Design Validation of Quadcopter Drones Using CAD Simulation - a Project-Based Approach

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Abstract

This paper aims to explain two drone projects that introduce students to Computer-Aided Design (CAD), design, analysis, and simulation through several project-based learning modules. In any Unmanned Aerial Vehicle (UAV) configuration, the airframe is one of the principal components of the whole structure that can be used as a design topic. So, students develop CAD models of airframes and used SolidWorks simulation software, to perform Finite Element (FE) analysis studies. The drone frame was simulated and analyzed in various conditions such as drop tests, during takeoff, and in-flight maneuvers. FE Analysis showed whether components of the airframe will break, fail, or properly work in desired operations.

Keywords

Simulation, CAD, Unmanned Aerial Vehicle, SolidWorks, Drone

1. Introduction

Project-based learning is an instructional approach designed to give students the opportunity to develop essential knowledge and skills through engaging projects set around challenges and problems they may face in the real world. Students learn to validate whether a drone is operational before it takes flight. The topic of drones is selected since they are already widely used in many fields of Science, Technology, Engineering, and Math (STEM). Also, drones serve in commercial and military sectors, and many industries rely on them for photography, deliveries, safety purposes, information-gathering, agriculture, infrastructure inspection, and many other applications.

The authors used two drone platforms to introduce students to principles of design and analysis concepts in several mini projects. Drone performance depends on many factors, which require design and simulation to evaluate behavior and performance under actual conditions. The process starts with the initial design of the airframe of the drone with a CAD model and ends with simulation and analysis to determine the stress and deformation of the drone in real-world operations. The combinations of 3D printing and FE analysis techniques enable the students to design and analyze the drone/UAV that would give the UAV better performance. Stress analysis is critical to understanding fundamental structural integrity influencing flight stability and safety. These processes of developing drones with specific conditions benefit students that eventually would be useful in designing, developing, and manufacturing mechanical parts including drones/UAVs.

1.1 Objectives
This article describes the design and simulation setup for two quadcopter drones. In this study, drone projects are selected for problem-based learning to address many challenges that students would face during the process of design, fabrication, simulation, and operation.

2. Literature Review
Application of SolidWorks simulation software in designing and analyzing the structure of airframes including stress, deformation, and vibration are reported in the following literature. Parandha and Li [2018] proposed a design of a 3D-printed quadrotor drone that forces are away from the fuselage. In this way, electronic components would receive minimal damage at the time of any failure. They built a CAD model of drone frame using SolidWorks and performed three types of finite analysis: static structural, impact analysis, and modal analysis. Patel et al. [2018] reported on the design and analysis of a multicopper. The structural analysis of the multicopper is reported in the literature. Moreover, Urdea [20213] used SolidWorks simulation software to report the stress and vibration of a drone. Kisabo *et al*. [2017] presented an approach that quickly takes a mission statement and translates it into an actual aircraft design. Rabbey [2013] proposed an experimental method to test the model of the UAV in the wind tunnel and the test data showed that the UAV was capable enough for flying. Mieloszyk *et al*. (2018) have presented a few selected practically feasible solutions for 3D printing, among many proposed manufacturing processes, that are applicable to critical structural parts. Sagar *et al.* [2021] have attempted to interpret the concept of Rapid Prototyping to reduce professional working time and to improve the effectiveness of the development of new solutions and models. In their study, Computer-Aided Modeling and static structural analysis of the quadcopter drone frame are carried out with the aid of the Autodesk Fusion 360 software tool.

3. Methods
Two UAVs were designed and fabricated with 3D printers taking into consideration using lightweight materials. Two quadcopter drone platforms, namely, Parallax ELEV-8 and COEX Clover were used in this project [8, 9]. Figures 1 and 2 present these two drones with complete equipment. The Acrylonitrile Butadiene Styrene (ABS) and carbon fiber composite materials were used in 3D printers to fabricate airframes of Parallax ELEV-8 and COEX Clover, respectively. Also, extensive simulation and analysis were carried out in the design phase which rapidly cut down the cost of design and improves the speed of releasing prototypes into the market. The main idea was to investigate the airframe structure of these two models for the purpose of stability of the drone in worse-case stress levels with allowable deformation in real-world operation.

Figure 1. Parallax ELEV-8 Drone

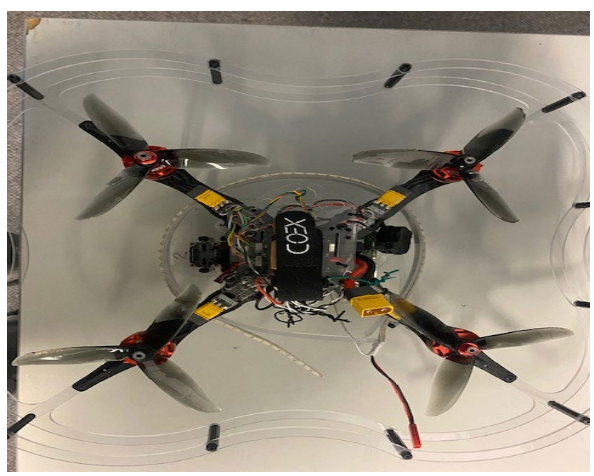

Figure 2. COEX Clover Drone

4. Data Collection and Results
The mass of the proposed drone including the airframe and electronic components is less than one kg. SolidWorks software was used for CAD modeling, simulation, and the analysis of the airframes as well.

A. *CAD Model and 3D printing*: The design of an airframe for a UAV is primarily an analytical and iterative process that is accompanied by the creation of CAD models of the airframe parts. The CAD models of different components of airframes are designed in SolidWorks software. Students use two different materials and the associated technology, including ABS and fiber carbon composites to prototype the parts of the airframes. Figures 3 and 4 show prototypes of different pieces of airframes by 3D printers and Figures 5 and 6 show assembled 3D printed airframes of the ELEV-8 and COEX-Clover drones, respectively.

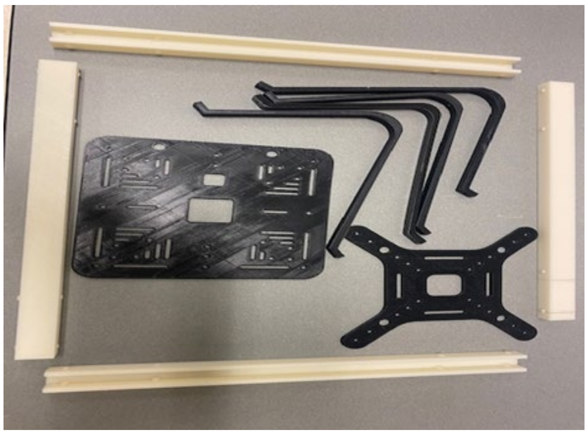

Figure 3. Components of ELEV-8 airframes

Figure 4. components of COEX airframes

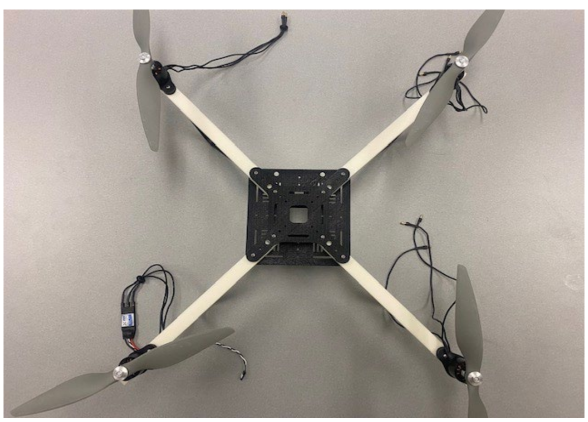

Figure 5. Assembled frame of ELEV-8

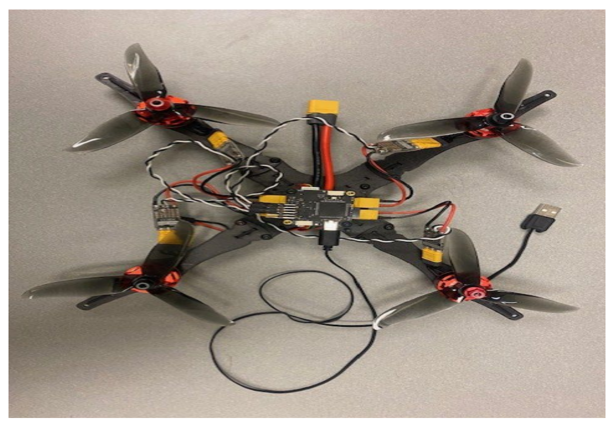

Figure 6. .Assembled frame of COEX

B. *Stress and deformation analysis*: The FE analyses was performed to validate the strength of drone parts for displacement and to determine the results of the drop test, takeoff, and during critical flight maneuvers of UAVs.

B:1. *Drop test*: The crash landing of the drone was investigated by using the drop test studied in SolidWorks simulation software. Figures 7 and 8 show CAD models of airframes with four arms that are used in the drop test study. The drop test evaluates the effect of impact on the drone when it is dropped freely from a height of 10 meters. The simulation results presented are for ELEV-8 and COEX drones with a mass of a little less than one kg. Figures 9 and 10 show Von Mises stress result analysis to measure the level of stress. Both figures show that high-value stresses are developed in the legs and sections that hit the ground. Deformation results are reported in Figures 11 and 12. The ELEV -8 and COEX drones experience deformations of less than 7 mm and 4 mm, respectively when hitting the ground.

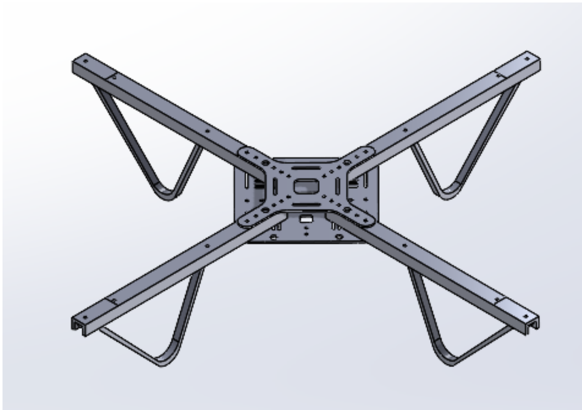

Figure 7. CAD model of ELEV-8

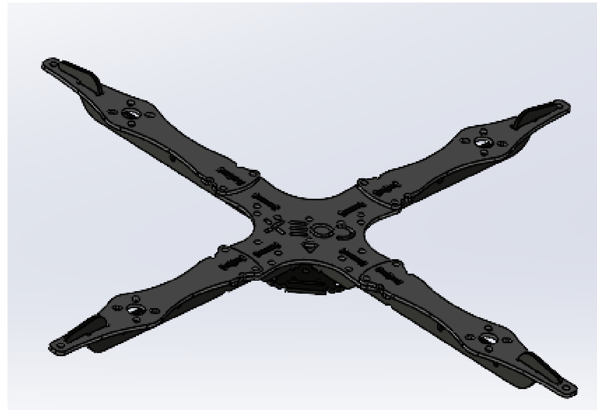

Figure 8. CAD model of COEX

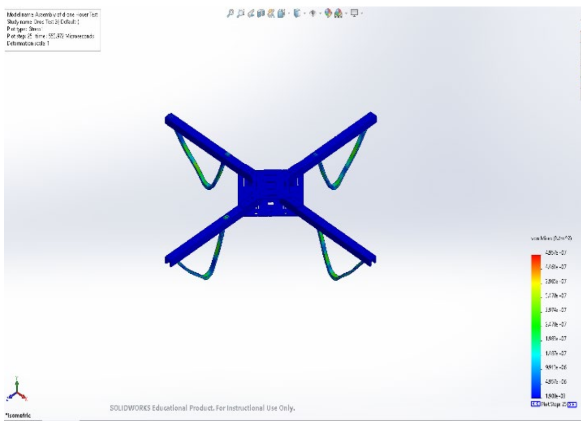

Figure 9. .Stress analysis of ELEV-8

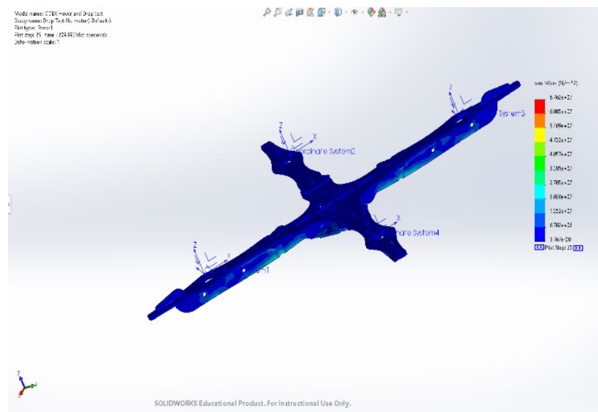

Figure 10. Stress analysis of COEX

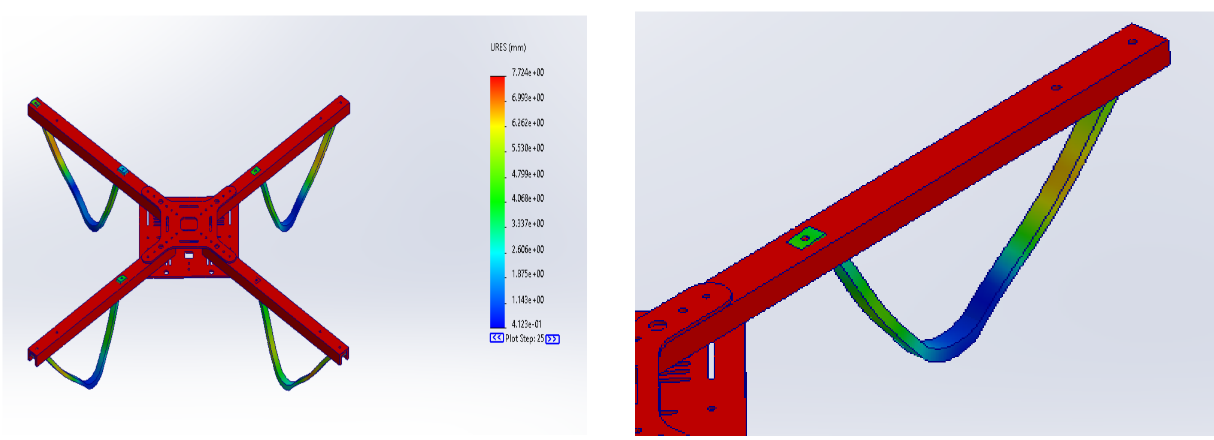

Figure 11. Deformation analysis of ELEV-8 drone

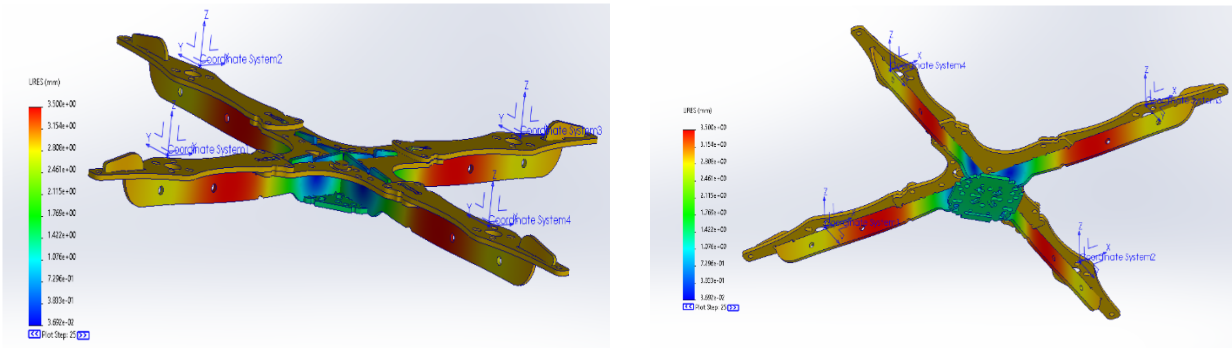

Figure 12 . Deformation analysis of COEX drone

B:2. *Takeoff test*. To perform FE analysis, it is important to define all the forces acting on the airframe including, the weight of the frame, motors, and electronic components. For simulation, a customized coordinated system for remote load location is defined and created. The lift force is considered 25 percent higher than the drone's total weight at the time of takeoff. The lift force is equally divided into four and applied at each propeller in the opposite direction of the weight of each motor. The force due to gravity is considered too. The same CAD models, figures 7 and 8, are used for the takeoff study as well. Figures 13-16 show Von Mises stress and deformation analysis at the time of the takeoff. The stress level during takeoff is in the low range. However, the locations where electric motors are installed experience more deflections.

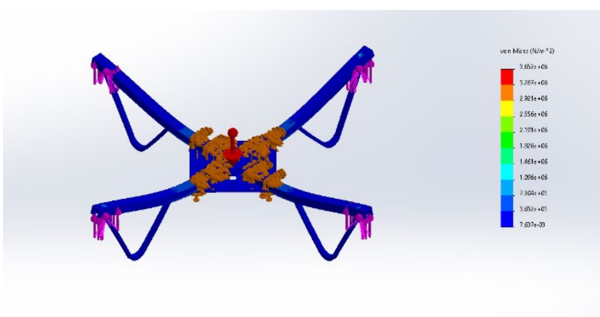

Figure 13. Stress analysis of ELEV-8 drone

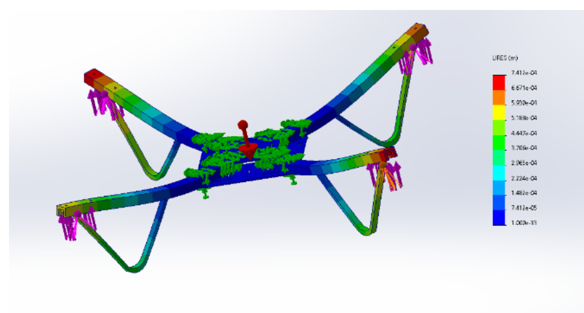

Figure 14. Defo rmation analysis of ELEV-8 drone

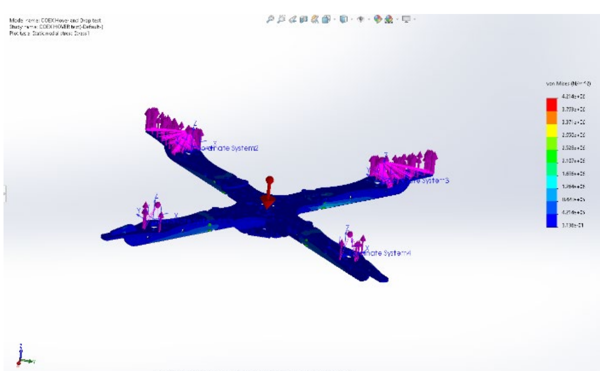

Figure 15 . Stress analysis of COEX drone

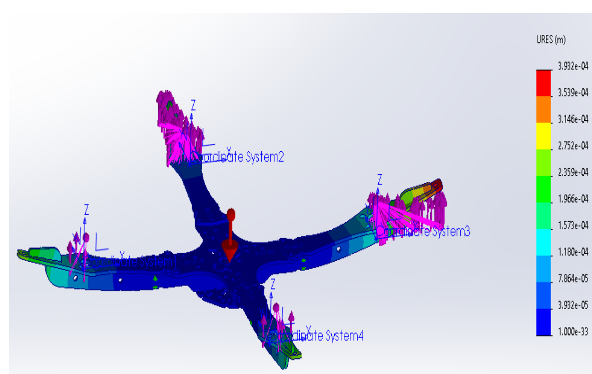

Figure 16. Deformation analysis of COEX drone

Results show that high deformations occur in locations where electric motors are mounted. The value of maximum deformations for ELEV-8 and COEX drones are less than 0.8 mm and 0.4 mm, respectively.

B:3. *Flight test*. To study whether the drone can fly successfully, airflow and aerodynamic performance in hover mode were studied. The fluid simulation software that simulates air flow around the drone is performed for aerodynamic stability. This study was important for the safety and overall performance of the drone and its surroundings. Figures 17 and 18 show the CAD models with propellers used in fluid simulation. Figures 19 and 20 show the result of the fluid simulations.

Figure 17. CAD model of ELEV-8 drone

Figure 18 . CAD model of COEX drone

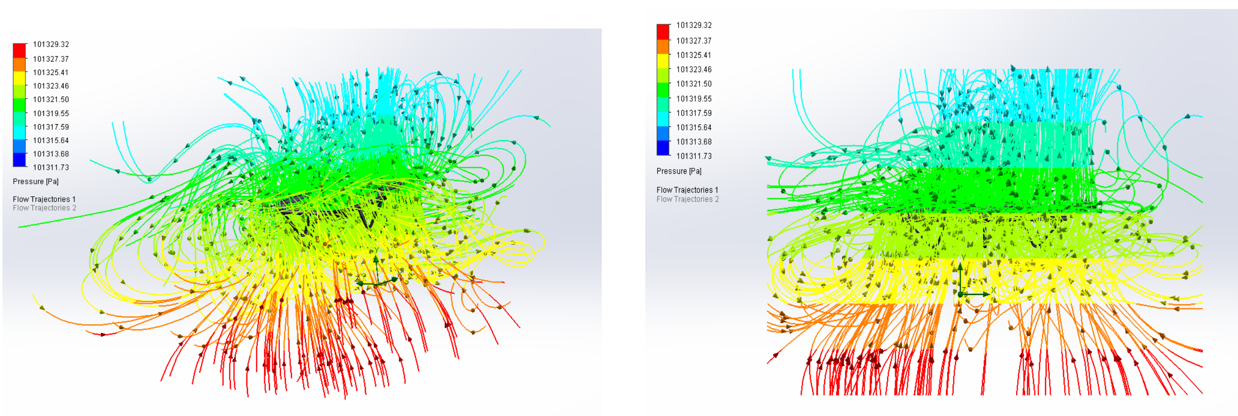

Figure 19. Flow trajectories of ELEV-8 drone

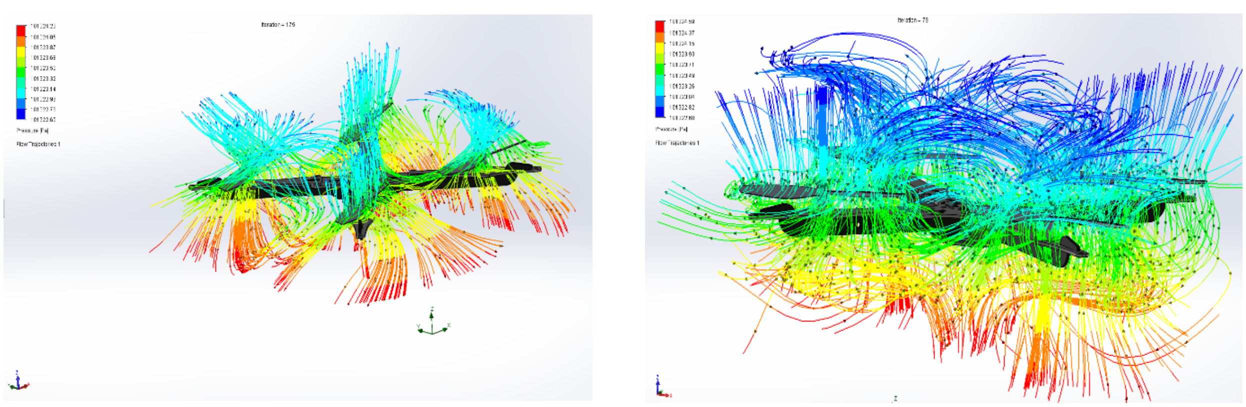

Figure 20. Flow trajectories of COEX drone

Simulation results indicate that the bottom of the drone has higher pressure than the top of the drone which causes the drone to fly.

Conclusion

Two 3D-printed quadcopters drones were considered for analyzing the performance of drones and the details were reported in this report. Further study would be aimed to perform vibration analysis and test the drone by mounting it in a 3D gimballed system for control and navigation study. This project provides a project-based learning opportunity to students and helps them develop hands-on skills, thus offering them real-world experience.

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COEX Clover Drone kit, https://coex.tech/clover

Biography

Dr. Akbar Eslami is a professor and Engineering Technology coordinator in the Department of Math, Computer Science, and Engineering Technology at Elizabeth City State University. He received his Ph.D. in Mechanical Engineering from Old Dominion University. His research interests are in Computer Aided Design and Manufacturing, Design Optimization, Finite Element Analysis, and Reverse Engineering.

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