Structural and CFD Analysis of Unmanned Aerial Vehicle by using COMSOL Multiphysics

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Abstract: *The purpose of this article is to reduce the structural weight and drag of an unmanned aerial vehicle (UAV) or drone while increasing its endurance. To achieve a high strength to weight ratio, Finite Element Analysis is used to study the structural strength characteristics of UAV frames. A computational fluid dynamic analysis (CFD) is performed for different angles of attack and vehicle speeds to estimate the drag coefficient using the k-e turbulence model. The analysis results show that the designed UAV vehicle has excellent performance characteristics and stability at 5° AoA and 3 m/sec. This article outlines the overall design of the unmanned aerial vehicle, which was created using the CATIA V6 platform. COMSOL 5.6 software is used for structural and CFD analysis.*

Key Words: *UAV, Finite Element Analysis, CFD, Topology Optimization*

1. INTRODUCTION

UAV is widely used in various fields at present. The UAV can be operated in both autonomous and manual mode. It can be used in places where humans can't access and also in emergency situations [1].

To ensure the efficiency of the UAV it has to be studied thoroughly before the actual flight to avoid errors and human fatal results. The UAV has many uses such as monitoring of the forests, fields and it is also used for preservation and supervision purposes.

The UAV's primary design has to undergo many analysis and tests before it can be built into an actual model. The primary design of the UAV is first created with the help of CATIA V6 software. Then it is imported into the COMSOL 5.6 platform to undergo various structural and CFD analysis.

To obtain an optimal design, the UAV has to undergo several aspects which include:

(i) Topological optimization by which the geometry of the object is defined, [2, 3],

(ii) Finite element analysis where the different materials are tested and the appropriate material matching the required conditions is selected,

(iii) the process where the UAV's main structure is studied [4].

2. STRUCTURAL ANALYSIS OF UAV

The structural analysis is performed for the primary design of the UAV using carbon fiber material to identify the forces and loads it can withstand. The main aim of the work is to reduce the structural weight of the UAV using the topology optimization [5]. The first step for the process is to design a UAV frame using CATIA V6.

Total part length (between tips) is of 583.85 mm (Fig. 1). As the second step, the analysis for the primary design of the UAV is performed using COMSOL software. The frame center point is considered to be fixed and point loads (vertical loads) are applied at the frame tip. A total of 20 N is produced by four motors together (Each 5N) shown in Fig. 2.

The result for the primary design model before optimization provides the following stress and displacement values 35017 N/m^2 (stress) and 6.8387e-8 m (displacement). The mass of the model is 1.1746kg.

The results of the topology optimization (Fig. 3) recommend to remove a certain section of material and to redesign the model, as shown in Fig. 4.

After removal of the required portions of the UAV, its weight is 890 gm; the analysis is performed for the same conditions, and the resulting stress and displacement are obtained as 53714 N/m^2 & 1.0355e-7m. Table 1 shows the comparison before and after the optimization designs.

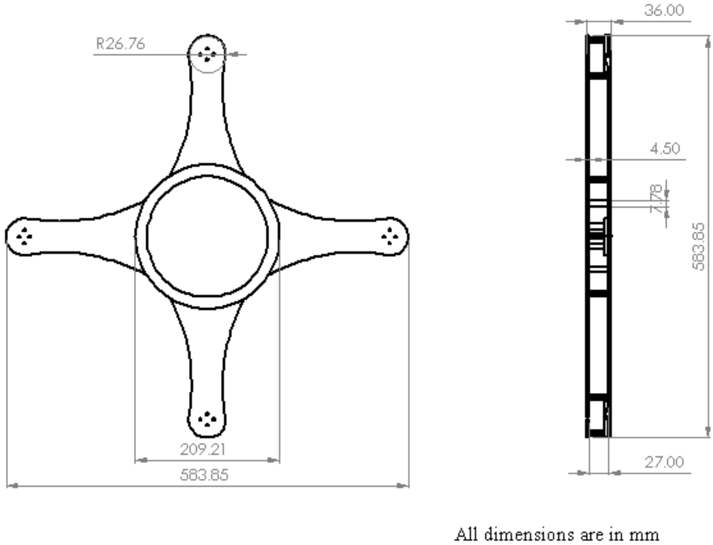


Fig. 1 – Preliminary model

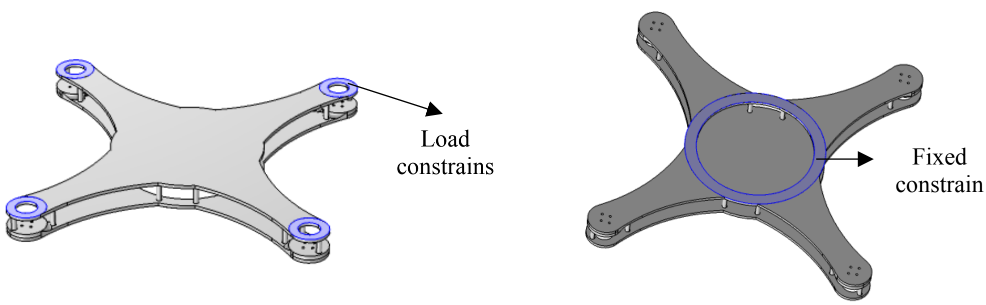


Fig. 2 – Boundary condition

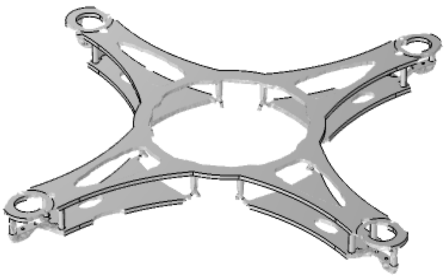


Fig. 3 – Topology optimization model

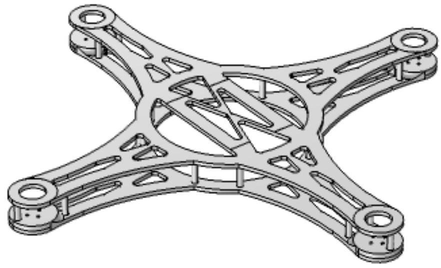
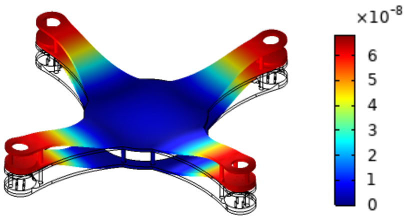
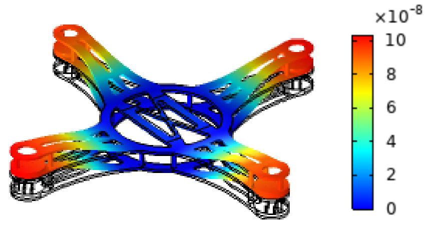
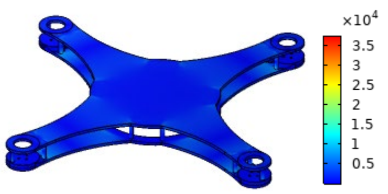
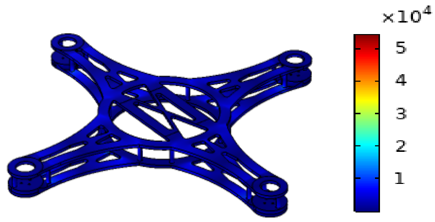


Fig. 4 – Redesign UAV model

Table 1 – Structural analysis results for before and after optimization models

Parameters	Before Optimization Model	After Optimization Model
Displacement plot		
Stress plot		

3. CFD ANALYSIS OF UAV

The CFD analysis is performed on primary design of the UAV for various conditions to identify and explore the forces and flow acting on the surface.

There are different kinds of forces acting on the vehicle and one of these is the drag. The flow properties are understood by knowing the low pressure, high pressure areas and recirculation of the flow.

The performance of the flight is majorly affected by the rate of climb, speed range and endurance parameters.

The stability of the vehicle is also majorly disturbed. To find out these effects the CFD analysis is performed on any new designs.

To avoid the formation of thick boundary layer and flow contact between the model and the wall of the domain, a bigger computational domain is designed.

The geometry of the mesh is set to 0.1scale with tetrahedral plane in a symmetry plane to lower the difficulty of the meshing.

The quality of the mesh can be verified using the skewness check. The velocity conditions are varied from 3m/s to 8m/s with a change in angle of attack from 0° to - 8° [6, 7].

After completing the analysis, the results of the drag coefficients are plotted in Table 2.

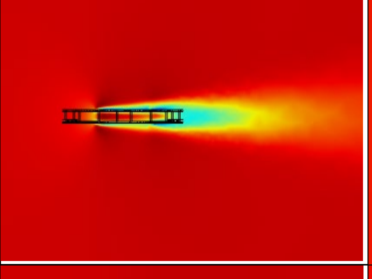
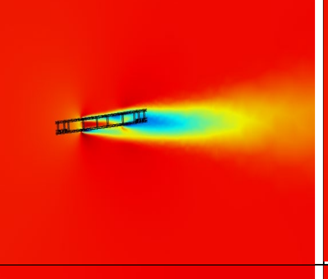
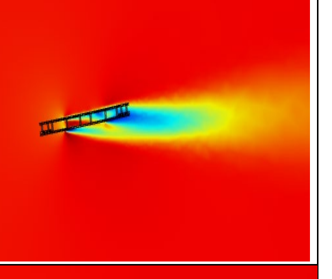
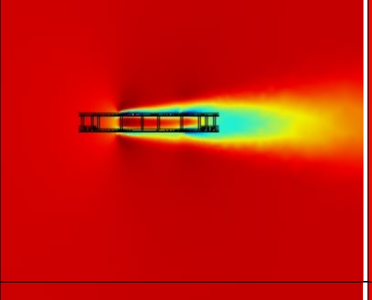
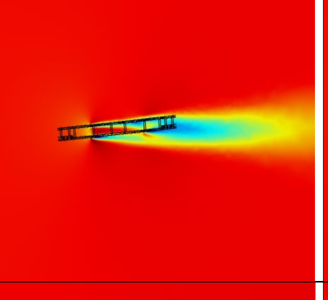
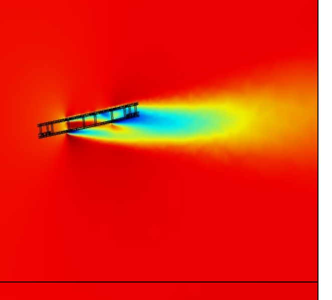
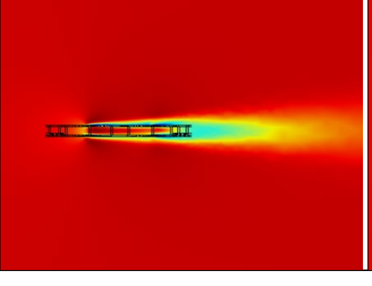
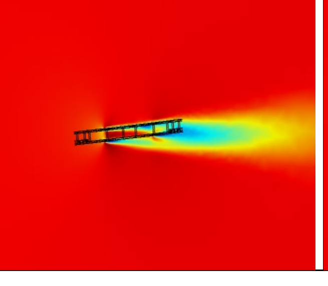
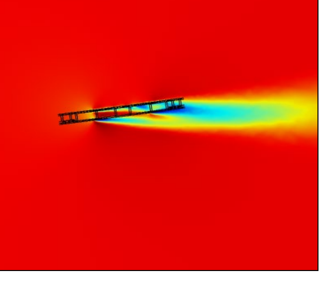
The reduction and surge in drag condition is experienced when the wind speed and the angle of attack is high.

The analysis of the UAV primary performed in CFD is shown in Table 3. According to the analysis, at 3m/sec velocity and the angle of attack of 5°, the UAV attains a very low drag force.

Table 2 – Estimation of Drag for Various AoA

Relative wind speed [m/s]	Parameters	AoA		
		0^0	-5^0	-8^0
3	CD	0.24731	0.054778	0.053772
	D	0.01396	8.62e-4	9.8714e-4
5	CD	0.23224	0.050264	0.050360
	D	0.0364	0.00219	0.002568
8	CD	0.22093	0.047061	0.047957
	D	0.08870	0.0052708	0.0062605

Table 3 – Estimation of Drag for Various AoA

V [m/s]	AOA (angle of attack)		
	0^0	-5^0	-8^0
3			
5			
8			

4. CONCLUSIONS

In this work, the structural analysis and CFD analysis of the primary design of an UAV has been performed using COMSOL software. The optimal design of the UAV is tested with the help of topology optimization approach. After optimization, the suggested areas have been removed from the primary design and then tested again for the same conditions. The results obtained show that the frame is weightless and also compelling at the same time. The finite element method was applied for the design with the help of the COMSOL software to identify whether the structure can withstand all types of forces and loads. With the help of the topology optimization, the material removal process has made the design weightless comparing to the predefined model. The CFD analysis is also performed on the final design (after material removal) to determine the aerodynamic forces and loads on the UAV when in flight. By comparing the different relative wind speeds for different angles of attack, the minimum drag value is obtained at an angle of attack of 5 degrees.

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