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Providing a Comprehensive Learning Experience in Applying Reverse Engineering Techniques and CAD for Redesign, Simulation, and Manufacturing of Diverse Drone Platforms

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Abstract

The undergraduate hands-on project presented herein outlines the process of using reverse engineering techniques and CAD to model, simulate, and fabricate two drones in a senior project course. The project introduces students to the conceptual design of drones and the practical applications of CAD and simulation software to validate the drone's operational capability. In addition, students add mechanical and electrical components, GPS, flight control unit, and telemetry system to the existing drone so that it can be flown autonomously. This project serves as a comprehensive learning experience, offering students the opportunity to engage in redesigning, simulating, fabricating, and testing fully functional drones. The design process starts with using reverse engineering techniques to scan the parts, create 3D computer models, and implement minor necessary modifications to the fuselage and wing of the drones in CAD software and carry out simulation by selecting appropriate materials, propulsion systems, and flight controllers. After successfully modeling drones in CAD, simulating, and validating the operational capabilities of the drone in CFD software, all airframe parts are printed by a 3D printer. Students also gain hands-on experience in assembling the drone from individual components, such as the airframe, motors, propellers, and flight controllers. In addition, they learn practical know-how of power distribution systems, wiring, assembling, and troubleshooting techniques. The other aspect of the project involves programming the drone's flight controller and onboard systems to communicate hardware with software. Finally, students conduct in-field flight operation of the drone to evaluate its stability and maneuverability. Students are required to develop a comprehensive project report and deliver presentations to showcase their achievements. In summary, the central goal of this project is to provide interdisciplinary students majoring in engineering, technology, and aviation science with comprehensive learning experience.

Introduction

The Unmanned Aircraft Systems (UAS) technology, known as drones, has seen extraordinary growth globally in recent years. The reverse engineering technique is popular for replicating and redesigning the existing drones. This project introduces drone reverse engineering concepts that are significant for undergraduate engineering students for several reasons. It provides hands-on experience with real-world technology, allowing students to apply theoretical knowledge in practical settings. This process enhances critical thinking and problem-solving skills as students analyze and deconstruct existing drone designs to understand their functionalities and limitations. Moreover, engaging in reverse engineering fosters innovation, encouraging students to develop their own designs and improvements. Additionally, it prepares students for future careers in aerospace, robotics, and defense, where understanding the mechanics of existing technologies is crucial. Also, this paper primarily focuses on developing design and activities as it is the pilot project. As the project gains momentum in subsequent semesters, assessment tools to measure effectiveness in student learning outcomes will be introduced.

Drone covers wide and different fields of application primarily due to their easy accessibility to dangerous and difficult areas and due to very sophisticated payload sensors providing high-resolution images in almost all frequency ranges [1]. A comprehensive review of research papers on the application of Unmanned Aerial Vehicles (UAV) is presented in [2]. Hence, it is imperative to provide opportunities to undergraduate students to help them learn various aspects of the design and development of such vehicles by implementing reverse engineering techniques.

Reverse engineering plays a vital role in manufacturing and has been widely recognized as an important technique in the product design cycle [3]. It improves the design of the part. When original CAD models are not available, it is often essential to redesign an existing part using reverse engineering. CAD models are also used for analysis and modifications to improve product design. After perfecting the design, the components are 3D printed. Students benefit greatly from learning about 3D design and printing [4]. Singh [5] has described the design of drone using basic principles and available components that provided a good reference to the students in the initial stages of the design process. Sharma [6] has described the design and fabrication of a hexacopter drone made of carbon fiber frame with microcontroller-based flight controller. Eslami [7] used reverse engineering techniques to create a CAD model of an old aircraft part and prototype it.

This project presents a unique opportunity for undergraduate students to gain hands-on learning experience in the design, prototyping, and fabrication of two educational fixed wing drones. It introduces the students to the exciting world of drone design, Reverse Engineering techniques, and the practical application of Computational Fluid Dynamics (CFD) engineering software for fluid simulation. The project also includes hands-on experience in integrating mechanical and electrical components, providing students with a practical understanding of their learning. Two drone models are considered for this project. ZOHD TALON GT and ZOHD Dart XL are shown in figures 1 and 2.

Fig 1: ZOHD TALON GT Drone

Fig 2: ZOHD Dart XL Drone

Methodology

The project unfolded in a series of innovative steps. These included the use of reverse engineering techniques to create CAD models, a creative redesign of the airframe and wing, analysis and simulation of the drone, and the pioneering process of prototyping fixed wing drones by a 3D printer. Two models were created as experimental aircraft platforms, and further analysis and simulations were conducted.

Step 1: Using reverse engineering techniques- the airframe of drone was disassembled into several components, including the wing and fuselage to figure out how they were assembled. Also, some analyses were performed, such as weight measurements and the type of wing airflow. Then, each component was individually scanned to capture both the front and back of the pieces and create cloud points. The scanning process and creation of cloud points are depicted in Figures 3 and 4.

Fig 3: Scanning the parts

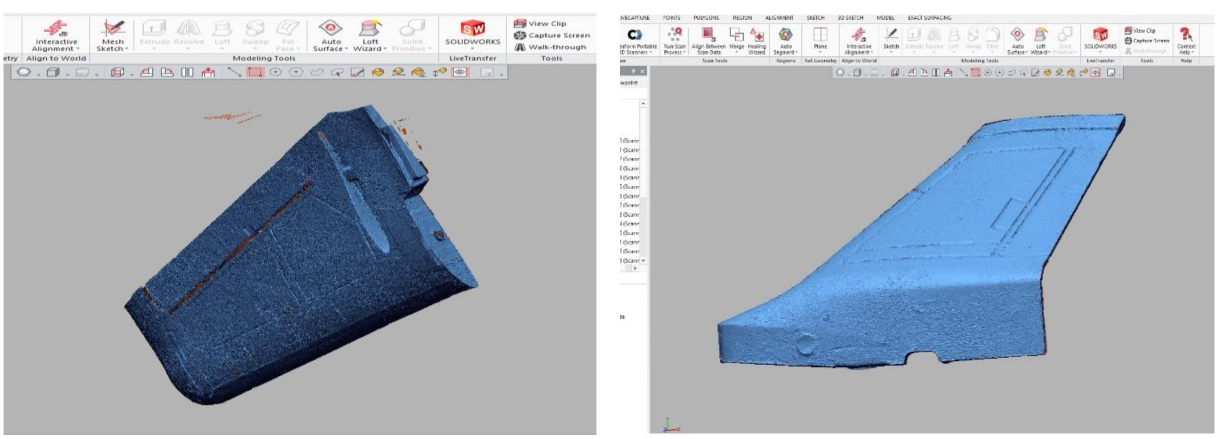

Fig 4: Cloud points of two parts of drone

Step 2: Creating CAD models- the process starts by converting cloud points to CAD models for further editing of the final design and simulation. The inside of the fuselage is redesigned to provide more space for placing electronic components. Due to size limitations in the prototyping of parts by 3D printer, some CAD models of components are divided into two or three pieces with proper connections that allow components to be easily assembled and disassembled without compromising the integrity of the structure. Figure 5 shows some CAD models of the drone's parts.

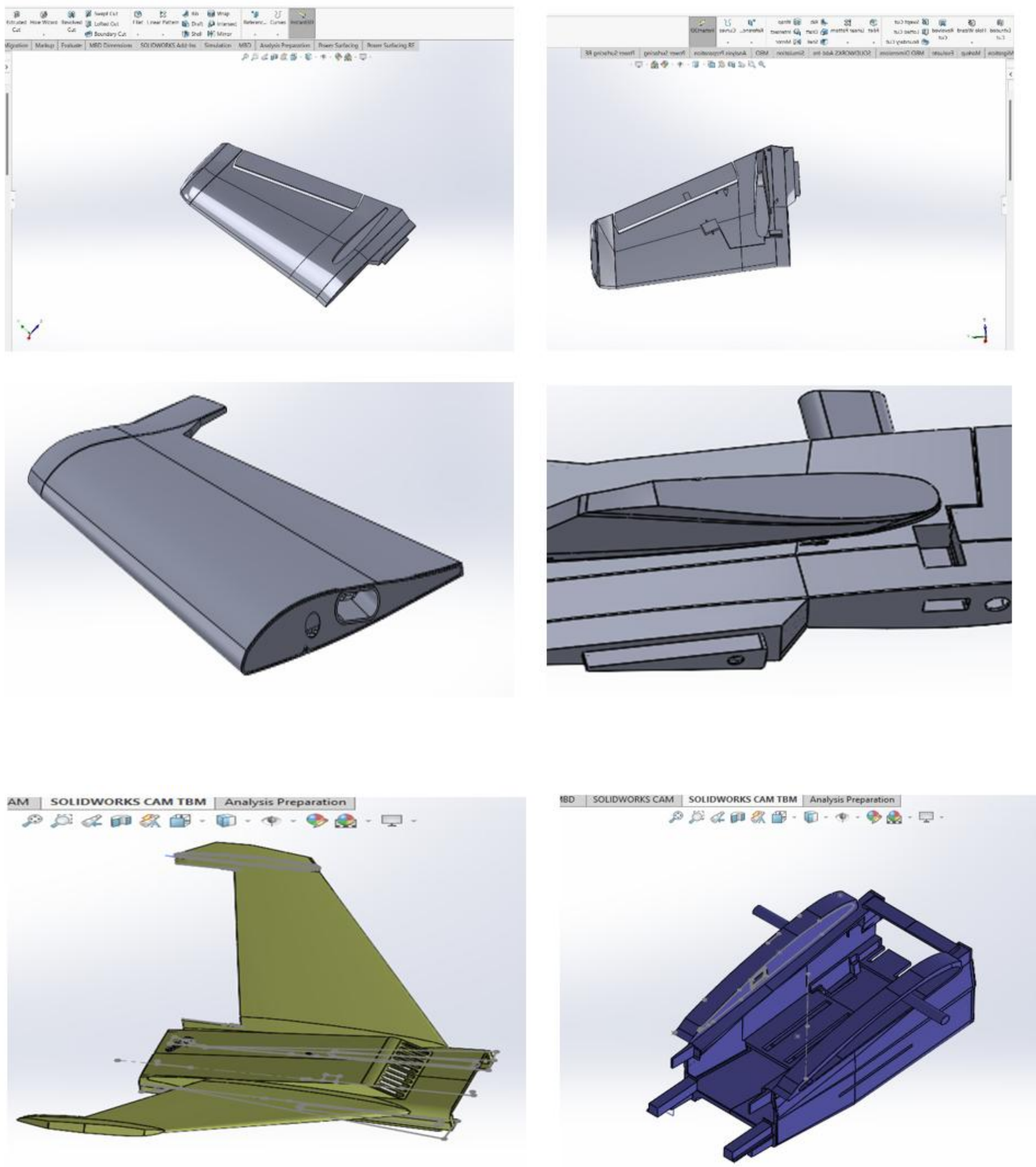

Fig 5: CAD models of some drone's parts

Step 3: Redesigning the inside the wing- The weight plays major concern in the operation of drones. To reduce weight without compromising the integrity of the structure, a new design with adding ribs inside the cavity is proposed. The new design is shown in figure 6.

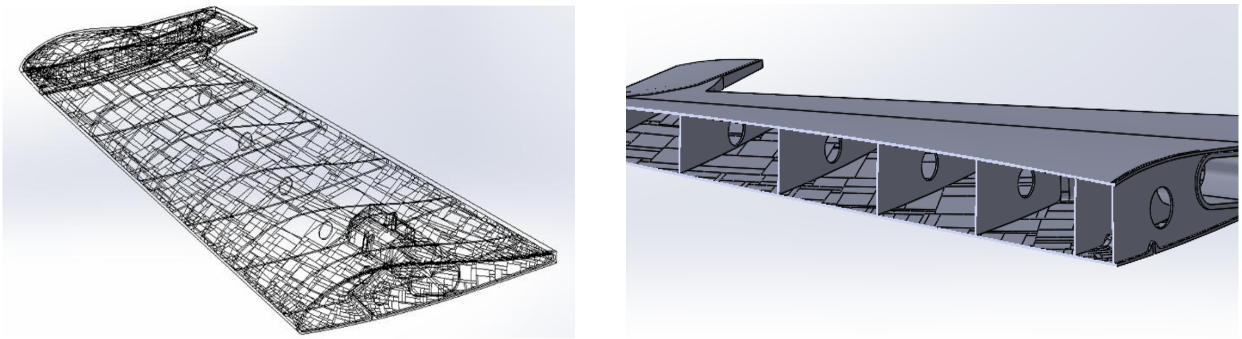

Fig 6: Redesign the inside the wing

Finally, all the pieces are assembled in CAD software, that two completed drones are shown in figure 7.

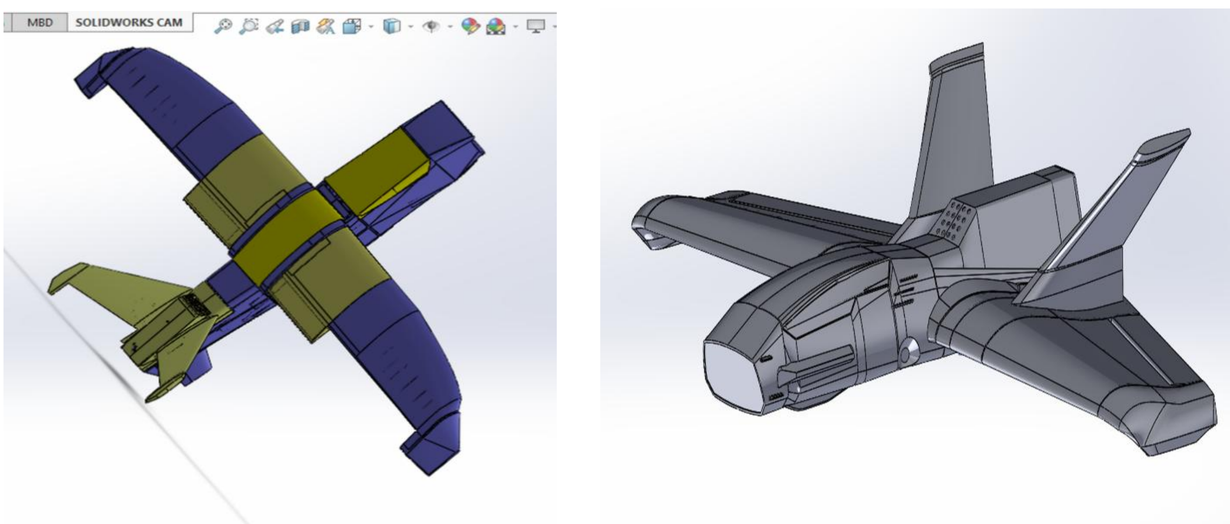

Fig 7: Assembled CAD models of two drones

Step 4: Flow Simulation of the drones- SolidWorks simulation software is utilized to study flow simulation over the UAV. Figure 8 shows the drone model in computational domain.

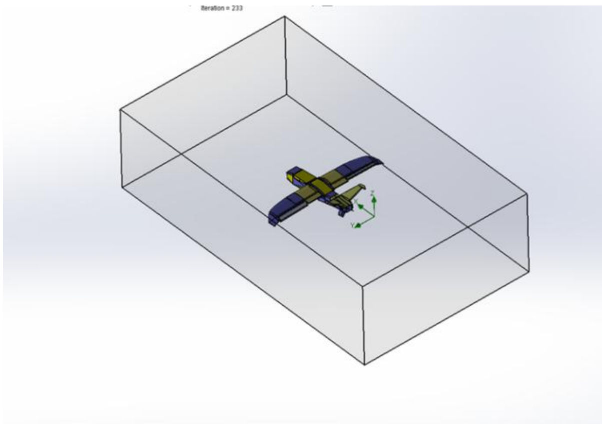

Fig 8: Drone model in computational domain

After applying boundary conditions, the velocities are set in X direction: 20 m/s, and in Y direction: 0 m/s

The simulation over the drone's body was completed in SolidWorks simulation software. Several parameters including pressure, velocity, and temperature distributions are studied and analyzed for two drones. Figure 9 shows the pressure contour through cut plot over the symmetrical sections. Some areas on the drone experience high pressure. Pressure is high at the nose of the aircraft.

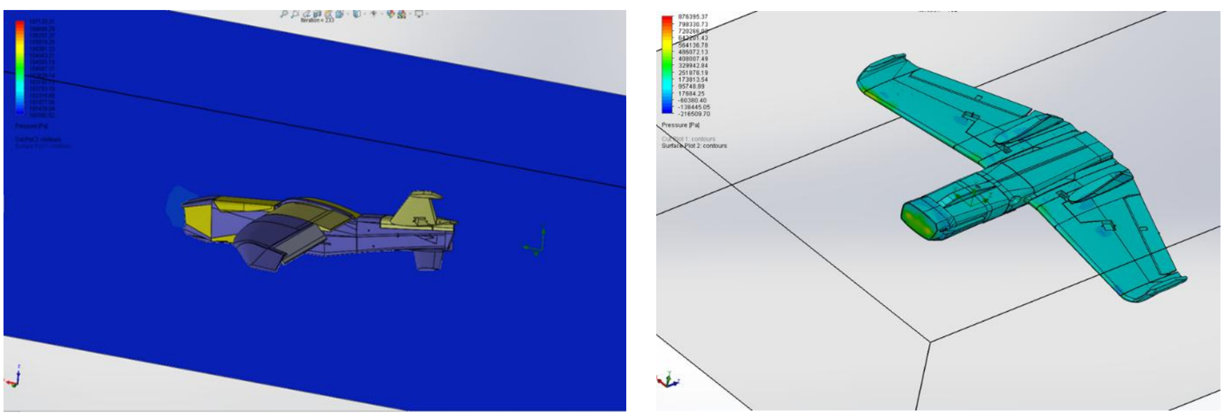

Fig 9: Pressure contour through symmetry section in isometric & cut plot view for drones

Figure 10 shows velocity distribution over the drones.

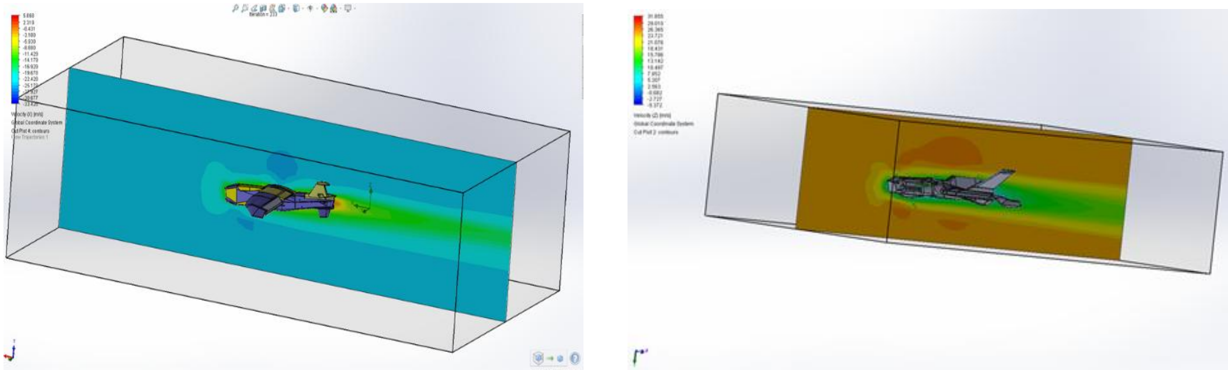

Fig.10: Velocity distribution through symmetry section & cut plot view

Figure 11 shows temperature distribution over the body of drones that indicates high temperature results along the surface.

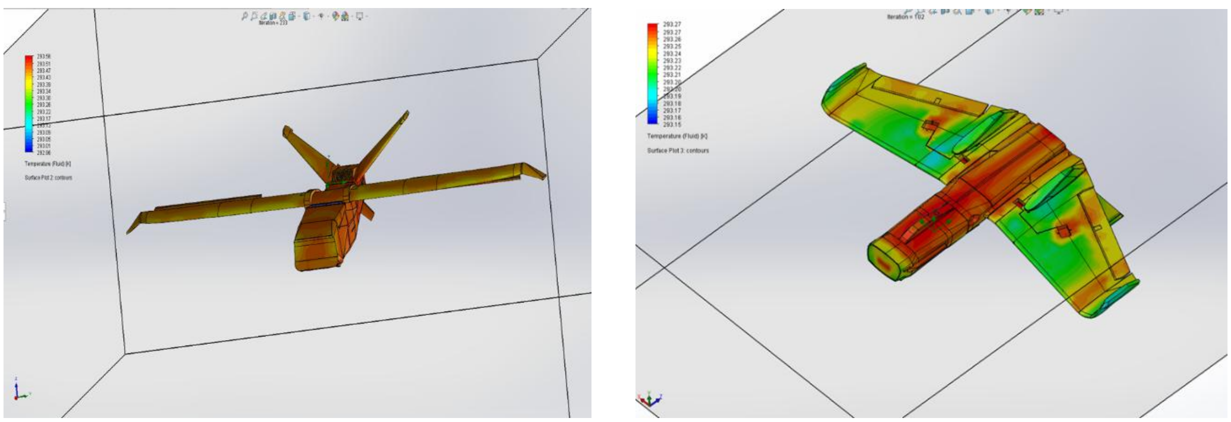

Fig 11: Temperature distribution on the body of drones

The flow trajectory in figure 12 shows fluid behavior around the drones, with trajectories tangent to the flow velocity at every point. The figures show the velocity vector over the upper and lower surfaces of the drones, respectively. The color of the flow in the figures indicates that velocity accelerates on the upper surface and decelerates on the lower surface of the UAV.

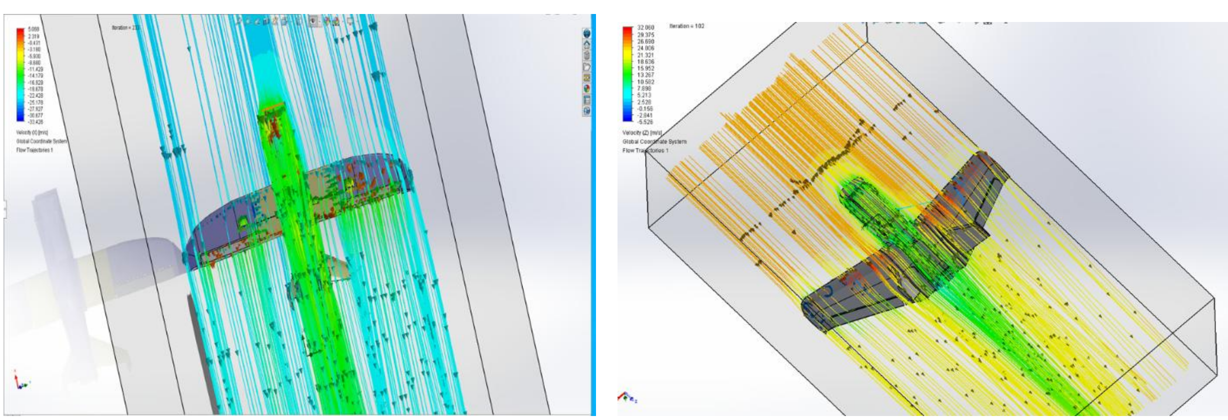

Fig 12: Flow Trajectory

Step 5: Printing the parts—After successfully simulating and validating the operation of the drones, a Stratasys 3D printer machine is used to prototype the components of the air frames and wings of two drones. Figure 13 shows some parts that are prototyped by the 3D printing machine.

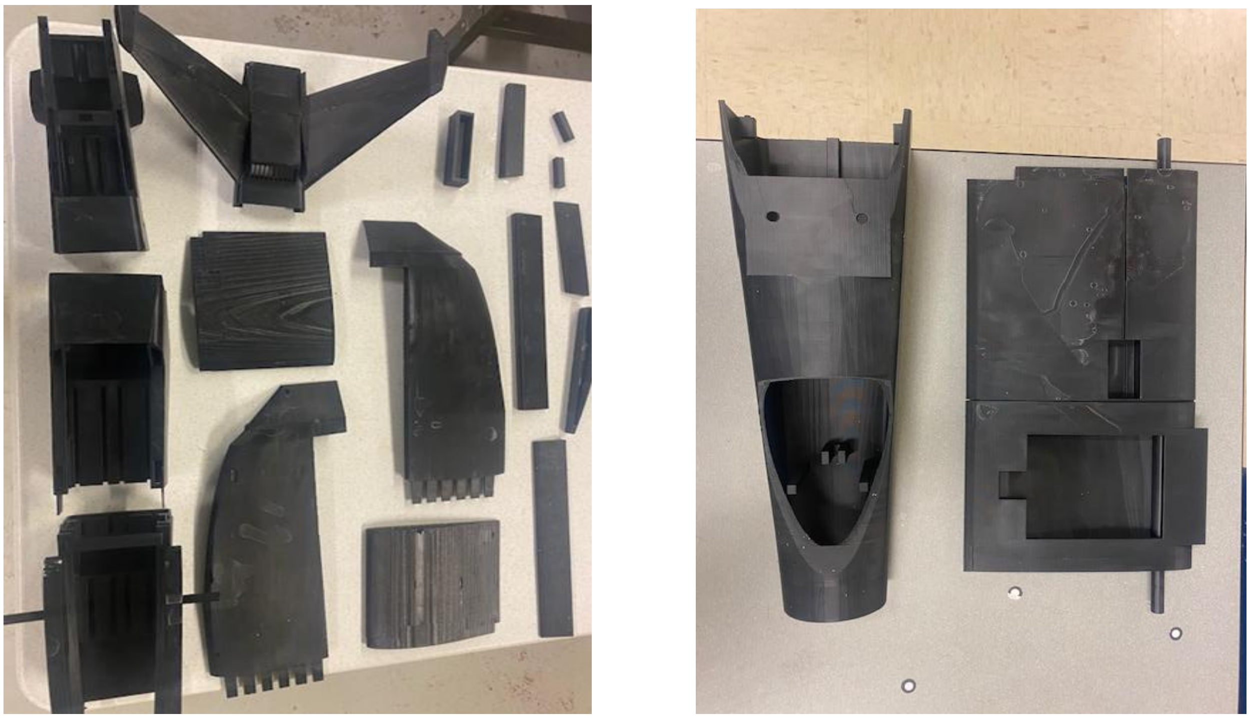

Fig 13: Prototyping the drones' components

Figures 14 and 15 show how closely prototype parts are like the original parts in ZOHD TALON GT and ZOHD Dart XL, respectively.

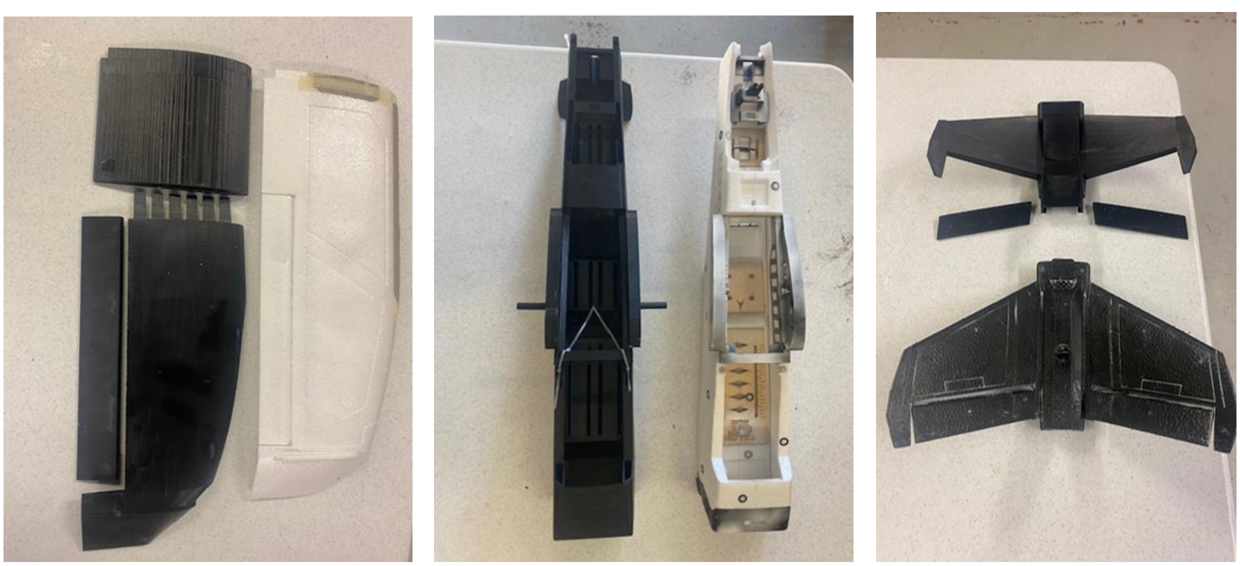

Fig14: comparison between prototyped part with original one in ZOHD TALON GT drone

Fig 15: comparison between prototyped part with original one in ZOHD Dart XL drone

Finally, all the parts are assembled that are shown in figure 16.

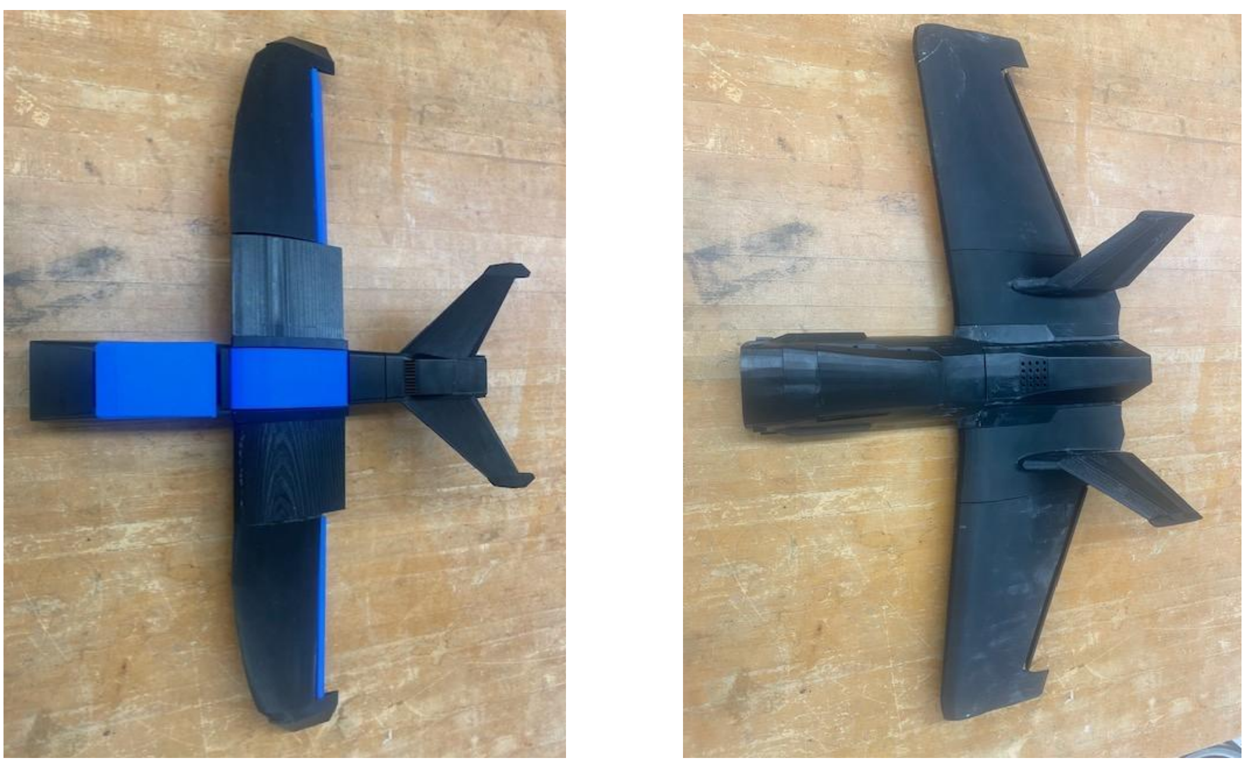

Fig 16: 3D printing drones

Autonomous Flight

The original ZOHD TALON GT drone is utilized to update the flight control system to autonomous flight. After installing Pixhawk [8] Cube Orange [9], GPS, and telemetry radio mounted inside and outside the airframe, the center of gravity (CG) was accurately assessed, and then an autonomous flight is attempted. Figure 17 shows the inside and outside of the drone.

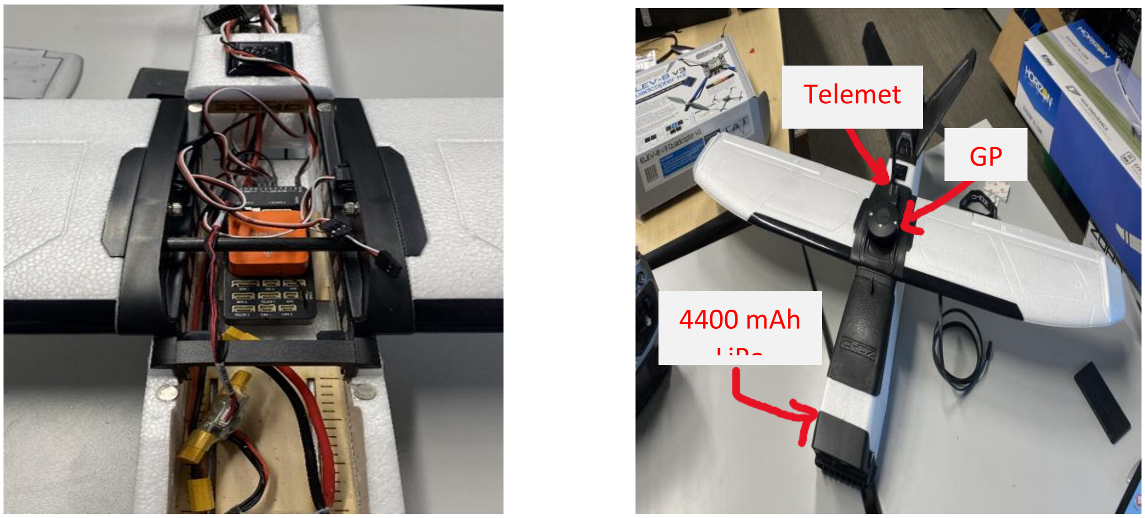

Fig 17: Inside and outside the drone

The mission consists of a hand-thrown automatic takeoff, a simple flight across empty fields, and an automatic landing. The mission had seven waypoints and lasted a little over 2 minutes. An initial altitude of 150 feet was set on waypoint 1 to provide clearance from nearby trees and power lines. From the launch point, the first waypoint was straight; waypoint 2 was located to the left; waypoint 3 was straight from waypoint 2, and so on until waypoint 5, where the mission instructed the Talon to decrease its altitude to 100 feet. Waypoint 6 was the start of the landing sequence, where the mission instructed the Talon to descend to 75 feet. The final waypoint was at 0 feet and was the final landing place of the Talon. Figure 18 shows a map of the waypoints with the actual flight flown by the ZOHD Talon GT Rebel. The purple line shows the actual route the Talon flew starting with the launch position at the furthest left point. When the hand launched the Talon, it was thrown at approximately a 10-degree angle, as shown in Figure 19.

The drone completed the autonomous flight successfully and landed safely.

Fig 18: Mission the ZOHD Talon flew autonomously

Fig 19: Hand-thrown automatic takeoff

Educational Value and Assessment of the Project

Designing a drone is a multidisciplinary project that requires integrating the knowledge of engineering, aerodynamics, electronics, and computer programming principles. This hands-on project enhances students' problem-solving abilities, creativity, and technical skills while promoting collaboration and critical thinking. Students developed technical skills in reverse engineering, CAD, simulation, programming, and flight control. In addition, students gained hands-on experiences with prototyping, using 3D printing, soldering, and assembly techniques, and learning system integration to ensure mechanical and electrical components function correctly. Three students participated in this project and expressed their satisfaction with the hands-on experience, highlighting how classroom learning can be applied to real-world projects.

This project is used to measure students' mastery in several subject areas. A survey was designed to get feedback from students that allowed the student to rate student's achievements in terms of how successful he/she was in achieving the stated learning outcomes and also rate the quality of the project and the instruction methods used. This survey indicated that the project worked well in the classroom setting and the project was used to validate ABET-ETAC student learning outcomes.

Conclusion

This project provides a platform for undergraduate students from engineering, technology and aviation science programs to acquire practical skills, foster interdisciplinary collaboration, and develop problem-solving abilities while working in teams. From conceptualizing the autonomous hardware systems to fabricating drone parts with integration of all components, the reverse engineering approach to designing the autonomous fixed wing unmanned aircraft system was successful. Apart from serving as a valuable introduction to the rapidly evolving field of drone technology, it provided students with the opportunity to learn about various aspects of engineering design and develop hands-on experience including 3D printing.

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