Design of a Hexacopter for Agricultural Spraying - A Collaboration Project between West Texas A&M University and FH JOANNEUM

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Abstract

At West Texas A&M University, students in the engineering programs are actively engaged in research projects designed to get them involved in global collaboration through problem solving. The project was initiated when a group of 13 senior engineering students from the Aviation Institute at FH JOANNEUM in Graz, Austria were commissioned in fall 2018 to conceptually design an agricultural spraying drone. The project was continued in spring 2019 by a group of 5 senior mechanical engineering students from West Texas A&M University. The students from the Aviation Institute were divided into three groups and were asked to deliver their conceptual designs of the drone along with numerical simulations. The engineering group from West Texas A&M University had to assess the three different preliminary designs provided by FH JOANNEUM, select the most appropriate one, construct and test the drone and its spraying system. The resulting system was capable of achieving the following: a flying time of at least 16.7 minutes covering a distance of 2 kilometers when operated in automatic mode, with the ability of carrying 2 kg of payload at takeoff and delivering a spray mist at a flow rate ranging between 0.37 and 0.45 liters/minute. The project created an opportunity for global virtual teams to form between the two universities, and provided an opportunity for the students to communicate effectively with a range of audiences, an ABET learning outcome criterion. This collaboration was very valuable in bridging the gap in the engineering curriculums between the United States and Austria.

Introduction

The purpose of this pilot project was to increase undergraduate and graduate students' interest at West Texas A&M University (WTAMU) in research on unmanned aerial vehicles (UAV) in areas of agricultural and surveying applications. This project provided the students with the opportunity to learn how to manage an international project and to work on a global team by collaborating with international students from another foreign institution. This pilot project was the start of international research activities with FH JOANNEUM (FHJ) in Graz, Austria creating a focus on aeronautics within the undergraduate mechanical engineering and graduate engineering programs at WTAMU. This international collaboration between the Mechanical Engineering program at WTAMU and the Aviation Institute at FHJ will strengthen the curriculum and research efforts in both undergraduate and graduate programs at WTAMU and FHJ by providing resources for advancing learning, understanding, discovery in the fields of aerial vehicles, controls and simulation, and managing an international project.

Project Initiation at FH JOANNEUM

The project was initiated when the authors commissioned a group of 13 senior engineering students from the Aviation Institute at FHJ to conceptually design an agricultural spraying drone. The project started during the 2018 winter semester at FHJ and was continued by a group of 5 senior mechanical engineering students enrolled in engineering design at WTAMU in spring 2019.

The drone had to be designed using a minimum of 6 propellers for stability control and had to meet the following constraints: a flying time of not less than 15 minutes, a minimal flight range of 2-3 km, and a capability to carry a minimum payload of 2 kg. For the spraying system, the fluid tank had to have a minimum capacity of 1.5 L, and the spray nozzles had to deliver variable flow while being remotely controlled from the ground. In order to keep the budget under $3k, the project dictated that the above constraints be placed on the drone flight range, payload and fluid reservoir capacity. Furthermore, this drone was intended to be a pilot drone that performs limited agricultural spraying. Dr. Issa jump-started the project via a WebEx meeting with the Austrian students in December 2018 (Fig. 1). The 13 students from the Aviation Institute at FHJ were divided into 3 groups, and were asked to deliver 3 different conceptual designs along with numerical simulations by the end of January 2019, coinciding with the end of the winter semester in Austria. The students at FHJ had to hold frequent meetings via WebEx with the students from WTAMU, and deliver a final presentation and a report at the beginning of the 2019 spring semester in the U.S. The WTAMU group had to assess the 3 preliminary designs provided by FHJ, select the most appropriate one, construct and test the drone. They were asked to make any necessary modifications to achieve improvements in the drone performance.

The 3 conceptual designs produced by FHJ aviation students were:

Team A

Figure 2 shows the drone designed by FHJ Team A. The drone has an estimated cost of approximately $2,500. It incorporated an exceptional mounting plate for additional components to be added to the drone. The group also incorporated a simple bracket design that makes the drone collapsible and easily transportable. Some of the drone components required large additive manufacturing systems (3-D Printers), which would not be readily available to WTAMU students. This raised some concerns with its manufacturability. However, the "sandwich" design used for the airframe provides an efficient use of space and reduces the weight of the drone. The landing gear in this design is mounted between two airframe plates made of carbon-reinforced plastic, providing a lot of support for the drone without damaging any other components upon impact. This design was chosen as the final design for the agriculture drone by WTAMU students, as it appeared to be the most robust in comparison to the other two designs.

Figure 1. Kick-off Meeting for the Hexacopter Project with FHJ Aviation Students

Figure 2. FHJ Aviation Students' Design by Team A

Team B

The drone designed by Team B at FHJ (Fig. 3), was submitted with an estimated cost of $2,250. Although the cost of the drone is low, the overall build of the drone didn't seem as strong as Team A's design. The fact that the legs are attached to the arms of the drone was seen as a major disadvantage as the loading will be transferred into the arms of the drone, which could be detrimental to the structure of the drone in the case of a rough landing. It was WTAMU group's view that the majority of the loading should be taken on by the body of the airframe, and not by the arms of the drone. This drone incorporated the sandwich-style body that was seen as a benefit.

Team C

The third drone design (Fig. 4) was submitted by FHJ Team C with an estimated cost of approximately $1,150. The cost was certainly acceptable, but it did not include the cost of the remote control system. Similar to Team B's design, the drone incorporated a landing gear attached to the arms that would transfer the load upon landing into the arms rather than the main body frame. Again, this was seen as a negative factor in the drone design. The upper part of the main body frame also appeared to be difficult to manufacture.

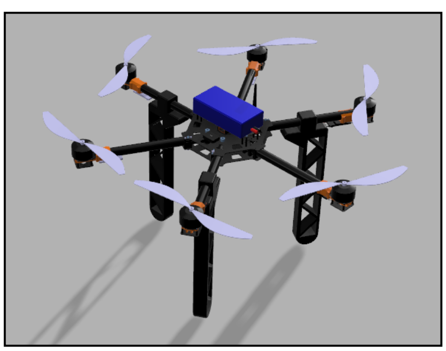

Figure 3. FHJ Aviation Students' Design by Team B

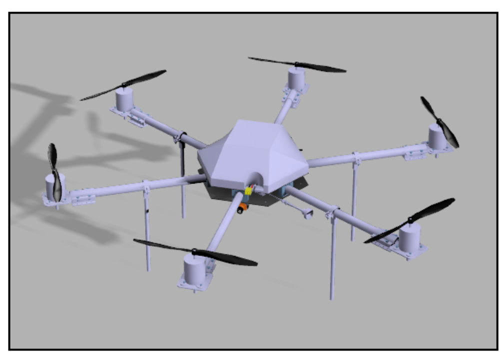

Figure 4. FHJ Aviation Students' Design by Team C

Project Completion at West Texas A&M University

After selecting the most appropriate design based on performance and cost, the group of 5 senior engineering students from the Mechanical Engineering Program at WTAMU constructed the drone, and designed its spraying system.

The propulsion system consisted of a series of batteries, propellers, motors, and electronic speed controllers. After the proper motors were selected, speed controllers were chosen to handle the maximum current rating of the motors. Once these components were selected and an optimum mission flight time was chosen, multiple batteries were selected based on the required total current drawn by the motors during operation. All components were designed based on a maximum drone weight of 10 kg. Brushless direct current motors were selected due to their efficiency as well as smaller size when compared to brushed motors [1]. The motor and propeller combination chosen were XOAR T5010 DC brushless motors and PJP-T-L 18X6.5 propellers (Figs. 5 and 6). They were larger than those recommended by FHJ, but had the same input voltage. The selection of larger propellers led to an increase in the efficiency of the motors from the original design, which led to a decrease in current requirement by the motors and an increase in the drone flight time. Numerical calculations performed by the students (initially by FHJ and later on revised by WTAMU) showed the motors to operate at 56% throttle. The relationship between thrust and throttle is shown in Fig. 7. The specific thrust of the motors, defined as the amount of thrust generated per Wattage usage by the motors, was calculated at hovering mode based on the manufacturer data [2]. It was found to be 9.56 g/W (Fig. 8). The electrical current requirement for each motor was calculated using the manufacturer's data [3]. For a thrust value of 1667 g, the required current of each motor was found to be 9.064 A. The motors were wired together in parallel (Fig. 9) to ensure the same voltage is given to each motor during hovering. Once the motors and propellers were selected, speed controllers were chosen based on the maximum current drawn by the motors, 36.35 A. Since speed controllers were rated in increments of 10 Amp, 40 Amp controllers were selected.

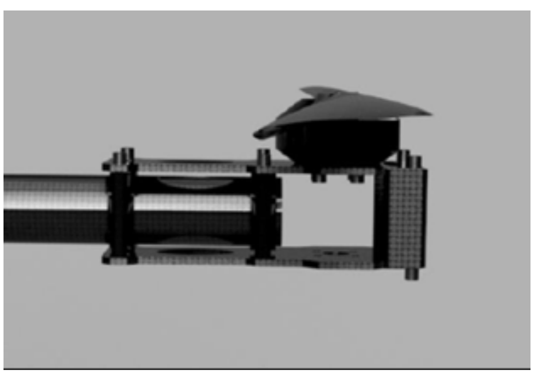

Figure 5. Chosen Motor-Propeller Mount

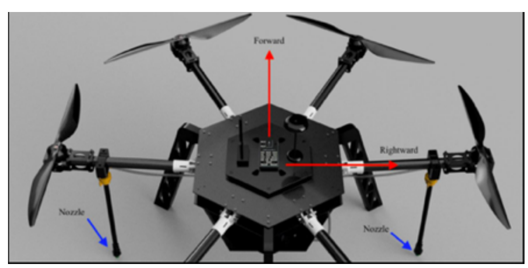

Figure 6. Chosen Fuselage Cross-Configuration

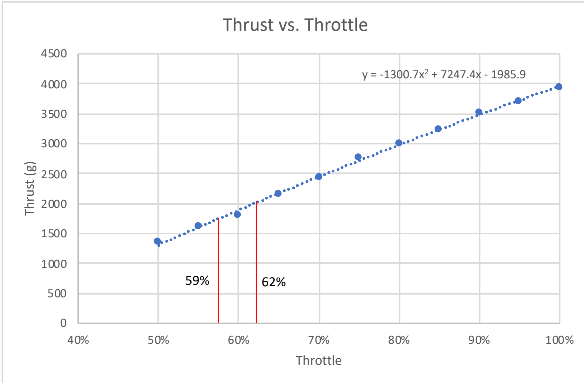

Figure 7. Thrust Versus Throttle (Simulations)

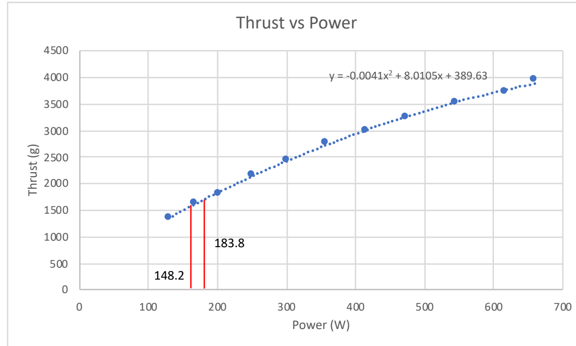

Figure 8. Thrust Versus Power (Simulations)

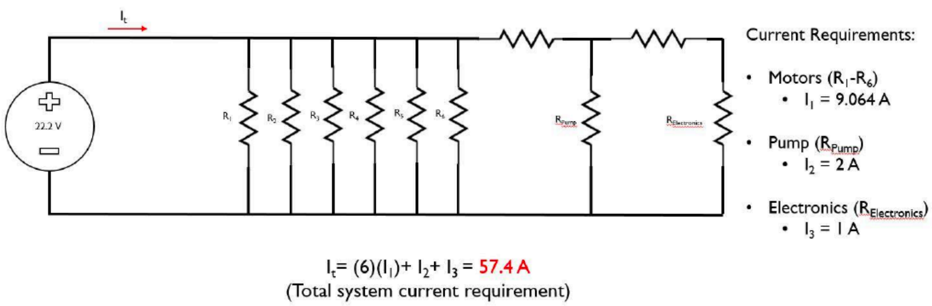

Figure 9. Drone Electric Circuit Diagram

Carbon-reinforced plastic was chosen for the blades and the frame due to its lightweight and rigidity. It is a durable material to use in the event of an object striking the propellers, while its rigidity has the benefit of reducing vibration. The landing gear was designed to be strong enough such that the drone can land without the risk of failure, but flexible enough to fail in the case of a rough landing (Figs. 10 and 11). The fluid tank (along with its lid) was designed to be hexagonal in shape to match the body of the hexacopter drone (Fig. 12), with baffles included to prevent the fluid from sloshing causing instability during flight. Both the landing gear and the tank were 3D-printed using durable photoreactive resin by FormLabs. A miniature geared-pump was selected to deliver a maximum flow rate of 2.52 L/min, and nozzles were chosen to deliver a hollow cone spray pattern dispersing fine mist with a Sauter Median Diameter ranging between 60 and 145 microns. A GoPro video camera [4] was installed for high-definition photography. The camera is to be controlled remotely via a GoPro remote controller, the range of which is 600 feet. After assembly of the drone system (Fig. 13), the drone had acquired the following features: A flight time capability of 16.7 minutes covering a distance of 2 kilometers when operated in automatic mode, the ability of carrying 2 kg of payload at takeoff, and the capability of delivering spray mist at a flow rate ranging between 0.37 and 0.45 liters/minute.

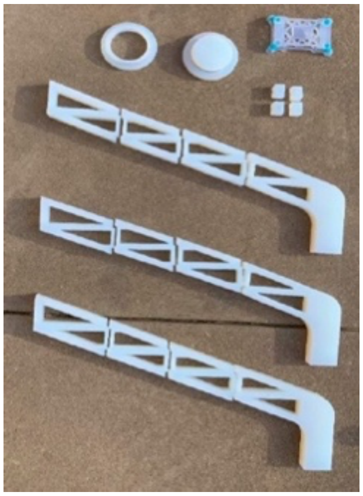

Figure 10. Assembly of the 3-D Printed Drone Legs

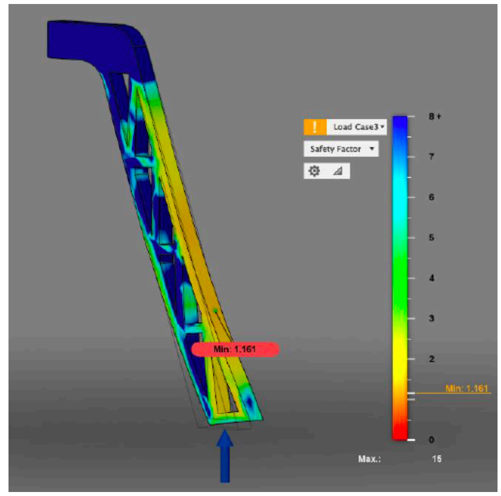

Figure 11. Load Analysis on the Drone Legs

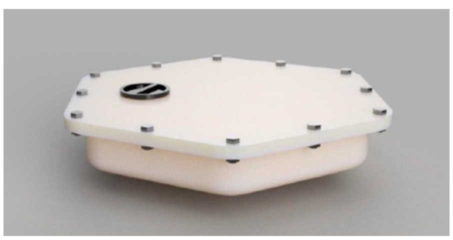

Figure 12. 3-D Printed Fluid Tank with its Lid

Figure 13. Hexacopter Final Design (WTAMU Engineering Team with FHJ Guest Prof., Dr. Puffing & WTAMU Prof., Dr. Issa)

Project Coordination Between the Two Universities

The project started at FHJ (Graz, Austria) in December 2018 as part of the course requirement in Applied Design, a 2nd-year level course in the aviation program with 5 ECTS (European Credit Transfer System) credits which is equivalent to 2.5 SCH (semester credit hours) in the U.S. Thirteen 2nd-year students from the Aviation Program at FHJ jump-started the project, but had to hold several WebEx meetings during the months of December and January with the 5 mechanical engineering students registered in Senior Design course at WTAMU before the project was to continue in Spring 2019 in the U.S. In the design course at WTAMU, emphasis is placed on performing analysis, generating and evaluating multiple solutions, including optimization, economic considerations and sustainability in engineering design. Students learning outcomes include all of ABET accreditation criteria [5].

FH JOANNEUM is a university of applied sciences whereas FH stands for Fachhochschule, a German/Austrian tertiary education institution that emerged from traditional engineering schools. Fachhochschule differs from the technical university through its more practical emphasis. Fachhochschule builds a strong relationship with industry. The Aviation Program at FHJ [6] offers B.S. and M.S. degrees in aviation. The program introduces students to integration of aircraft systems, flight controls, airborne radars, aircraft certification process, and to design of commercial aircrafts. It is important to keep in mind that the Bachelor of Science degree in the Fachhochschule system consists of 6 semesters with a total of 180 ECTS credits (90 SCH credits), while in the U.S. the Bachelor of Science degree consists of 8 semesters with a total of 120 SCH credits. However, the degree in the Fachhochschule system does not include any core curriculum courses (humanities, social science courses, electives, etc…).

During the WebEx meetings, the students on both sides discussed the process associated with the fabrication and the assembly of the drone system components. The students at FHJ had to give frequent updates to the students at WTAMU, and deliver a final presentation along with a report at the start of the spring semester in the U.S. Towards the middle of the 2019 spring semester at WTAMU, Dr. Puffing visited WTAMU as a guest professor, and delivered a series of lectures on aircraft design, supervised the continuation of the project and mentored to the U.S. group of students along with Dr. Issa.

During the next few semesters, an assessment study will be conducted on the built hexacopter drone by another group of students that will include students from both universities. Modifications will be done on the drone based on flight simulation tests that will be performed.

Project Assessment

This international and multidisciplinary involvement between WTAMU and FH JOANNEUM gave the students on both sides the opportunity to continue improving their problem-solving, teamwork, and communications skills. The difference between the educational systems of Austrians and American students was a challenge that led to a great learning opportunity for students on both sides. The curriculum for WTAMU students is focused on theoretical engineering design and analysis, while that for FH JOANEUMM students is focused on industrial design. The students had to communicate to bridge this gap between their engineering curriculums. In addition to that, the students on both sides had to face the challenges associated with the language and cultural differences. However, such diversity led to a greater learning experience for all students.

The project identified with ABET student learning outcomes and particularly outcome 3(3): "an ability to communicate effectively with a range of audiences". It is becoming increasingly important for engineering programs in the U.S. to give their students enough preparation to work in an international environment setting. With the increase in globalizations, many recruiters nowadays are looking for good communication skills and international exposure when hiring recent graduates. Even though the teams on both ends did not meet in person, this project created an opportunity for global virtual teams to form. This international experience enlightened and exposed the students to different cultures, an essential capability to have as an engineer.

The pilot project was assessed by comparing the performance of this particular group of WTAMU students in Senior Design with other project groups who worked on other senior design projects that did not have an international focus. The project was assessed by a group of engineering faculty at WTAMU during senior design presentations in Spring 2019 using a rubric for assessment that is on ABET's students learning outcome criterion a through k. Scores ranging from 1 to 4 were assigned where 1 stands for an unacceptable performance, 2 stands for an acceptable performance, 3 stands for commendable performance, and 4 stands for an outstanding performance. The gathered data is shown in Table 1 and Fig. 14. The scores below reflect the performance of the entire global team that included both WTAMU and FHJ students. The following categories were assessed in evaluating WTAMU engineering students: 1) Underpinning knowledge and understanding, 2) Engineering analysis, 3) Engineering design, 4) Engineering practice, 5) Intellectual abilities, 6) Practical skills, 7) Investigation, 8) Economic, social and environmental skills, and 9) Transferable skills. In general this international project performed noticeably better than the rest of the local projects in the course resulting in an average improvement of 9%. The highest categories were: Engineering practice (*graduates can analyze complex problems and use appropriate solving strategies*), and the global, economic, societal and environmental skills categories. It is obvious that working in a global team helped the students analyze complex problems such as designing a drone. Also, the awareness of global and societal issues (working with a foreign culture via online) have been a high point in this collaboration.

Table 1. International Pilot Project Assessment and Its Comparison to the Entire Course Projects

Outcome Category	ABET Criterion	Pilot Project			Course	Percentage Improvement
		Mean	Min	Max	Mean	%
Underpinning Knowledge & Understanding	a, h	3.15	2.50	4.00	2.94	7
Engineering Analysis	b, e, k	3.43	2.67	4.00	3.16	9
Engineering Design	c, j	3.55	3.00	4.00	3.19	11
Engineering Practice	k	3.50	3.00	4.00	2.96	18
Intellectual Abilities	b, j	3.20	2.50	4.00	3.21	0
Practical Skills	d, h	3.55	3.00	4.00	3.36	6
Investigations	b, c	3.40	2.50	4.00	3.20	6
Economic, Social & Environmental	f, h	3.55	3.00	4.00	3.12	14
Transferable Skils	d, g, i, j	3.65	3.25	4.00	3.33	10
Average	**a ---> k**	**3.44**			**3.16**	**9**

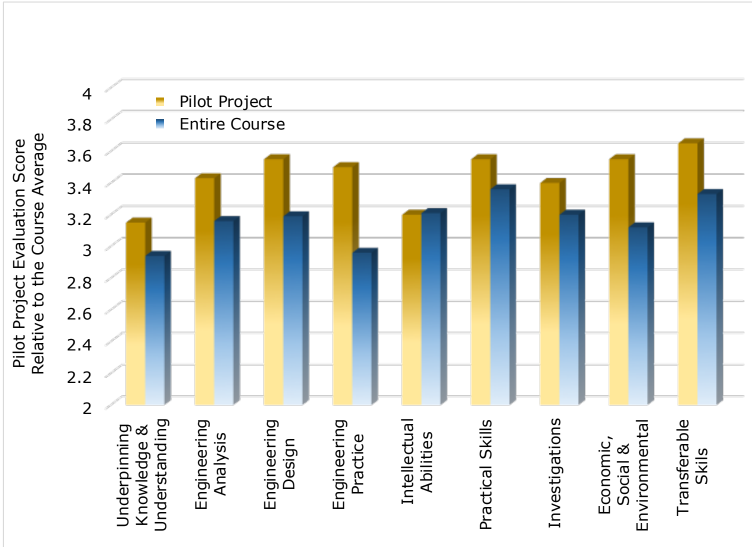

Figure 14. Assessment of the International Pilot Project

Conclusions

Engineering students from the Mechanical Engineering Program at WTAMU and from the Aviation Institute at FHJ, in Graz, Austria collaborated on an international project to design a hexacopter agricultural drone. The project started in Austria by 3 groups of aviation students from FHJ who produced conceptual designs of the drone , and concluded in the U.S. by a group of mechanical engineering students from WTAMU that assessed the different designs, selected the most appropriate one, and assembled the drone system. The produced system had a flying time capability of 16.7 minutes covering a distance of 2 kilometers with the ability of carrying 2 kg of payload at takeoff. The international project performed better than the rest of the projects in the course with an average improvement of 9% on ABET's students learning outcome criteria. This reflects on the performance of the entire global team that includes both WTAMU and FHJ students. The international and multidisciplinary focus of this project gave the students on both sides the opportunity to continue improving their problem-solving, teamwork, and communications skills.

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