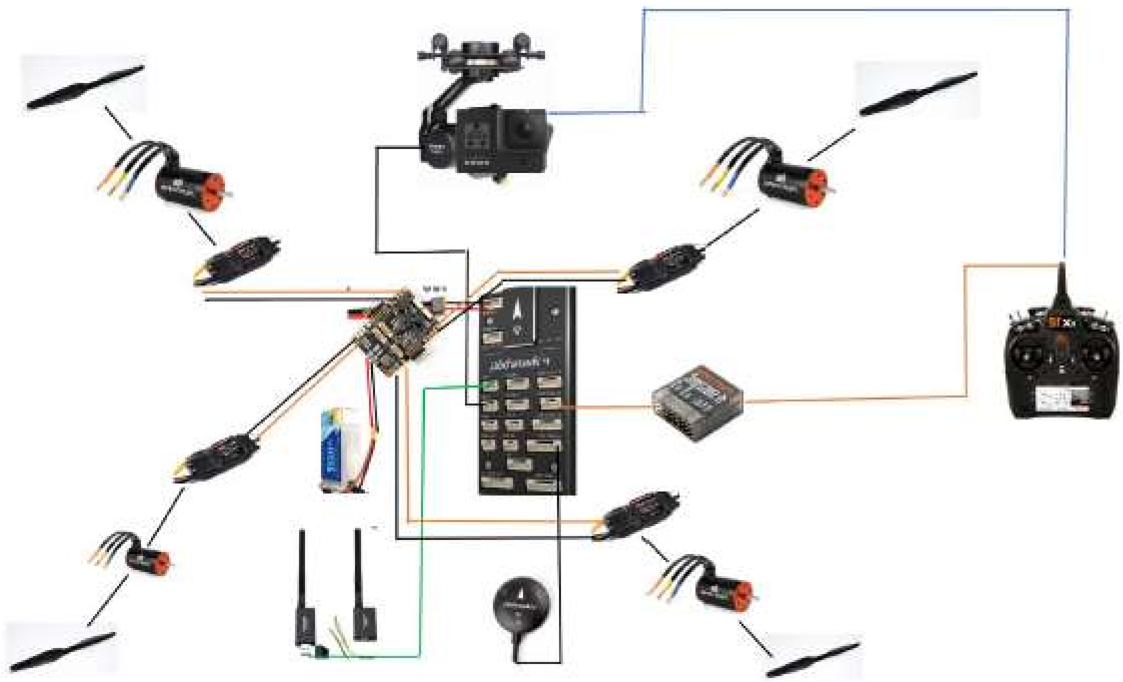

Figure 2: Electrical Diagram for the UAS

The assembly with the manhole probing module attached is shown in Figure *3*.

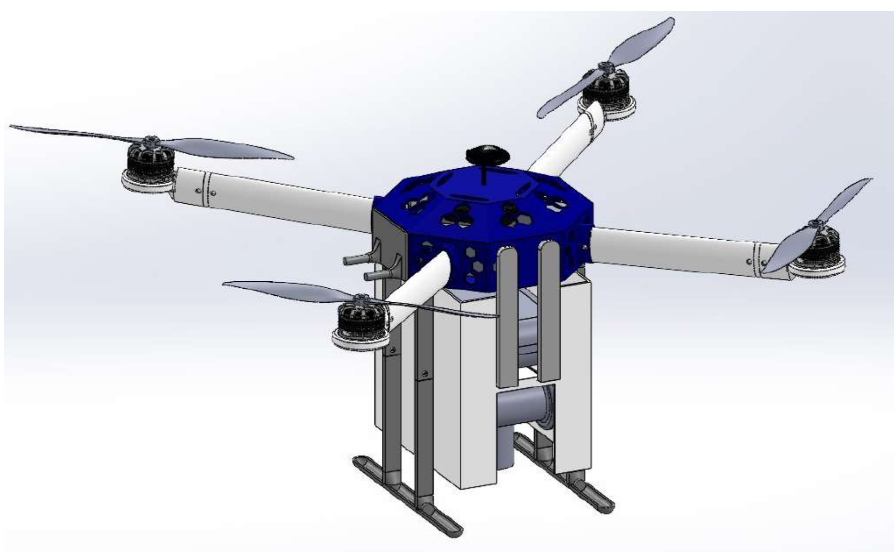

Figure 3: UAS Assembly with manhole probing module

Students also perform Finite Element Analysis (FEA) using SolidWorks® simulations. Analyses like this help make design decisions in terms of size, material, and dimensions of the various components of the aircraft. For example, yield strength of the landing gear is estimated as shown in Figure 4. Landing gears for missions 1, 2 and 3 are designed, fabricated and tested in the lab as shown in Figure 5. A 3D printed model of the UAS is shown in Figure 6.

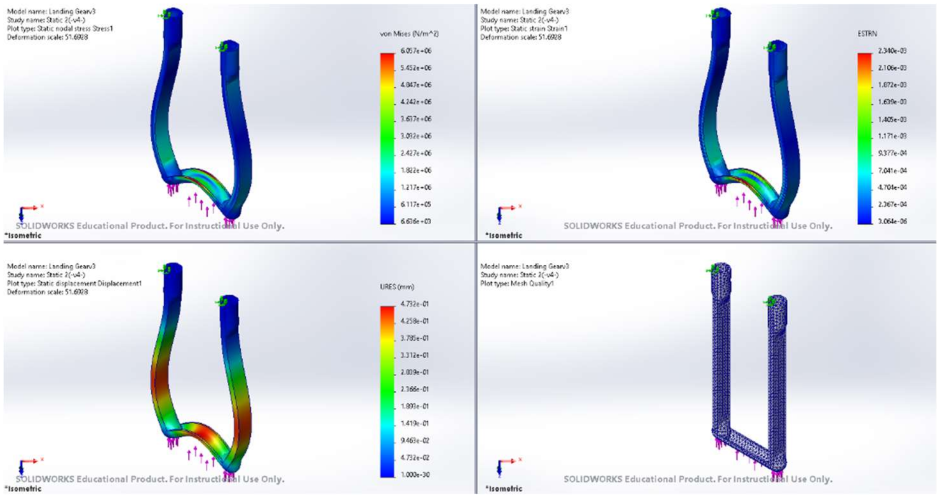

Figure 4: Yield strength test of landing gear - computer simulations

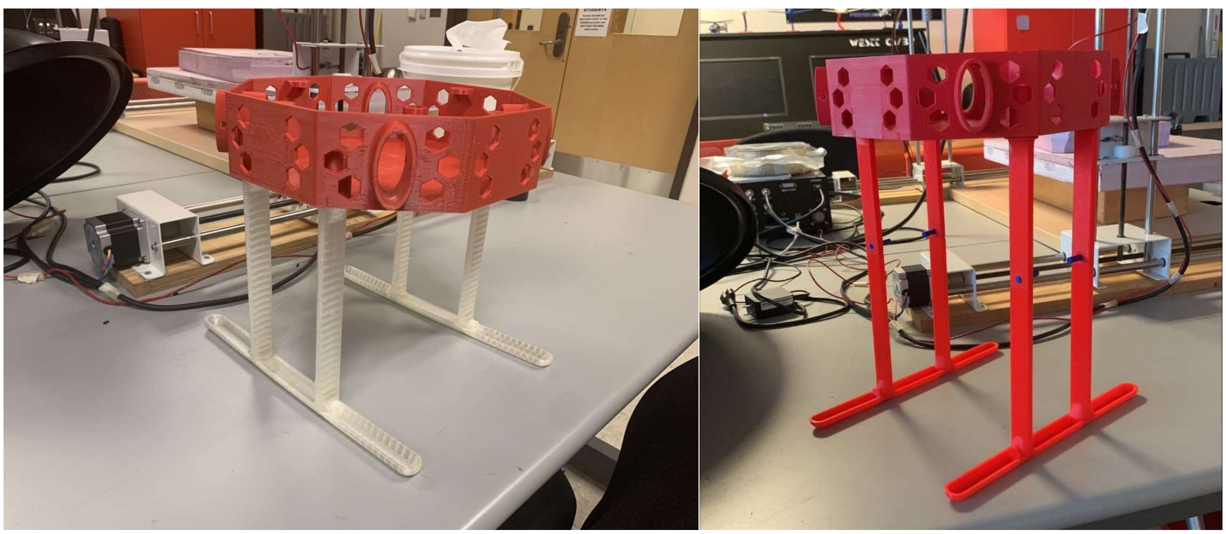

Figure 5: 3D printed landing gears for surveying and manhole probing missions

Students are involved in the complete aircraft design cycle. Their contributions include but are not limited to performing literature review, selecting off the shelf components, designing parts and assemblies, fabricating parts, integration, and flight etc. Students assert that their learning of the subject matter increased many folds by getting involved in all these steps of the study. Their level of engagement improved. The corresponding academic courses in aerodynamics, propulsion, aircraft design and others became a lot more relevant. Student perceptions are discussed in the following sections.

Figure 6: 3D Printed Assembly of the UAS

Student Participation

All engineering students (freshman to senior) from all disciplines are invited to participate in this research. Many of the students enrolled are from the Mechanical Engineering department. Almost half of these students are also enrolled in the Aerospace Engineering minor program. Table 1 lists the breakdown by majors and years.

Table 1: Student Breakdown

Student No.	**Major**	**Year**	**Working Sub-Group**
1	Mechanical Engineering	Senior	Systems
2	Robotics and Mechatronics Engineering	Junior	Avionics
3	Mechanical Engineering	Junior	Systems
4	Robotics and Mechatronics Engineering	Junior	Avionics
5	Mechanical Engineering	Junior	Systems
6	Civil Engineering	Junior	Structures
7	Mechanical Engineering	Junior	Structures
8	Mechanical Engineering	Freshman	Systems
9	Computer Engineering	Senior	Systems

Learning Objectives

The following are the learning objectives of the research course. Upon successful completion of the course, students will be able to:

1. Describe past research studies in their field of study
2. Articulate how their research study contributes to their academic field
3. Work independently and in groups to solve technical problems
4. Communicate effectively by documenting research progress, writing a final report, and orally communicating their research.
5. Reflect on their research project, including strengths, weaknesses, and things they would do differently in another research context

Note that these objectives are not covered in a typical engineering course. So, this research experience gives students additional opportunities to develop skills that they would not ordinarily gain in a traditional curriculum.

Student Tasks and Schedule

Various student tasks and schedule for this UAS project are listed in Table 2 in the form of a Gantt chart.

Table 2: Tasks and Schedule of the Project

No.	Task	Responsibility	Aug		Sep				Oct				Nov				Dec	
1	Identify and update UAS parts	Student#1	■	■	■	■	■	■										
2	Write Report	Student#1,3	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	Thrust, payload and power calculations - Spreadsheet	Student#4	■	■	■													
4	CAD Models - Fuselage	Student#5	■	■	■	■	■											
5	CAD Models - Landing Gear	Student#5, 6	■	■														
6	CAD Model - Spool/telescoping cylinders assembly	Student#7	■	■	■	■	■	■										
7	3D Printing	Student#3, 6	■	■	■													
8	Electrical Wiring	Student#7	■	■	■	■	■	■	■									
9	Connector Types	Student#7, 8	■	■														
10	Video Link + Gimbal	Student#9	■	■	■	■	■	■	■									
11	FPV Setup	Student#7	■	■	■	■	■											
12	Radio Connection Setup + Gyro + GPS + Accelerometer	Student#7	■	■	■	■	■	■	■	■								
13	Flight Tests	All Students				■	■	■	■	■	■	■	■	■	■	■	■	■
14	Oral Presentation + Paper	All Students	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Students are asked to keep track of their tasks and update the Gantt chart as they make progress.

Assessments

Students enrolled in this research course get a letter grade at the end of the semester. The research credit they receive counts towards their technical electives. The grade is based on written report and oral presentation, reflection, and the level of contribution towards the final product. It is observed that students naturally tend to go above and beyond the minimum expectations for the grade. This shows that the students enrolled in the course do this because of their interest and not because it is a requirement for their program.

Dissemination Plan

For the QEP, this project demonstrates that there is a tangible product at the end of the experience. In this case, that tangible product is the fully operational UAS. In addition, students present paper, poster, and oral presentations at campus symposium, local and regional professional student conferences including AIAA SE conference, NCUR, and others. The findings will be disseminated publicly. Since the majority of the time is spent designing and developing the project, dissemination will occur in the following semester; this may preclude some students from participating. However, all students will have the opportunity to present or publish their undergraduate research work.

VIP Project Funding

This project is done as part of the Vertically Integrated Project (VIP) program. The program is designed to facilitate long-term research involving large teams of students and faculty members. Students gain valuable research skills and academic credit through their participation, and faculty are able to scale up their research through the framework provided by VIP. VIP projects are interdisciplinary involving multiple perspectives to solve big problems. The interdisciplinary perspective comes from the recruitment of students from diverse majors. This perspective also comes from having faculty investigators from diverse disciplines. The project is based on faculty research interest, which allows teams to thrive for extended periods of time and helps advance scholarly agenda. Faculty bring their expertise and enthusiasm to their VIP teams.

Student Perspectives

Students working on the project are asked the following questions regarding their experience with this project. Some of the questions and responses are summarized below.

1. <u>What is the value of doing this research to you?</u>

One student remarked:

"This project's main benefits are the relationships I make and the doors it could open. I am working with a team of some remarkably talented individuals. It's great to have these connections and learn from their expertise. Also, a university-related project is a great way to open doors. Many recruiters filling very competitive positions are looking for students involved in hands-on projects like this. All of my portfolio consists of either personal projects or projects for a client, and even though I have done some impressive work, it's hard to be considered without a university-related activity."

Another student added:

"The opportunity to work on this hands-on research project has provided me with real experience on the design and manufacturing process from requirements and concepts to assembly and production. As a student who was unable to work in an internship or co-op position, this is a valuable substitute."

Another student pointed out that:

"It is not often a student can participate in solving a real-world engineering problem. I am very grateful to be able to work alongside a field experienced advisor and learn new ideas/concepts from teammates. I have learned technical skills with various components, software, hardware, and research, while also learning the importance of good communication. I feel working with this team has provided valuable skills that have improved me as a young engineer."

Another student added:

"…To take me out of my comfort zone as a student and provide an opportunity for applications of knowledge outside of the classroom or homework assignment."

2. <u>What do you expect to learn / gain from this experience?</u>

One student pointed out:

"So far, I have learned a lot about drones and motors in general. Especially things like drone weight, motor parameters, and FPV. It is hard to think of any specific things I could learn or gain during the remainder of the project, but in general, there are many things to be learned from doing work."

Another student remarked:

"Up to this point, I have learned that while it is important to have a team with a variety of skillsets, it is equally important that multiple members are able to verify the same data and information. This experience is one that I expect will continue to influence my interactions with engineering teams throughout my career."

Another student asserted:

"I expected to grow my knowledge in commercial UAS development and research skills."

Another student added:

"Further experience in a collaborative setting, opportunities to learn and improve my own disciplines. While this is not work experience, I see this research opportunity as being very valuable while an undergrad student. It's a glimpse into the future ideally."

3. <u>How can this research project / experience be improved?</u>

One student pointed out:

"It isn't easy to have ten people communicate effectively on the same level. There have been a few times when teammates had to redesign components because it wouldn't work with other systems that were made. Other times I have been given an identical task as another teammate by accident. It would help to have some management structure that would help keep everyone on the same page. For example, there could be a mechanical lead, an electrical lead, and a project manager. Each lead could make sure that the individual components of that system will work together and maintain a list of tasks needed to be done to continue work. The project manager would be in charge of keeping the group organized and on the same page, and they would make sure that what the mechanical and electrical teams are doing will work together."

Another student mentioned:

"The leadership hierarchy was good, but could have been more cleanly structured. [X] and I were the heads of our corresponding departments. However, since [X] was unable to attend the general body meetings and I was often unavailable during the time he was available, communication between both groups was slow and technical issues sometimes occurred as a result."

One student suggested:

"I understand this is a first-time type of project but having a more equipped lab space with proper ventilation, tooling, and workspace would be greatly appreciated. This would save time, improve the workplace environment, and reduce the usage of personal equipment."

Another student pointed out:

"Environment; more accommodating workstations with soldering irons, hand tools and so on. More dedicated meetings, we meet once a week as a progress report but what if we were able to meet together weekly for a block of 'work' time."

4. <u>Do you have any other comments?</u>

One student remarked:

"Overall, I'm very satisfied with this research project, and I believe that it will become very impactful as the team continues to grow."

Another student asserted:

"I am very grateful to be apart of this team and this learning opportunity. I have learned in areas I did not expect, and I look forward to seeing this project through."

Another student remarked:

"I think that something like this research is very valuable for someone like me. It takes me out of where I am comfortable and challenges me and I want to succeed, grow, and become a better engineer or at the very least a better group members, while still undergrad."

The feedback received from students is invaluable. It will be helpful in updating and improving this research course the next time it is offered.

Conclusion and Future Work

In this working paper, details of the research-based course are highlighted. In this on-going project, students custom design and build a UAS for a local civil engineering company. The UAS is designed to perform specific missions and carry specific payload. The pedagogical research goals, student participation, learning objectives, assessment, dissemination plan, student tasks and schedule, and student feedback are discussed. As evident from their feedback, students are extremely satisfied with the research experience and acknowledge the various benefits gained from participating in this study. The future plan is to continue to offer this course every fall and spring semester, seek funding from other external organizations, and continue to improve the process through internal and external feedback.

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