IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Design and Analysis of 3D Printed Quadrotor Frame

Sai Mallikarjun Parandha[1], Zheng Li[2]

Graduate Student, Mechanical Engineering, University of Bridgeport, Bridgeport, USA[1]

Professor, Mechanical Engineering, University of Bridgeport, Bridgeport, USA[2]

Abstract: UAVs- Unmanned Aerial Vehicles in a broader context are known as drones. This research emphasizes more on 3D printing a quadrotor with 'X' shaped frame. We built a CAD model of drone frame using SOLIDWORKS, following that; we performed three types of finite analysis 1. Static structural, 2. Impact analysis, and 3. Modal analysis. The drone frame is simulated and analysed under various boundary conditions such as lift, drag, and thrust till the optimized results of minimum displacement, a factor of safety is achieved. We printed the frame of drone on PRUSA I3 Mk3 3D printer by using ABS-PC and carbon fiberglass materials as the filament.

Keywords: 3D Printed Drone, Drone Frame Analysis, Structural Analysis, Drop Test.

Citations: Kumar, Nathan, 2012. | Russell Rip, M. Hasik, 2010.

I. INTRODUCTION

Drones can be very first responders during rescue operations or natural calamities. These first responders can be used to locate and rescue the casualties, monitor pollution level in the atmosphere, surveillance and many more, which brings us an overview of an UAVs. These robotic maneuvers can be guided by installing various modules such as GPS, imaging sensors and other proximity sensors on them. Drones are highly resilient and agile in nature, as they fly in four dimensions roll, pitch, yaw and space with six degrees of freedom, three translational and three rotational. Through these characteristics, drones can be safely piloted and monitored from remote distances.

Classification: Drones are initially classified based on their anatomy, operations, size and weight. As an example, let's consider multirotor drones, drones with multiple fixed wings. Multirotor drones are known for their agility and maneuverability. They are further classified depending on various factors like number of rotors used, position and orientation of rotors and frame shape.

Drone classification is also done by their usage in various fields and is shown as below:

Agriculture: Precision farming can be achieved by patrolling orchards over crop-lines; large areas can be covered using multiple drones at the same time and 3D information can be obtained using thermal imaging sensors. This is also known as NDVI Mapping.

Archaeology: Information about the landscapes and their 3D information about historical sites can be documented. *Construction:* 3D- Maps of the building and construction sites can be obtained, progress can be monitored.

Photography: Drones play a prominent role in capturing breath-taking visuals in the entertainment industry.

First responders: Drones can be used in rescue operations and emergency medical services, military operations etc.

Additive Manufacturing: A plethora of technological advancements in rapid prototyping industry made industrial 3D printers affordable, available as per user convenience. By using 3D printing technology, drones can be fully customized, printed using various materials such as PLA, ABS, ABS-PC, Carbon fiber, etc. This is cost, time and user effective procedure.

II. DESIGN

CAD Model: Aforesaid, a CAD model of our X framed drone is designed in SOLIDWORKS by considering several constraints. Those constraints consist of the length of the propeller, which determines the length of an arm; few electronic components, in which flight controller and power distribution board determines the fuselage dimensions; the

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

motor rotor diameter and electronic speed controller width that contributes in determining the arm width of the drone. The above description gives the knowledge of the basic components necessary while building a drone from the scratch.

Arms of the drone are independent, and they are designed to translate force away from the fuselage. In this way, the electronic components can be at their minimal damage at the times of any failures and accidents.

Fig 1.a) Quadrotor frame assembly in isometric view.

The frame is designed to accommodate 5040 propellers and Emax- RS2205 2300kv brushless DC motors on the arm.

Fig 1.b) Quadrotor frame assembly in exploded view.

Fuselage: Fuselage is the eye of all electronic components located on the drone. For example, flight controller, power distribution board, receiver, ESC etc. This fuselage can accommodate DYS FC omnibus pro, Matek XT-60 PDB onboard.

Fig 2.a) Highlighted surface area is the fuselage

To minimize damage to the electronic components of the fuselage, a housing is designed to protect the components during crash landing or collision.

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

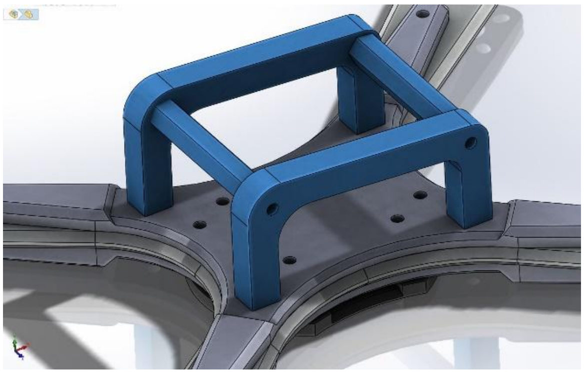

Fig 2.b) Housing for the fuselage

Frame geometry: Dimensions are as follows Length X Breadth X Height & Diagonal length.
175.14mm X 171.42mm X 48.75mm X 226mm.

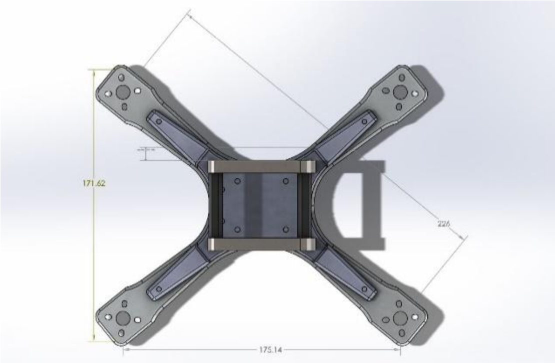

Fig 3.a) Top-view of the frame with dimensions.

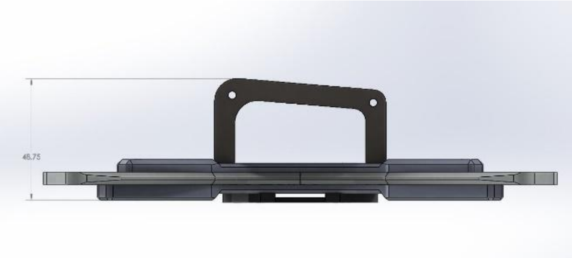

Fig 3.b) Side-view of the frame with dimensions.

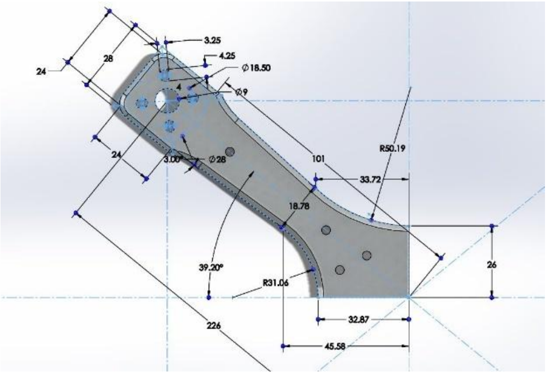

Fig 3.c) Top-view of the arm with dimensions.

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

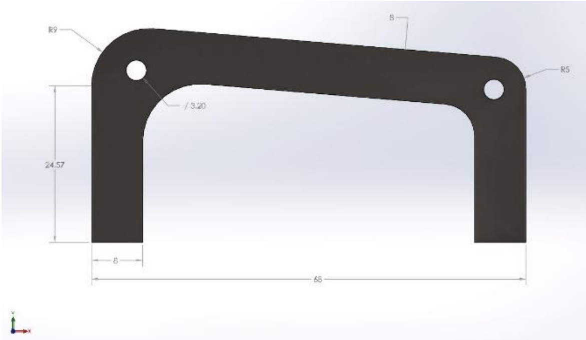

Fig 3.d) Side-view of the fuselage housing bracket with dimensions.

III. ANALYSIS

To perform FE analysis, the forces acting on a frame are determined, which are 1.The *Weight* of the frame and all the electronic components on it normal to the ground, 2. *Lift* force direction is a resultant between thrust and vertical take-off, towards the direction of motion, 3. *Thrust* generated by the propeller and motor towards the direction of motion and 4. *Drag* force acting in opposite direction of motion. The following forces acting on a frame are illustrated in the picture below.

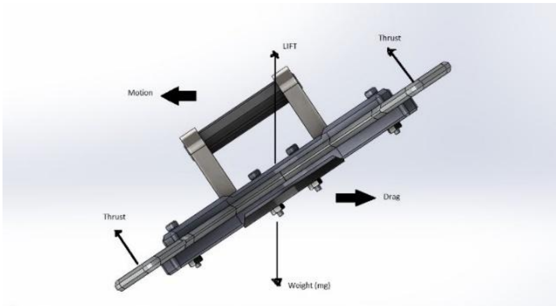

Fig 4.a) Free-body diagram representing the forces acting on the frame.

Resultant forces: The forces acting on the frame are calculated manually and applied during the simulation procedure which results in three plots, they are:

1. Von Mises stress,
2. Displacement,
3. Strain deformation

Static structural analysis: It is carried out by considering non-linear analysis based on the rate of deformation, material, etc. this phenomenon is known as plasticity. By calculating thrust to weight ratio we get theoretical lift force value. So, by applying thrust across each arm of the drone during structural analysis by deciding fixture position and adding gravitational force acting on frame results as in Fig 4.b).

Quadrotor thrust, and weight can be calculated as follows:
Assuming X=motor thrust, n= number of motors, W= weight and T= hover throttle percentage. Therefore,

Payload capacity = (n.X.T) – W,

Thrust can be calculated by using the equation below,

$$Thrust, F = \frac{([mV]_2 - [mV]_1)}{(t_2 - t_1)}$$

Whereas,

$$m^* = \rho.V.A,$$

ρ = density,

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

V = velocity,
A = Area
L = reference length of the air foil or propeller

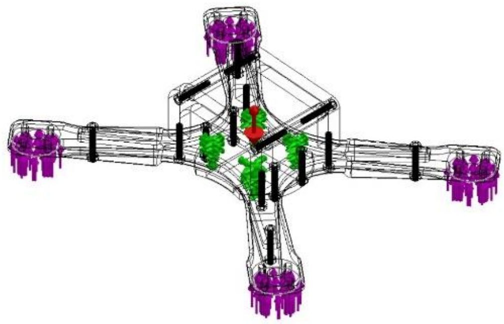

Fig 4.b) Forces acting on the frame represented in SOLIDWORKS Simulation.

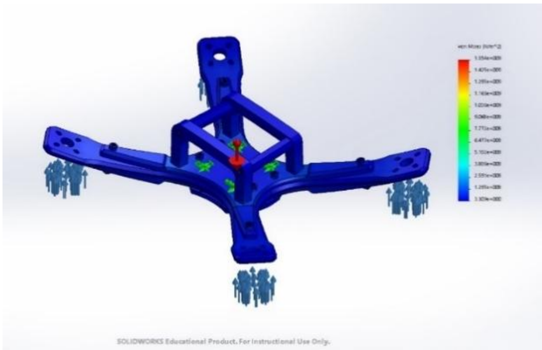

Fig 4.d) Von Mises stress

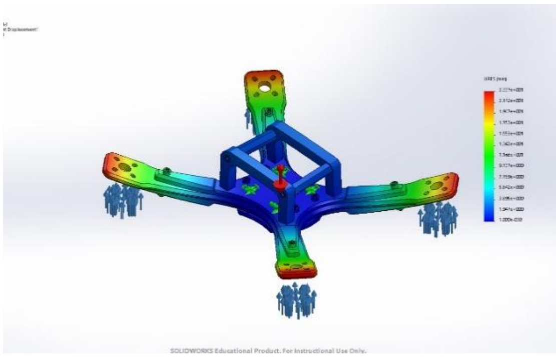

Fig 4.e) Displacement

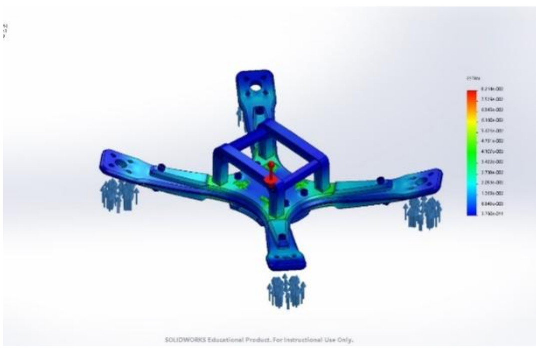

Fig 4.f) Strain deformation

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Impact analysis: Crash-landing of the drone can be testified by using this simulation procedure SOLIDWORKS can run a real-time sequence of cycles where a drone flying twenty-five feet above the ground is crash-landed on the ground. Compiling all the data it gives you the simulated results.

As per work-energy theorem and Newton's second law,

$$F = m*a$$

And, amount of work done is equal to the potential energy exchanged – Coriolis principle of work, by this we get,

$$W = F*D$$

Therefore, Net work done by all forces

$$W = m*g*h$$

$$W = 450 \text{ grams} * 9.8 \text{ m/s}^2 * 25 \text{ feet (considering all units into SI units)}$$
$$= 0.45 \text{ kg } 9.8 \text{ m/s}^2 * 7.62 \text{ m}$$

$$W = 33.6 \text{ kg m}^2/\text{s}^2 = \mathbf{33.6\ N\text{-}m}$$

By inputting all the parameters, we can define a function and get the following sequence cycles for the drop test.

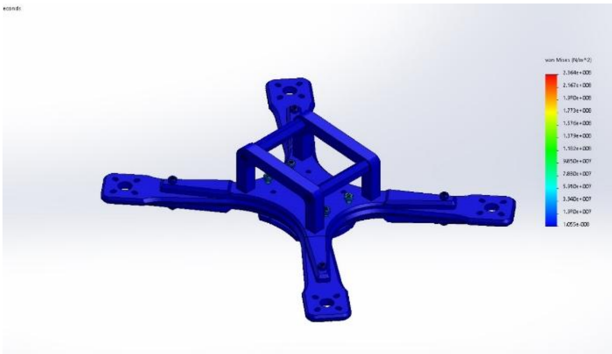

Fig 5.a) Von Mises stress during the impact.

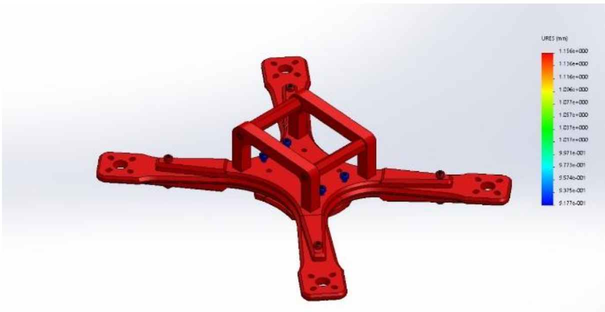

Fig 5.b) Resulted in displacement during the impact.

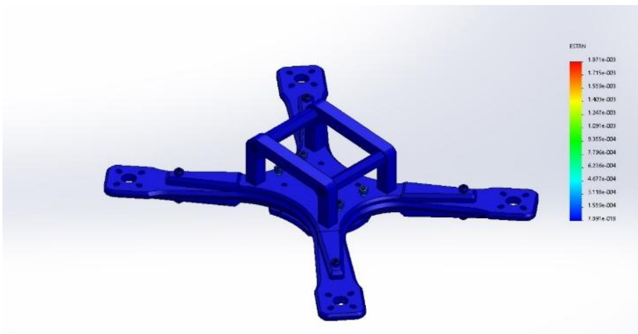

Fig 5.c) Strain deformation during the impact.

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Modal analysis: Motors undergo vibrational excitation and translate that to the body or the frame. To measure such dynamic excitation on the frame modal analysis is considered. Now considering the average rpm that the motor can generate during the throttle and convert that into the frequency, we can measure the vibrational excitation.

$$1 \text{ Rpm} = \frac{1}{60}\ Hz$$

For example, Emax- RS2205 2300kv at 75 percentage of throttle generates around 18,350 rpm and by converting it into frequency we get **305.8 Hz**.

Using a different range of amplitudes, we can calculate the translation of the vibration along the frame. We can observe some deformation after 416 Hz.

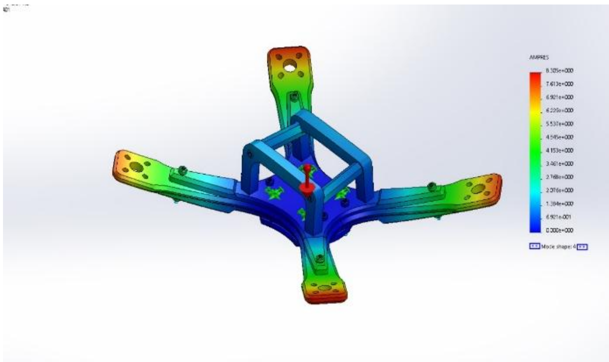

Fig 6.a) Resultant amplitude plot at 416 Hz.

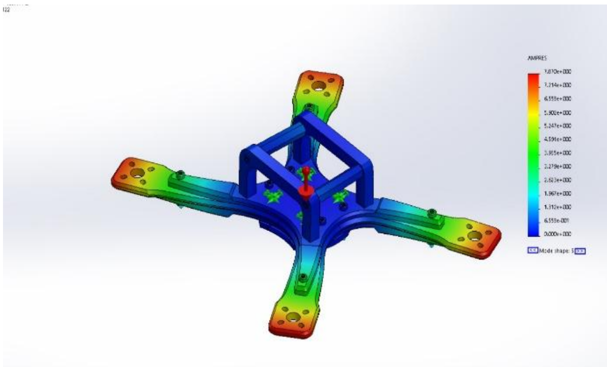

Fig 6.b) Resultant amplitude plot at 464.5 Hz.

IV. CONCLUSION AND FUTURE WORKS

A 3D printed quadrotor frame with safety factor 2.5 is attained and various finite element analysis performed on the frame are distinctly mentioned and plotted in the figures. Further, we can 3D print a 3- axis gimbal and attach it to our quadcopter for aerial photography. Also, we can upgrade them by attaching few thermal imaging sensors and gas sensors to measure radiation and air pollution at certain heights. This shows the main advantage of the 3D printed quadcopters and makes them stand distinct to the market-ready drones. We can customize them to make them work in any environment just by changing the printing filaments.

Fig 7.a) 3D printed drone assembly isometric view.

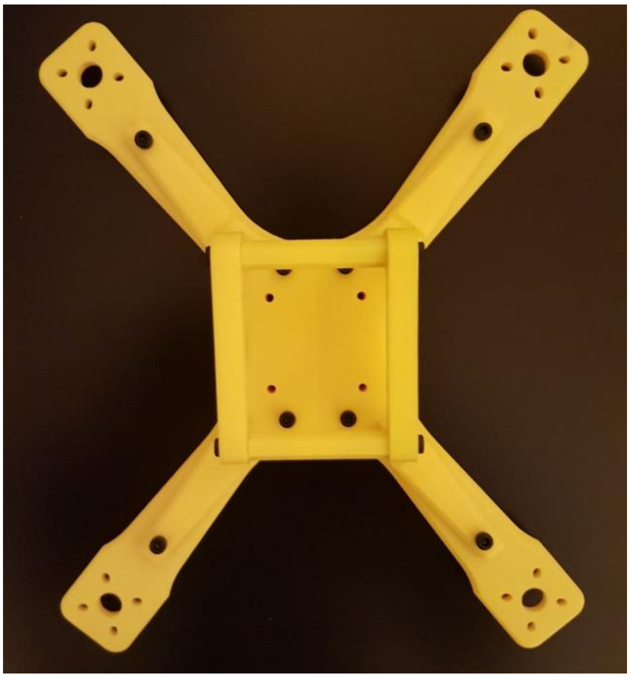

Fig 7.b) 3D printed drone assembly top view.

Fig 7.c) 3D printed drone assembly bottom view.

REFERENCES

[1] American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN: 2320-0936 Volume-5, Issue-9, pp-130-138.
[2] *DJI Innovations Spreading Wings S1000*,http://www.dji.com/product/spreading-wings-s1000.
[3] *D Robotics*, [online] Available: http://3drobotics.com/
[4] Vijay Kumar, Nathan Michael, "Opportunities and challenges with autonomous micro aerial vehicles", *The International Journal of Robotics Research*, vol. 31, no. 11, pp. 1279-1291, 2012.
[5] Kinematic Analysis of Quadrotors with Manufacturing Errors Yash Mulgaonkar, Caitlin Powers, and Vijay Kumar.
[6] QUADCOPTER BODY FRAME MODEL AND ANALYSIS Endrowednes KUANTAMA, Dan CRACIUN, Radu TARCA3.
[7] Michael Russell Rip, James M. Hasik, "The Precision Revolution: GPS and the Future of Aerial Warfare," Naval Institute Press. p. 65. ISBN 1-55750-973-5. Retrieved January 14, 2010.
[8] https://www.3dhubs.com/knowledge-base/additive-manufacturing-process.