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Preliminary structural integrity investigation for quadcopter frame to be deployed for pest control

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ABSTRACT – Quadcopters are one of the most versatile unmanned aerial vehicles deployed for various purposes. In this study it is going to be used as part of a system used for bird control therefore the structural integrity is investigated. The aim of the paper is to investigate the structural and aerodynamic behaviour of a quadcopter intended for bird control. A model of the drone has been developed in SolidWorks, then structural along with flow analysis carried out using ANSYS software. The structural analysis shows promising results as the stress built up due to the loads applied are within the safe range.

1. INTRODUCTION

Birds are one the most destructive to cereal farms in Nigeria and their control is of major concern. Various studies have introduced the use of aerial devices for pest control to varying degrees of success. The use of quadcopters has gained traction due to its high manoeuvrability and simple design [1]. But as the unmanned aerial vehicle (UAV) will lift the payload is of upmost importance. How much thrust it will require and the effect load will have on the structure needs to be investigated. A CAD model of the quadcopter is often used for the investigation as it is cheaper and can be rendered for various what if scenarios.

SolidWorks is used to model the drone and investigation regarding the structure and computational fluid dynamics analysis (CFD) conducted in ANSYS as provided in different literature [1-3]. The structural analysis is used to determine the stresses acting on the various components together with its resulting deformations. The CFD on the other hand reveals the effects of wind acting on the quadcopter structure. Some of the parameters obtained from flow simulation are the wind pressure, lift and drag forces acting on the quadcopter surface.

2. METHODOLOGY

The method is adopted from previous literature [1]. The model will be selected, modelled and analysis carried out as depicted in Figure 1.

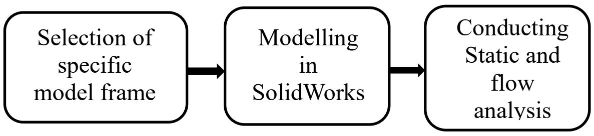

Figure 1 Methodology block diagram.

The F450 was selected for this analysis, it was modelled using SolidWorks 2020 design software. The dimension specifications were obtained from product user manual and other literature [3]. The various loads were also obtained likewise, electrical components, masses were obtained from manufacturer specifications.

Other component loads like liquid repellent, pump and mp3 player added. The total weight W_t is obtained using Equation (1) [4].

$$W_t = W_E + W_P \quad (1)$$

Where, W_E is the empty weight and W_P is the payload weight. The empty load includes the frame, battery, electronic speed controllers (ESCs) and motor weights while the payload are additional weights on the frame. Weight acting directly on the upper plate is determined as 9.2 N. The required thrust Th_r used was obtained as 7.48 N using Equation (2) as provided by Saheb and Babu [4].

$$Th_r = \frac{W_t \times 2}{4} \quad (2)$$

A propeller 1045, battery with capacity 3300 mAh 3S/11.1 V and 930 Kv motor were selected for the set up [5,6]. Equation (3) is used to determine the thrust produced by the motor [4].

$$T = \sqrt[3]{2 \times \pi \times r_p^2 \times \rho_{air} \times (P \times \eta_h)^2} \quad (3)$$

Where r_p is the radius of the propeller in m, ρ_{air} is the air density 1.225 kg/m^3, P is the power and η_h the hovering efficiency. P is obtained from Equation (4) [4].

$$P = k \times N^{pf} \quad (4)$$

Where k is the propeller constant, N is the speed in revolutions per minute ((rpm) in thousands) and pf is the power factor. k and pf for 1045 propeller values are 0.144 and 3.2 respectively [5]. The produced thrust is 15.72 N.

The material used are Nylon 6 (with density 1148 kg/m^3, yield strength 43.1 MPa and 0.35 Poisson ratio) for the arms and E-glass fibre (with density 2660 kg/m^3, shear modulus 30 GPa and 0.22 Poisson ratio) for the frames [1].

As for the CFD simulation, the external study excluding cavities and internal spaces was considered with laminar flow options selected for the analysis. The effect of quadcopter movement at 0° and 30° was investigated.

The study area where the quadcopter will be deployed is Bida, Niger State Nigeria. A speed of 7 m/s is suggested by Radiansyah, et al. [6] for wild life monitoring speed to be employed for UAVs, same will be adopted for the study since the drone is to be deployed for pest monitoring and control.

3. RESULTS AND DISCUSSION

3.1 Structural analysis

The maximum stress obtained on the frame is 18.51 MPa are more prevalent on the top plate as seen in Figure 2, and a minimum of 0.092 MPa recorded at the mid regions of the arms. The maximum deformation recorded is 1.62 mm along with a strain of 0.0086.

The stresses present in the arm is spread across the length of the arm towards the fixtures [7] and range from 0.0015 to 39.13 MPa. Both stresses are within the safe working stress of the components, so design is safe. The stress concentration areas are similar to those recorded in previous literature [1,7]

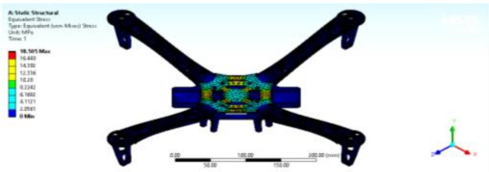

Figure 2 Frame structure results for stress analysis.

3.2 CFD analysis

The drag and lift force obtained are 1.14 N and 0.052 N respectively for the 0° flight configuration of the drone. The total pressure on the surface is determined to be 3.508×10^{-5} MPa as shown in Figure 3. The pressures are more prevalent on the arms in the same direction as the wind flow.

Figure 3 Total surface pressure flow simulation result.

There is an increase in the drag force to 1.78 N as the quadcopter is tilted 30°. The force becomes -0.78 N. The negative value insinuating a push downwards. This will necessitate expending more force to keep the drone hovering. Also increased is the total pressure to 3.689×10^{-5} MPa. The pressure is present more in the geometry areas with sudden changes and sharp corners (Figure 4).

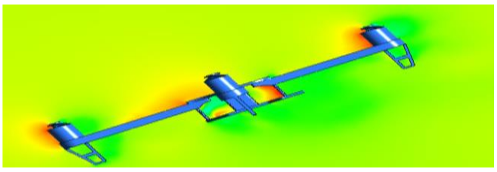

Figure 4 Pressure on sharp corners.

4. CONCLUSION

The structure of the drone selected to be deployed for bird control has been successfully analysed for suitability of purpose. The structure was modelled in SolidWorks and analysed using ANSYS Workbench simulation tools. Maximum stresses obtained are 18.51 and 39.13 MPa for the frame and arm structures, respectively. The stress is well within safe working limits for the material, therefore safe for use. The CFD flow reveal higher drag of 1.78 N during roll and pitch motions. Minimizing those movement patterns will be incorporated in designing the flight mission during operation to save battery life when drone is deployed.

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