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Structural Investigation of Agricultural UAV

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***Abstract*- UAV Technology has improved exponentially in the last few cycles, and we can discuss its importance as new resolutions to all challenging queries that include managed services on a unique land that a computer can make floating above it. It covers UAV that produces agricultural projects like spraying, an examination of products for vast hectare fields. Structural analysis is the purpose of the consequences of pressures on concrete buildings and their elements. The structural analysis applies applied mechanics, materials science, and applied mathematics to measure a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The analysis results verify a structure's fitness for use, often precluding physical tests. This report presents the results of structural analysis of the Agricultural Unmanned Aerial Vehicle in compliance with the requirements of DGCA. The analysis includes the Strength of Materials approach to determine loads (Shear Force and Bending Moments) which is utilized for further analysis using the Finite Element Analysis (FEA) approach. Commercial FEA software ANSYS is used for this purpose. The static structural analyses of the UAV are performed under different load conditions. The consequences of these researches show that the planned construction is safe within the flight envelope. This paper lays the structural analysis framework, which could as a source for additional temporary separation. The products can be increased additional to effective reports like Crash Test, sloshing examination of Fuel tanks, Etc. to mimic real-time events. This paper is required to showcase the structure's authenticity (hypothetical load circumstances compelling) for certification determinations and vibration endorsement from DGCA.**

***Keywords*- UAV, Structural analysis, Agricultural Unmanned Aerial vehicles, DGCA, ANSYS.**

I. INTRODUCTION

1. Unmanned Aerial Vehicle:

An unmanned aerial vehicle (UAV) is an aircraft without a human pilot traveling. UAVs are elements of an unmanned aircraft system (UAS), including a UAV, a ground-based controller, and a method of information among the pair. UAVs' flight may precede with different independence stages: unless following exclusive government by an individual engineer or autonomously by onboard computers.

Compared to human-crewed aircraft, UAVs were originally used for missions too "dull, dirty or dangerous" for humans. While they originated mainly in military applications, their use is rapidly increasing to business, accurate, recreational, agricultural, and other purposes, such as controlling, peacekeeping, monitoring, product deliveries, atmospheric photography, horticulture, stealing, and vibration racing.

Civilian UAVs now vastly outnumber military UAVs, with estimations of over a million sold by 2015, so they are early practical employment of independent things, to be succeeded by independent car and residence robots.

2. Applications of UAV:

There are numerous civilians, commercial, military, and aerospace applications for UAVs. These include:

- **Civil:** Disaster relief, archaeology, conservation (pollution monitoring and poaching), law enforcement, crime, and Terrorism.
- **Commercial:** Aerial surveillance,filmmaking, journalism, scientific research, surveying, cargo transport, and agriculture.
- **Military:** Reconnaissance, attack, demining, and target practice.

3. Types of UAV/Drones:

UAVs / Drones can be classified on a different basis – say based on usage like parasites for photography, UAV for aerial mapping, drones for surveillance, etc. However, the best classification of drones can be made based on aerial platforms.

Based on the nature of the aerial platform used, there are four major types of drones.

3.1 Fixed-wing UAV: Fixed-wing drones are entirely different in design and build to multi-rotor type drones. They use a wing-like the regular airplanes out there. Unlike multi-rotor drones, fixed-wing type models never utilize energy to stay afloat on-air, challenging gravity. Instead, they drive onward on their set course or set by the guide control if their energy source permits. Most fixed-wing drones have an average flying time of a couple of hours. Owing to their higher-flying time and fuel efficiency, fixed-wing drones are ideal for long-distance operations (be it mapping or surveillance).

However, they cannot be used for aerial photography where the drone needs to be kept still on the air for a period. The other downsides of fixed-wing drones are the more expensive costs & skill training required in flying. It is not easy to put a fixed-wing drone in the air. It would help if you either had a runway or a catapult launcher to install a fixed wing drone on its path in the air. A runway or a chute, or a net is necessary to safely land them back in the ground.

Fig 1. Fixed Wing UAV.

3.2 Single Rotor Drones: Single rotor drones are very comparable in design & structure to original helicopters. Unlike a multi-rotor drone, a single rotor model has just one oversized rotor plus a small-sized one on the drone's tail to restrain its heading. Single rotor drones are much experienced than multi-rotor reports. They have longer flying times and can even be powered by gas turbines. In aerodynamics, the more under the number of rotors, the more inferior the object's spin. Furthermore, that is many purposes why quadcopters are more durable than octocopters. For that reason, single rotor drones are very effective than multi- rotor drones.

Fig 2. Single Rotor Drone.

3.3 Multi Rotor Drones: Multi Rotor drones are the most common types of drones which are used by professionals and hobbyists alike. They are used for most common applications like aerial photography, aerial video surveillance etc. Different types of products are available in this segment in the market say multi-rotor drones for professional uses like aerial photography and there are lots of variants for hobby purposes like amateur drone racing, or leisure flying.

Out of all the 4 drone types (based on aerial platform), multi-rotor drones are the easiest to manufacture and they are the cheapest option available as well. Multi- rotor drones can be further classified based on the number of rotors on the platform. They are Tricopter (3 rotors), Quadcopter (4 rotors), Hexacopter (6 rotors) and Octocopter (8 rotors). Out of these, Quadcopters are the most popular and widely used variant. At present, most of the multi-rotor drones out there are capable of only a 20 to 30 minutes flying time (often with a minimal payload like a camera).

Fig 3. Multi rotor drone.

3.4 Hybrid VTOL: These heterogeneous organizations produce fixed-wing support' battles (besides expensive flying practice) among rotor-based models (hover). This approach has from solely the 1960s outside enough interest.

Fig 4. Hybrid VTOL.

Nevertheless, this concept has some new growth and management with the most advanced present sensors (gyroscopes and accelerometers). Hybrid VTOLs are a performance of self- regulation and standard gliding. An up right lift to lift the drone into the atmosphere from the territory. Gyros and accelerometers operate in automatic mode (autopilot thought) to retain the drone secured in the space—remote- based (or even added) manual power to control the drone on the coveted program.

4. Scope of Project:

For handling different farming enterprises, similar sprinkling in wide spread farming. The contemporary society was created to study for safe, dependable & experienced technology for long-duration sustainable production and transferred their actions by taking UAV Technology & Solutions.

Away In this design, we determined to do a Structural investigation of an Agri-UAV design, and this design has to transfer static review and increase it for dynamic examination to identify and improve several imperfections in architectural composition. So that this representation can be applied to gardening garden projects with combined flight arrangements.

II. LITERATURE REVIEW

1. "Structural Analysis of Arm of Multicopter with Various Loads" Brijesh Patel, R. P. Sukhija, J. V. Sai Prassana Kumar:
A significant development occurs due to small unmanned air systems known as drones, Unmanned Aerial vehicles (UAV), or Unmanned Aerial Systems. As these systems have many components where primary research have been done, which focuses on new applications of UAV's, control optimization, Enhancement of Endurance Limit, GPS, Autopilot, Etc. There is small research done on Structural Components of Hexarotor.

In order to get High Endurance, the structural Analysis has to perform. Multicopter possesses a lightweight frame, high thrust motor landing gear, and a conventional structural arrangement. A great need for structural Analysis of the arm of a multicopter with the motor mounted should be examined.

Structural Vibration Analysis of Carbon Fiber Arm of Hexarotor, as due to high RPM of Motors the arm is affected by many structural loads. This paper discusses the experimental and numerical vibration analysis of a Hexarotor Arm and subordinate structure.

This research provides an analysis of the vibration sources affecting the Hexarotor and experimental modal analysis of the carbon fiber arm of Hexarotor. The resulting data will provide the area of low vibration, which results from the mounting of other instruments for better operation.
2."Analysis of Plates by using ANSYS" N.V.Divya, Syed Rizwan:
This paper is required to analyze the Plate deflections and distances under different loading requirements to confirm their potential breakdown situations. This system means to depart the aluminum plate under varying brands of charging conditions. The examination was taken out concerning the Kirchhoff thin plate study and finite element structure software ANSYS. It is reassuring to receive the advantages at affection courses and for the general outline of the program. By searching the intelligent controllers with the ANSYS result, we can obtain the plate's optimum thickness.

3."Design and Static Structural Analysis of an Aerial and Underwater Drone." Abishini A, Priyanka Bas B, Raque Bertilla A, Haston Amit Kumar:
This scheme would like to complete vibrations for submarine and airborne monitoring at our coastline and enlarge its utilization to discover marine air noises and destructions. Submarine vibrations must recognize essential circumstances such as palatability and happiness, examining the drone's fundamental uprightness and energy demands. This design uses an innovative quadcopter layout with a new modernized architectural geometry. The complete frame is designed employing CATIA. The new device is approved for its successful implementation within stress analysis utilizing ANSYS. Also, becoming a matter for the invention is decided by comparing five other materials.

We want to create fluctuations for marine and airborne monitoring at our coastline and discover submarine air noises and destructions in this picture. Submersible fluctuations must recognize related circumstances such as palatability and happiness, examining the drone's architectural honesty and energy demands. This design uses an innovative quadcopter layout with a modern modernized architectural geometry. The complete structure is produced using CATIA. The new device is approved for its successful implementation throughout stress examination using ANSYS. Also, a proper matter for the invention is decided by matching five other elements.

4."Structural Analysis of Quadcopter Frame" Rahul Singha, Rajeev Kumara, Abhishek Mishra, Anshul Agarwal:
The quadcopter is an advanced, highly maneuverable aircraft that has a simple design and structure. It has a high load-carrying capacity and other characteristics. The quadcopter is one of the UAV (Unmanned aerial vehicles) used to lift, carry, observe, rescue, and collect data from one place to another in lesser time and without taking much space and cost.

It can be used for surveillance purposes and military operations. The quadcopter structure's static and dynamic characteristics have been analyzed by determining and analyzing the quadcopter dynamics. This paper describes the quadcopter frame model's overall design, then analyzing the frame with commercial Finite element code ANSYS 18.0 (Academic research). Selecting the necessary material and structure that meets the strength and stiffness of the requirement of the system.

5."Simulation and Analysis of a Quadrotor UAV while Landing." P.V.Sawalakhe, J.A. Shaaikh:
Unmanned aerial means are generally employed in dispute and nonmilitary changes in modern occasions. Quadrotor Unmanned Aerial Vehicles (UAV) provides numerous choices among other UAV's, in separate segments, due to their potential to flutter and Vertical Take-Off and Landing (VTOL) capacity. The mathematical simulation approach can be utilized for the investigation of UAVs. The simulation organization can decrease the flight duration, expense, and uncertainty and increase its production while vertical take-off and landing (VTOL). While piloting the UAV, the vehicle's kinetic power is

received by the UAV support, following high-stress companies. Other members of the UAV also provide the forces.

The impact of the landing pressures and forces on the airframe of the quadrotor unmanned air transport must be thoroughly understood, and the UAV must be planned subsequently to not break during arrival. The simulation process can explain these forces to ensure the sustainability of the UAV structure. This commitment involves fundamental and frequency analysis for the Quadrotor UAV chassis.

III. CONCEPTS AND THEORY

1. Quadcopter Features:
The quad-rotor is an aircraft with four rotors in a coupling. This program is finished to attach, walk forward, sideward, after, lead, and guide the restoration, modification, and yaw machetes individually. The four rotors alternate clockwise and counter-clockwise similar it is presented in Fig. 3.1. Clockwise (CW) machines, displayed in blue, use traditional propellers and counter-clockwise (CCW) motors, displayed in red, practice pusher propellers.

Fig 5. Quadcopter in X configuration.

This four-rotor aircraft has some advantages over the standard helicopter. Due to the motors' rotation (clock and counter-clockwise), gyroscopic influences and aero-dynamic energies tend to cancel in flight. Throttle input is the sum of each motor's thrust (motors 1, 2, 3, and 4). This force makes the quadcopter fly. Roll movement is achieved by expanding or reducing rear motors' speed (motors 2 and 4) and decreasing or expanding front motors (motors 3 and 1) individually. Pitch movement is achieved likewise using lateral motors. Lastly, yaw movement is accomplished by increasing or decreasing the counter-clockwise motors' speed while decreasing or increasing the clockwise motors' speed. Figure 3.2 shows the UAV's angles of rotation.

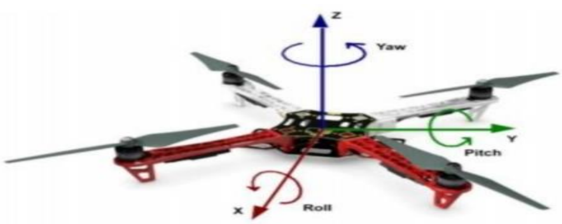

Fig 6. Angles of rotation of Quadcopter.

The quad-rotor frame consists of a rigid body with four arms attached in an X configuration. A motor is mounted at the end of each arm.

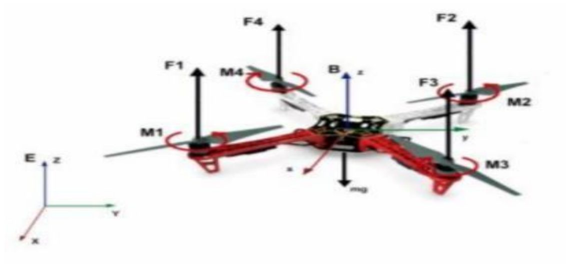

Fig 7. Forces and Moments in a Quadcopter.

2. ARM Analysis:
The Quadcopter arm can be modeled as a cantilever beam setup with loads acting along the beam's length.

The Strength of Materials Equations to estimate the Shear Force including Bending Moment is:

Shear Force at any point = Load (P)

Bending Moment, (x< a) = P(x − a)

Bending Moment, (x> a) = 0

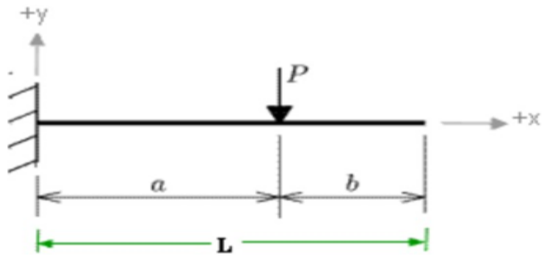

Fig 8. Cantilever beam setup.

3. Tank Division:
The fluid inside the Fuel and Agricultural Matter tank would provide a Hydrostatic pressure on the Tank structure resistance below static situations. The description for calculating Hydrostatic Pressure is provided below:

Hydrostatic Pressure, $dP = -\rho * g * dh$

Where,
ρ = Density of the fluid (kg/m3)
g = Acceleration due to gravity (m/s2)
dh = Change in the height of the fluid (m)

4. Factor of Safety (FOS):
The proportion of a structure's absolute strength (structural capacity) to actual applied load; is a type of a design's reliability. This is a measured value and is sometimes referred to as a realized safety factor for the sake of clarity. Then the formula is given below:

$$\text{The factor of safety (FOS)} = \frac{\text{Ultimate Stress}}{\text{Working Stress}}$$

5. Category of UAV:
Civil RPA (Remotely Piloted Aircraft) is categorized following Max.

All-Up-Weight (including payload) as designated below:
5.1 Nano: Less than or equal to 250g.
5.2 Micro: Greater than 250g and less than or equal to 2 kg.
5.3 Small: Greater than 2 kg and less than or equal to 25 kg.
5.4 Medium: Greater than 25 kg and less than or equal to 150 kg.
5.5 Large: Greater than 150 kg.

6. Strength Specifications:
- Express, that airframe structure, shall be adjusted to withstand flight limit quantities externally failure, malfunction, or permanent deformation.
- Candidate has to present interpretation of the construction dispensing that the factor of safety of 1.5 has been applied.
- Permission is adequate from the construction and segments and from territory.

7. Material Resources:
The mainframe, its subcomponents, arms, its subcomponents, and the drone's grounding equipment are composed of Aluminum alloy AA 7075 T6 (ASTM).Zinc is the principal alloying component of AA 7075. It has superior construction characteristics, including tremendous flexibility, high toughness, toughness, and excellent tiredness reconstruction, and has significantly greater corrosion protection than the 2000 compounds.

It is the various generally accepted aluminum alloy for highly stressed structural purposes and has been widely employed in aircraft structural components. T6 temper 7075 has a terminal tensile strength of 572 MPa and yield strength of at least 503 MPa. It has a breakdown elongation of 9%.

The fuel tank and the agricultural material tank are both constructed from High-Density Polyethylene; HDPE is known for its high strength-to-density ratio.

As the title implies, HDPE has a high density extending from 0.958g/cc.

Although the weight of HDPE is only marginally more expensive than that of low-density polyethylene, the variation in power transcends the variation in density, according to HDPE, a more critical specific health. It is also more complicated and more covered and can endure moderately higher warmth. It is also contrary to many solutions, and significantly it can withstand corrosion occasioned by fuel.

IV. METHODOLOGY

1. Work Flow:
The plan of action is presented in the flowchart shown below.

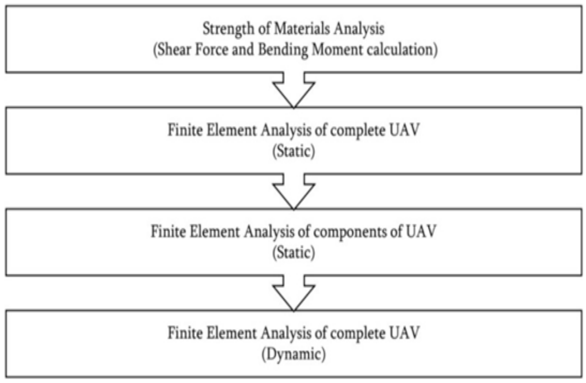

Fig 9. Work Plan.

2. **Analysis Methodology**
When composing a structure or a machine, the engineer must consider all the authorities acting on the house or the organization and its element components. The authorities' results are then examined about the establishment of the construction, and the ingredient components are made powerful enough to fulfill their purposes.

The organizations to be analyzed depending on the character and direction of the composition.

3. Mechanics of Materials Approach:
A substance's strength can confront a utilized load externally negligence or plastic deformation in the materials approach mechanics. The range of energy of elements sells with violence and deformations that emerge from their performance on a material. A load connected to a mechanical feature will cause internal forces within the member-termed importance when performed on a unit.

The pressures are working on the physical cause of deformation of the substance in different practices, including separating them altogether. Deformation of the substance is called strain throughout those deformations and stored on a unit foundation.

4. Finite Element Analysis Program:
The finite course element was original issued by Clough in 1960. In the early 1960s, designers practiced approaching stress analysis queries, fluid flow, heat transfer, and other states. The first publication on the FEM by Zienkiewicz and Chung was published in 1967.

In the late 1960s and early 1970s, the FEM was employed to different communications difficulties. Most business FEM software packages were introduced in the 1970s. (Abaqus, Adina, Ansys, etc.).

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The steps required are as regards:

- FEM practices the thought of piecewise polynomial interpolation.
- By combining elements, the field capacity matures introduced over the complete construction in a piecewise manner.
- A collection of contemporary algebraic comparisons at joints.
- The fundamental algebraic method for solving the deformation at joints managing FEM is

$$\{F\} = \{K\} * \{Q\}$$

Where,
F - Applied Force Matrix
K- Stiffness Matrix
Q – Global Deflection Matrix

Thus, the deformation at nodes can be obtained from

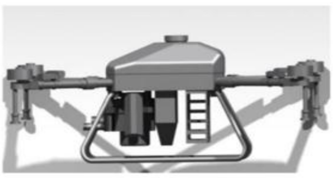
$$\{Q\} = (\{K\} \wedge (-1)) * \{F\}$$

Since the geometries are too complex to be solved by hand calculations, we go for a commercial FEM software package (In our case, ANSYS).

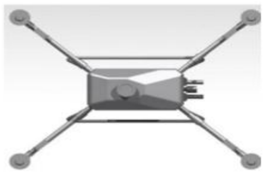
From both Mechanics of Materials and Finite Element Analysis, one can deduce the Factor of Safety (FOS) of the designed structure under static loading conditions.

V. UAV DESIGN

1. Design Diagrams:
The CAD diagrams of the UAV are given below.



(a)Side View



(b) Top View

(c) Front View

(d) Bottom View

(e) Isometric View

Fig 10. Design Diagrams of UAV.

2. Technical Specifications:

Table 1. General Specifications of UAV.

GENERAL SPECIFICATIONS	
Operating Altitude	0.5 - 5m (Maximum – up to 15 m)
Operating Speed	5 m/s
Propulsion System / Fuel	Hybrid Engine / Petrol
Fuel Tank Capacity	3.5 Liters
Payload Tank Capacity	16 Liters
System Endurance	40 min
Maximum Take Off Weight (MTOW)	46.9 kg (Medium category as per DGCA)
Empty / Body weight	24.72 kg

Table 2. Weight Specifications of UAV.

WEIGHT SPECIFICATIONS		
S. No	COMPONENTS	WEIGHT in kg
1	Air Frame with Electronics	13.588
2	Payload	16.000
3	Battery (2)	2.660
4	Motors (4)	3.992
5	Engine Generator	7.200
6	Propeller (4)	0.860
7	Fuel	2.700
	Maximum Take-Off Weight	46.94

Table 3. Dimensions of UAV.

DIMENSIONS	
Overall Length	1.3695 m
Overall Width	1.4749 m
Overall Height	0.53789 m
Propeller tip to tip distance (Diagonal)	2.695 m
Arm Length	0.70535 m

VI. STATIC STRUCTURAL ANALYSIS OF UAV

1. Mesh Convergence
Mesh convergence defines how many components are needed in a model to guarantee that examination results are not influenced by increasing the mesh size. System acknowledgment (stress, deformation) will concentrate on a repeatable answer with reducing component size. Following concentration, additional mesh filtration does not change outcomes. At this point, the design and its decisions are sovereign of the mesh. A mesh convergence research confirms that the FEA model has concentrated on an answer. It also supports Mesh Independence, and additional refinement is optional.

Table 4. Mesh Convergence.

Mesh Size (mm)	Max Deformations (mm)
0.5	1.1424
0.75	1.1412
1	1.1416
1.25	1.1427
1.5	1.1422
1.75	1.1415

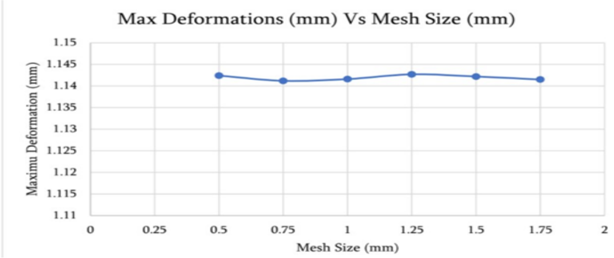


Fig 11. Mesh Convergence.

2. Static Structural Analysis Of Complete UAV Mesh:

Table 5. Mesh Details Setup and Result.

Physical Preference	Mechanical
Average Surface Area	2.1878e-03 m^2
Minimum Edge length	5.1212e-05 m
Element size	1.5e-03 m
Nodes	2665114
Elements	1524831

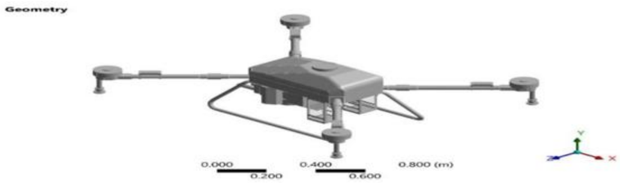


Fig 12. Complete UAV-CAD Model.

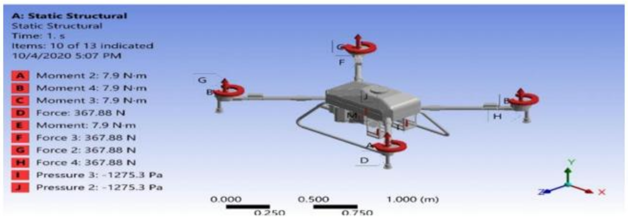


Fig 13. Complete UAV-Boundary Conditions (Forces and Moments).

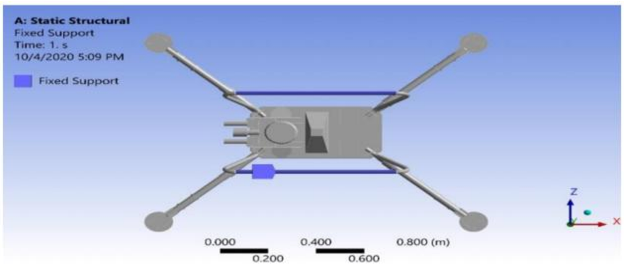


Fig 14. Complete UAV-Boundary Conditions (Fixed Supports).

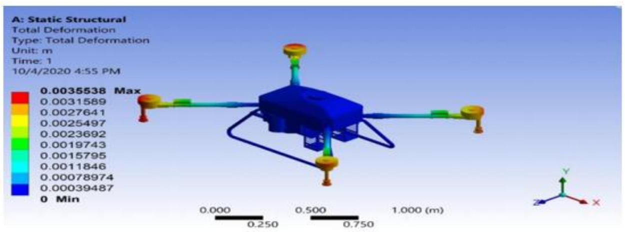


Fig 15. Complete UAV-Total Deformation.

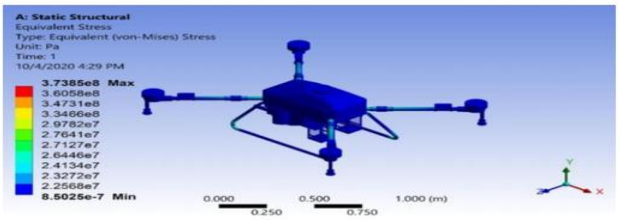


Fig 16. Complete UAV-Equivalent Stress.

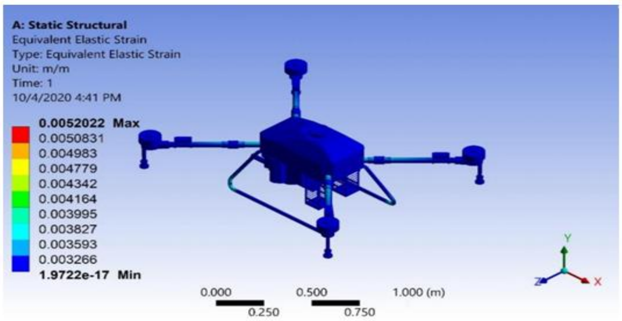


Fig 17. Complete UAV-Equivalent Strain.

3. Static Structural Analysis of Individual Components of UAV:

The UAV arm is formed as a cantilever beam with the motor and propeller combination's stress load serving as the intensive load near the point.

The beam is determined for its Shear Force and Bending Moment conditions applying the Mechanics of Materials program, and the effects are displayed here.

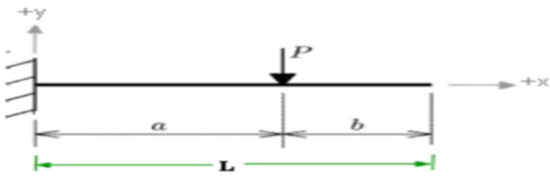


Fig 18. Cantilever beam setup.

Table 6. Cantilever beam parameters.

Length of the beam, L	70.535 cm
a	64.535 cm
b	6 cm
Load, P	367.875 N

Table 7. **TEXT HERE TABLE TITLE.**

Stations		Shear force	Bending Moment
(cm)	(m)	(N)	(N-m)
0	0	0	0
1.4107	0.014107	0	0
2.8214	0.028214	0	0
4.2321	0.042321	0	0
5.6428	0.056428	0	0
7.0535	0.070535	367.875	-3.875563125
8.4642	0.084642	367.875	-9.06517575
9.8749	0.098749	367.875	-14.25478838
11.2856	0.112856	367.875	-19.444401
12.6963	0.126963	367.875	-24.63401363
14.107	0.14107	367.875	-29.82362625
15.5177	0.155177	367.875	-35.01323888
16.9284	0.169284	367.875	-40.2028515

18.3391	0.183391	367.875	-45.39246413
19.7498	0.197498	367.875	-50.58207675
21.1605	0.211605	367.875	-55.77168938
22.5712	0.225712	367.875	-60.961302
23.9819	0.239819	367.875	-66.15091463
25.3926	0.253926	367.875	-71.34052725
26.8033	0.268033	367.875	-76.53013988
28.214	0.28214	367.875	-81.7197525
29.6247	0.296247	367.875	-86.90936513
31.0354	0.310354	367.875	-92.09897775
32.4461	0.324461	367.875	-97.28859038
33.8568	0.338568	367.875	-102.478203
35.2675	0.352675	367.875	-107.6678156
36.6782	0.366782	367.875	-112.8574283
38.0889	0.380889	367.875	-118.0470409
39.4996	0.394996	367.875	-123.2366535
40.9103	0.409103	367.875	-128.4262661
42.321	0.42321	367.875	-133.6158788
43.7317	0.437317	367.875	-138.8054914
45.1424	0.451424	367.875	-143.995104
46.5531	0.465531	367.875	-149.1847166
47.9638	0.4796638	367.875	-154.3743293
49.3745	0.493745	367.875	-159.5639419
50.7852	0.507852	367.875	-164.7535545
52.1959	0.521959	367.875	-169.9431671
53.6066	0.536066	367.875	-175.1327798
55.0173	0.550173	367.875	-180.3223924
56.428	0.56428	367.875	-185.512005
57.8387	0.578387	367.875	-190.7016176
59.2494	0.592494	367.875	-195.8912303
60.6601	0.606601	367.875	-201.0808429
62.0708	0.620708	367.875	-206.2704555
63.4815	0.634815	367.875	-211.4600681
64.8922	0.648922	367.875	-216.6496808
66.3029	0.663029	367.875	-221.8392934
67.7136	0.677136	367.875	-227.028906
69.1243	0.691243	367.875	-232.2185186
70.535	0.70535	367.875	-237.4081313

The Bending Moment values given above will be accepted as information for separating the individual elements in the UAV arm.

4. Analysis of Arm-Short Part:

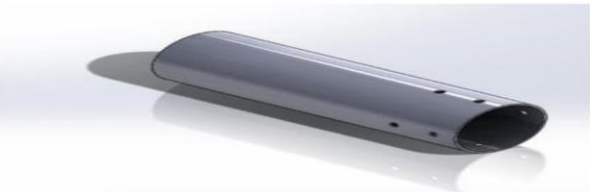


Fig 19. Arm Short Part-CAD Model.

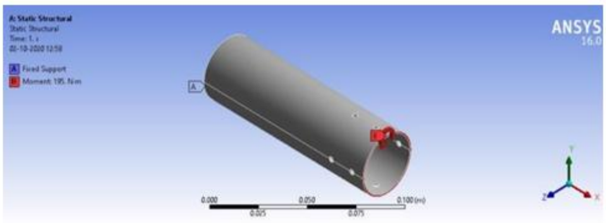


Fig 20. Arm Short Part-Boundary Condition (Moment).

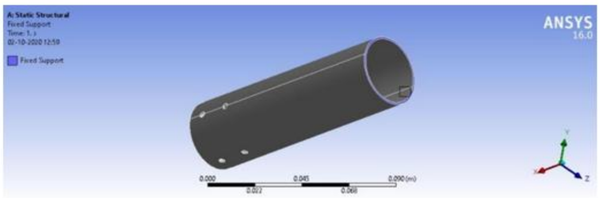


Fig 21. Arm Short Part-Boundary Condition (Fixed Support).

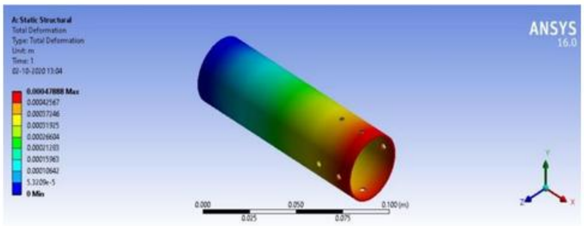


Fig 22. Arm Short Part-Total Deformation.

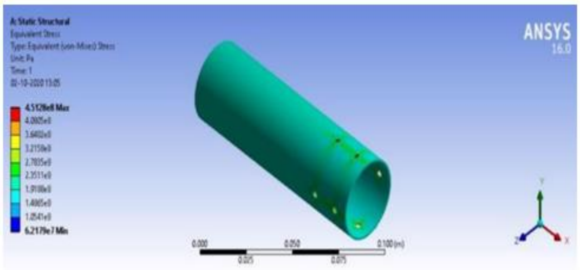


Fig 23. Arm Short Part-Equivalent Stress.

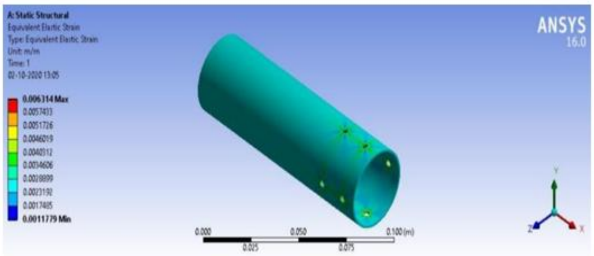


Fig 24. Arm Short Part-Equivalent Strain.

5. Analysis of Arm-Short Part Connector:

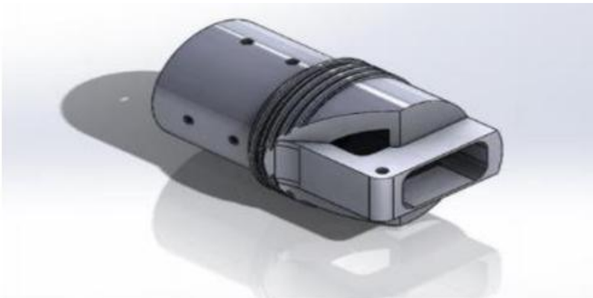


Fig 25. Arm Short Part Connector-CAD Model.

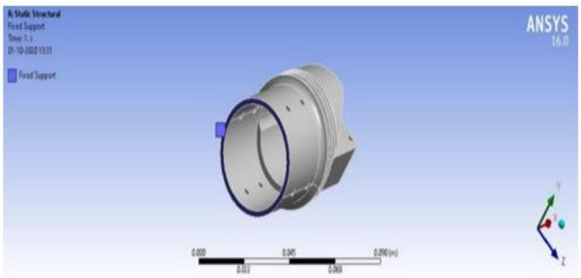


Fig 26. Arm Short Part Connector-Boundary Condition (Fixed Support).

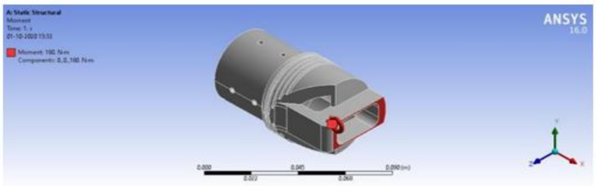


Fig 27. Arm Short Part Connector-Boundary Condition (Moment).

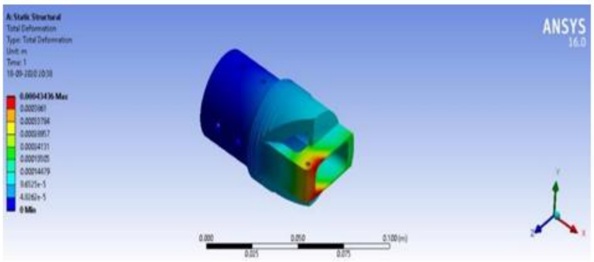


Fig 28. Arm Short Part Connector-Total Deformation.

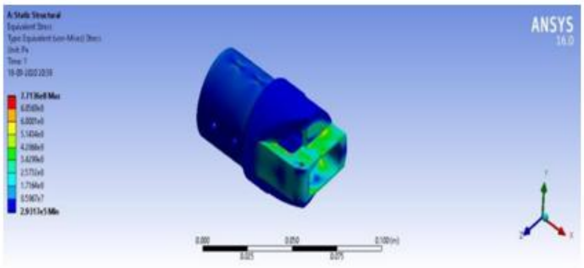


Fig 29. Arm Short Part Connector-Equivalent Stress.

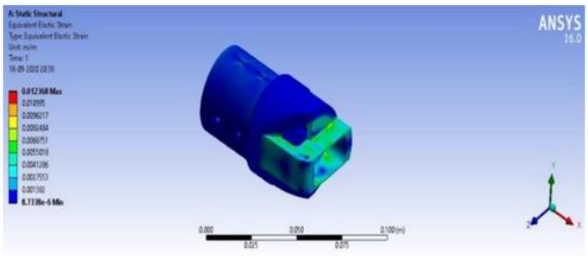


Fig 30. Arm Short Part Connector-Equivalent Strain.

6. Analysis of Arm-Cylindrical Screw Lock:

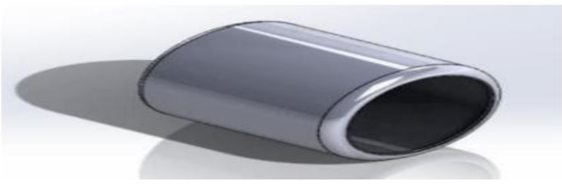


Fig 31. Arm Cylindrical Screw Lock-CAD Model.

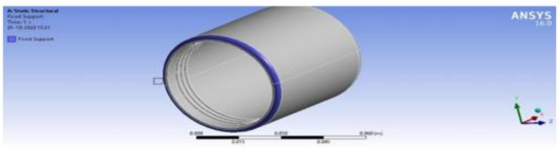


Fig 32. Arm Cylindrical Screw Lock-Boundary Condition (Fixed Support).

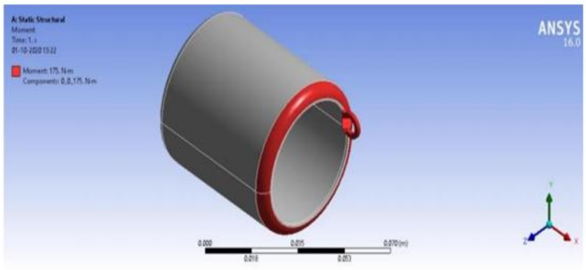


Fig 33. Arm Cylindrical Screw Lock-Boundary Condition (Moment).

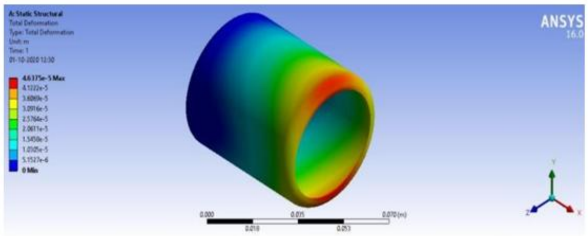


Fig 34. Arm Cylindrical Screw Lock-Total Deformation.

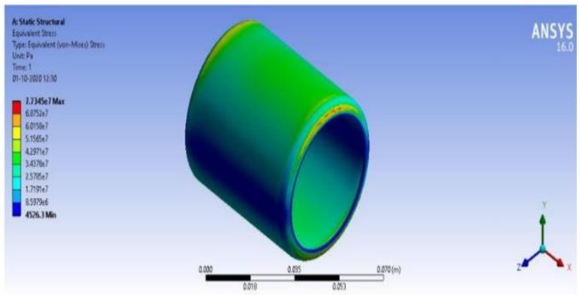


Fig 35. Arm Cylindrical Screw Lock-Equivalent Stress.

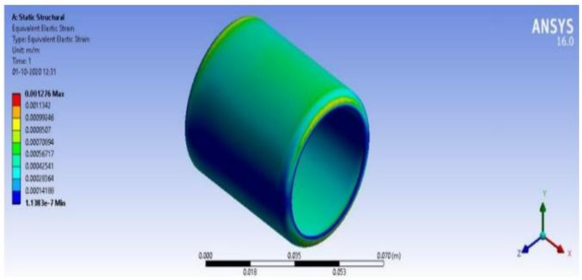


Fig 36. Arm Cylindrical Screw Lock-Equivalent Strain

7. Analysis of Arm-Long Part Connector:

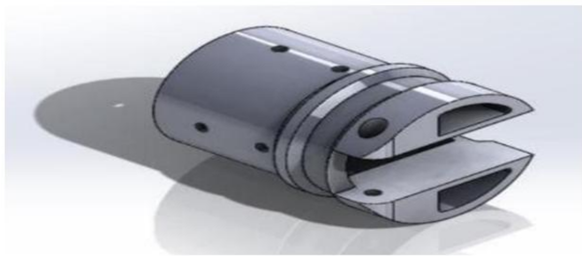


Fig 37. Arm Long Part Connector-CAD Model.

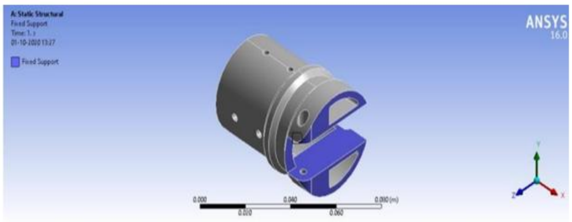


Fig 38. Arm Long Part Connector-Boundary Condition (Fixed Support).

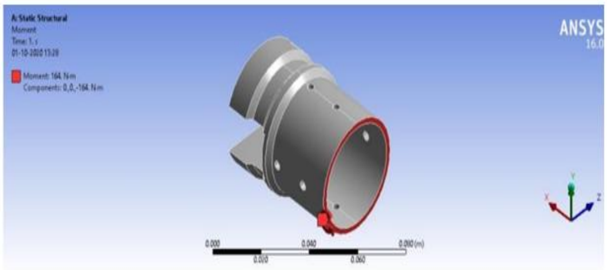


Fig 39. Arm Long Part Connector-Boundary Condition (Moment).

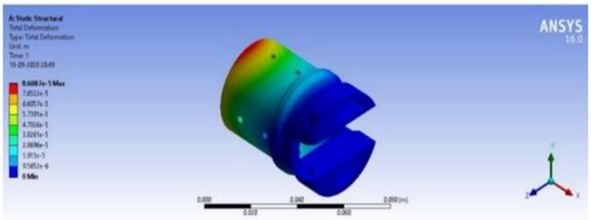


Fig 40. Arm Long Part Connector-Total Deformation.

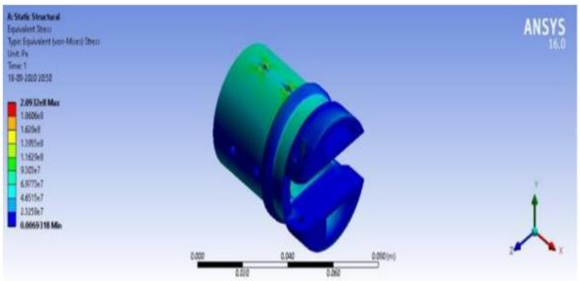


Fig 41. Arm Long Part Connector-Equivalent Stress.

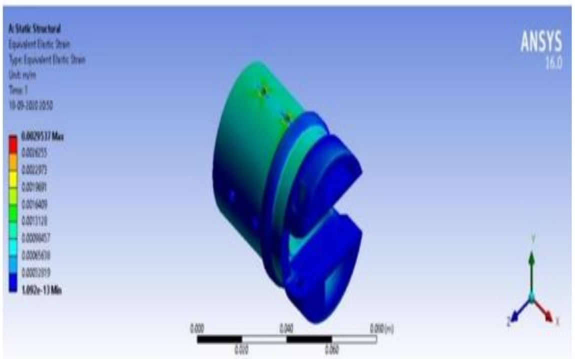


Fig 42. Arm Long Part Connector-Equivalent Strain.

8. Analysis of Arm-Long Part:

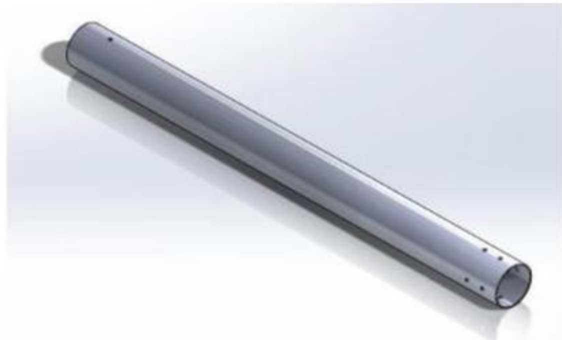


Fig 43. Arm Long Part-CAD Model.

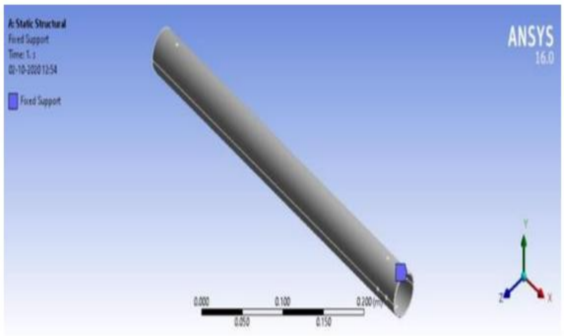


Fig 44. Arm Long Part-Boundary Condition (Fixed Support).

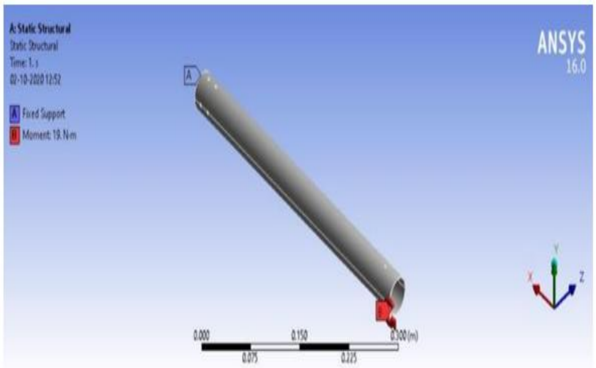


Fig 45. Arm Long Part-Boundary Condition (Moment).

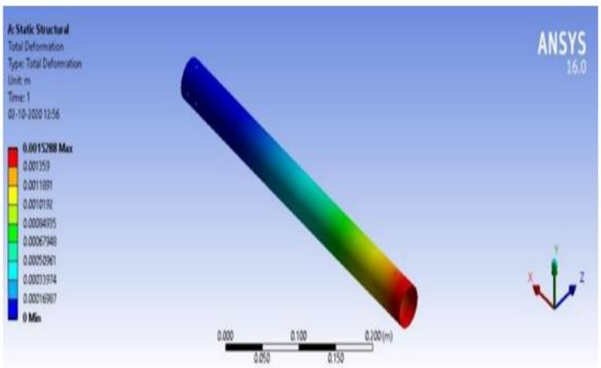


Fig 46. Arm Long Part-Total Deformation.

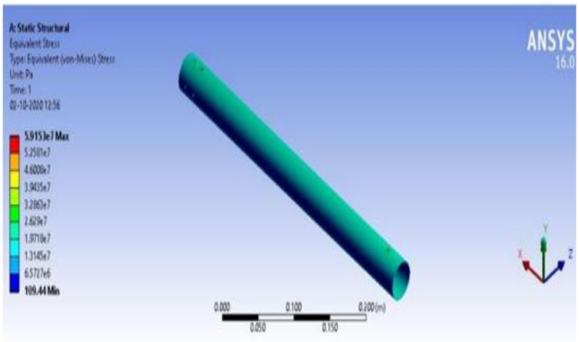


Fig 47. Arm Long Part-Equivalent Stress.

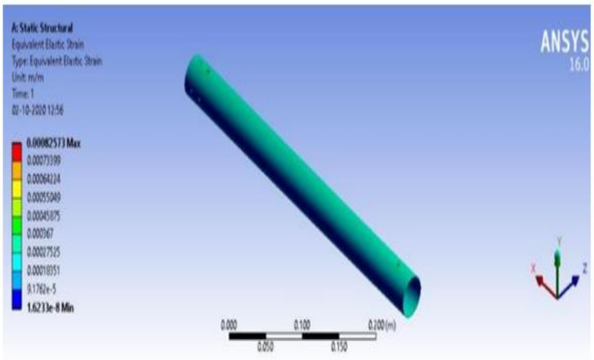


Fig 48. Arm Long Part-Equivalent Strain.

9. Analysis of Arm-ESC Unit Support 1:

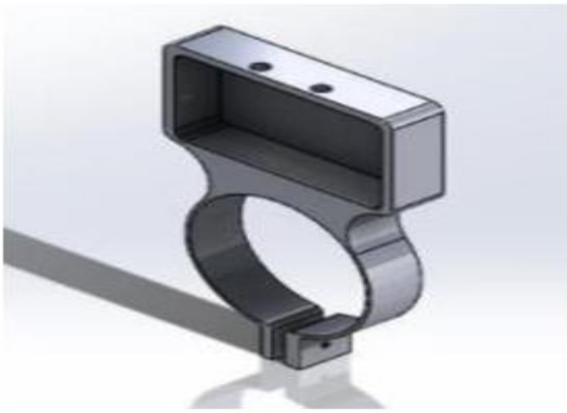


Fig 49. Arm ESC Unit Support 1-CAD Model.

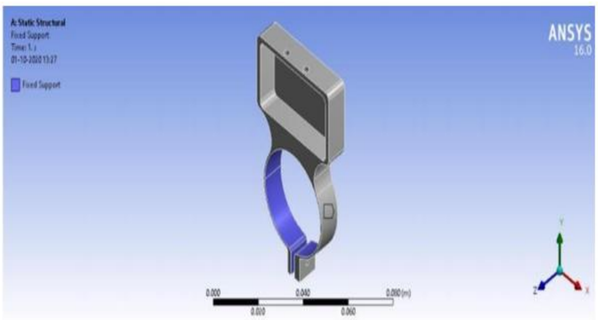


Fig 50. Arm ESC Unit Support 1-Boundary Condition (Fixed Support).

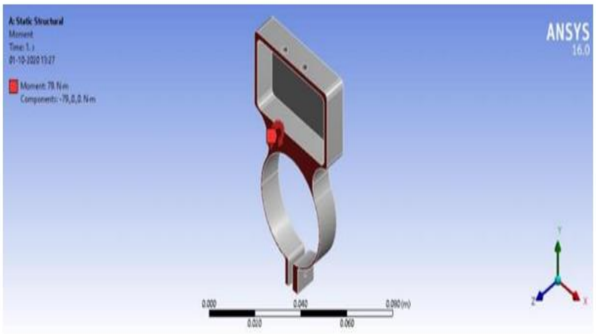


Fig 51. Arm ESC Unit Support 1-Boundary Condition (Moment).

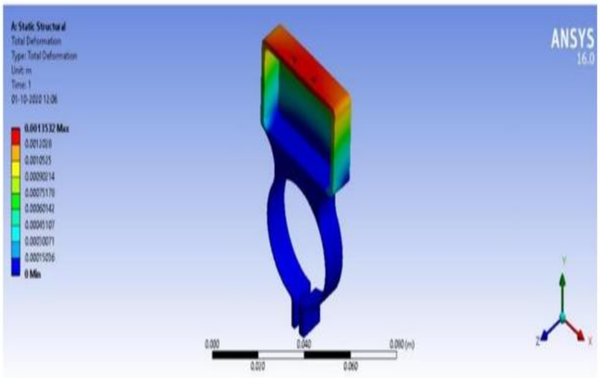


Fig 52. Arm ESCUnit Support 1-Total Deformation.

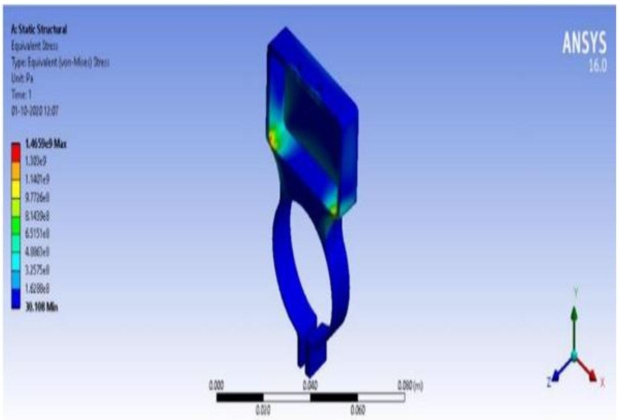


Fig 53. Arm ESC Unit Support 1-Equivalent Stress.

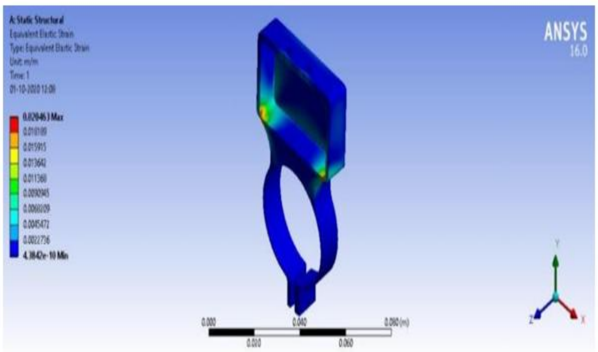


Fig 54. Arm ESC Unit Support 1-Equivalent Strain.

10. Analysis of Arm-ESC Unit Support 2 6.3.9 Analysis of Arm-Main Motor Housing Underbody:

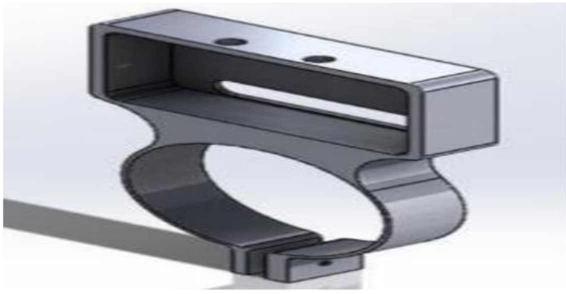


Fig 56. Arm ESC Unit Support 2-CAD Model.

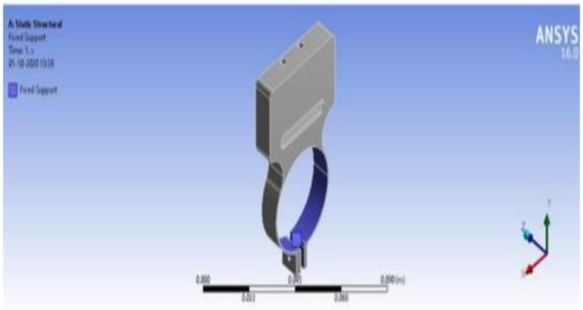


Fig 57. Arm ESC Unit Support 2-Boundary Condition (Fixed Support).

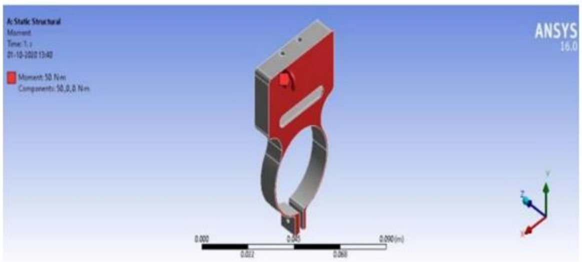


Fig 58. Arm ESC Unit Support 2-Boundary Condition (Moment).

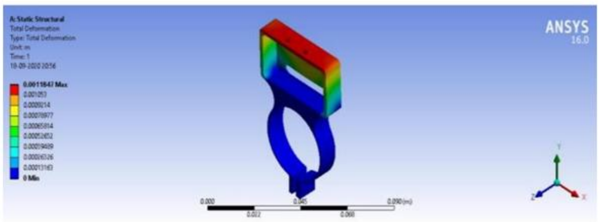


Fig 59. Arm ESCUnit Support 2-Total Deformation.

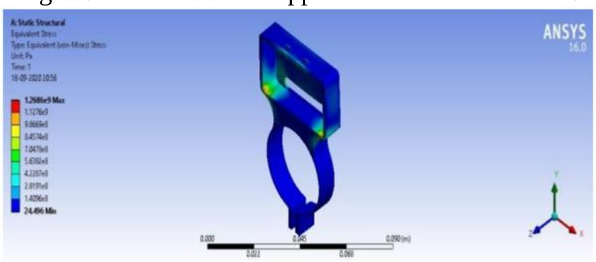


Fig 60. Arm ESC Unit Support 2-Equivalent Stress.

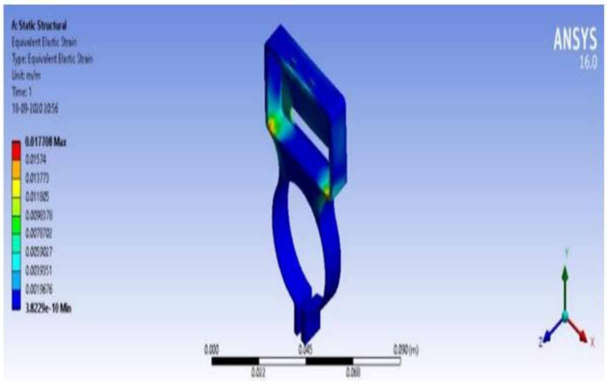


Fig 61. Arm ESC Unit Support 2-Equivalent Strain.

11. Analysis of Arm-Main Motor Housing:

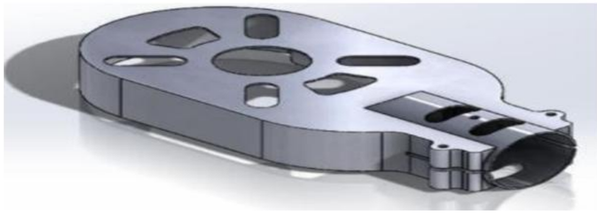


Fig 62. Arm Main Motor Housing-CAD Model.

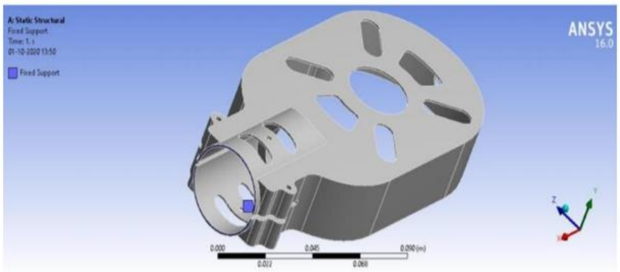


Fig 63. Arm Main Motor Housing-Boundary Condition (Fixed Support).

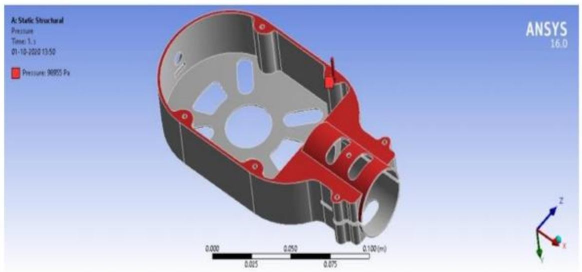


Fig 64. Arm Main Motor Housing-Boundary Condition (Moment).

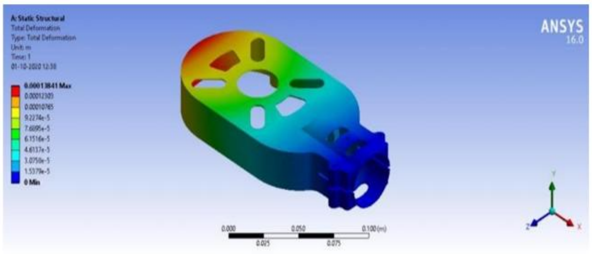


Fig 65. Arm Main Motor Housing-Total Deformation.

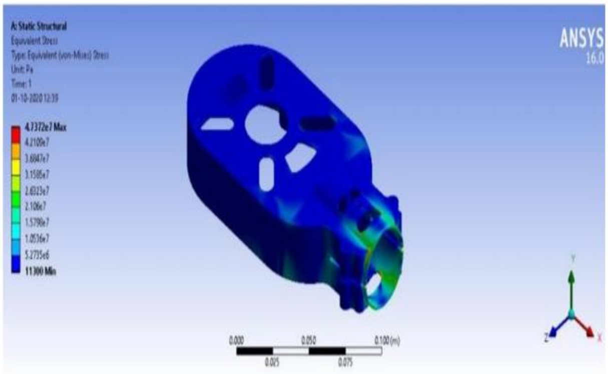


Fig 66. Arm Main Motor Housing-Equivalent Stress.

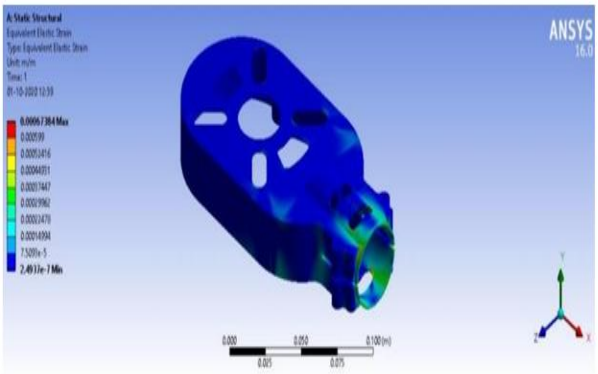


Fig 67. Arm Main Motor Housing-Equivalent Strain.

12. Analysis of Arm-Main Motor Housing Underbody:

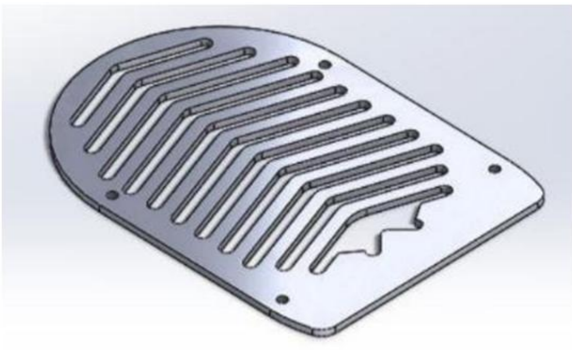


Fig 68. Arm Main Motor Housing Underbody- CAD Model.

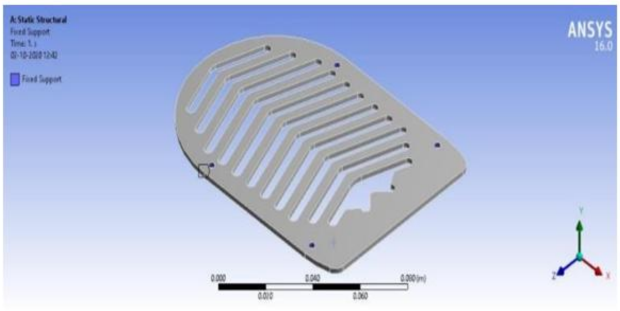


Fig 69. Arm Main Motor Housing Underbody- Boundary Condition (Fixed Support).

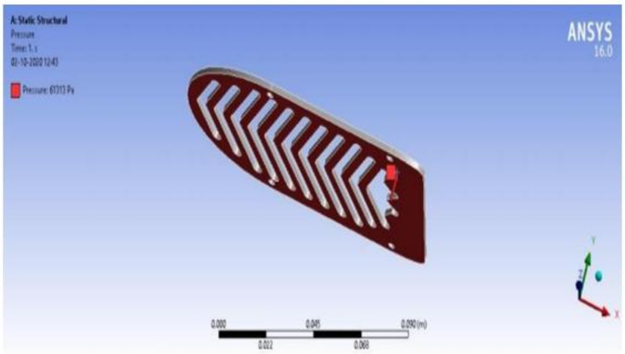


Fig 70. Arm Main Motor Housing Underbody- Boundary Condition (Moment).

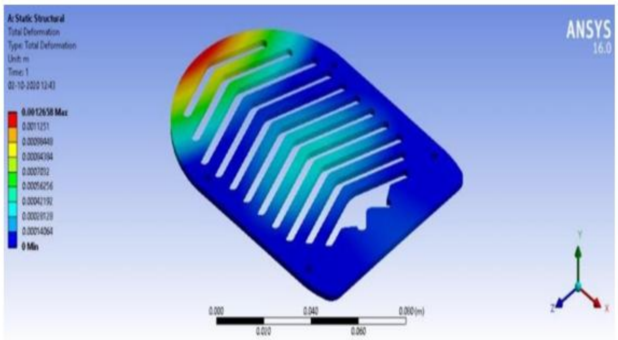


Fig 71. Arm Main Motor Housing Underbody- Total Deformation.

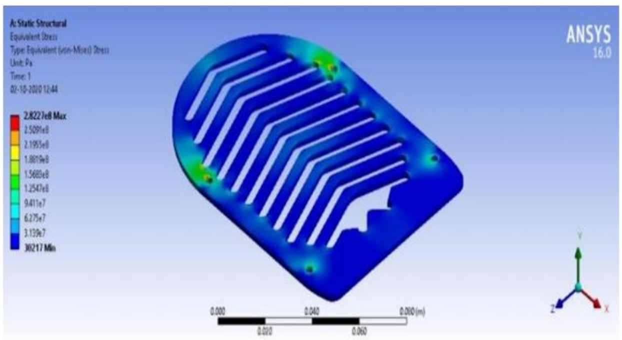


Fig 72. Arm Main Motor Housing Underbody- Equivalent Stress.

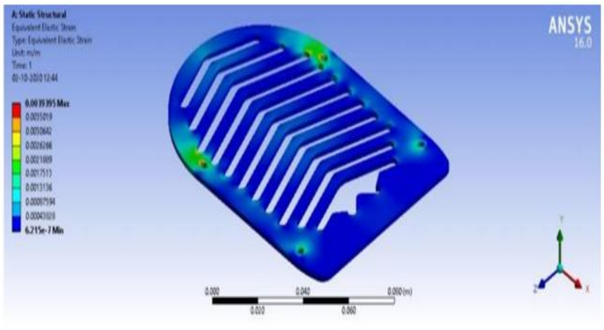


Fig 73. Arm Main Motor Housing Underbody- Equivalent Strain.

13. Analysis of Arm-Sprinkler Assembly:

Fig 74. Arm Sprinkler Assembly-CAD Model.

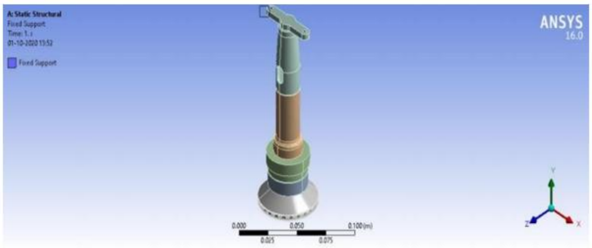


Fig 75. Arm Sprinkler Assembly-Boundary Condition (Fixed Support).

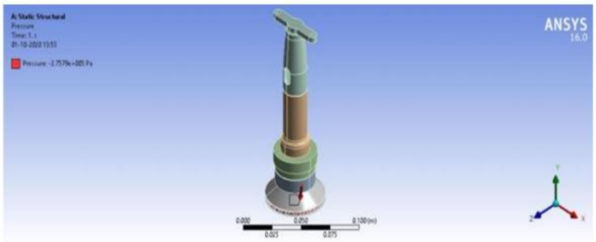


Fig 76. Arm Sprinkler Assembly-Boundary Condition (Pressure).

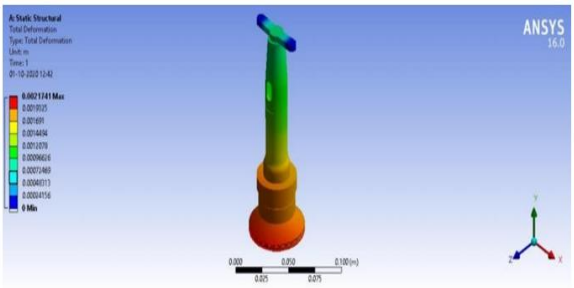


Fig 77. Arm Sprinkler Assembly-Total Deformation.

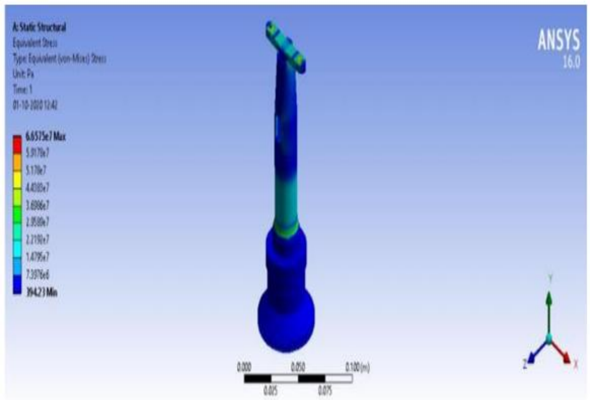


Fig 78. Arm Sprinkler Assembly-Equivalent Stress.

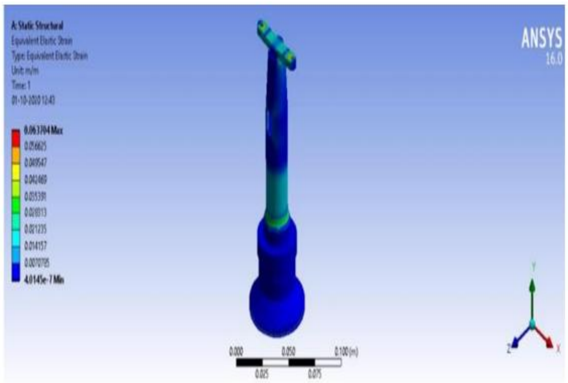


Fig 79. Arm Sprinkler Assembly-Equivalent Strain.

14. Analysis of plate:

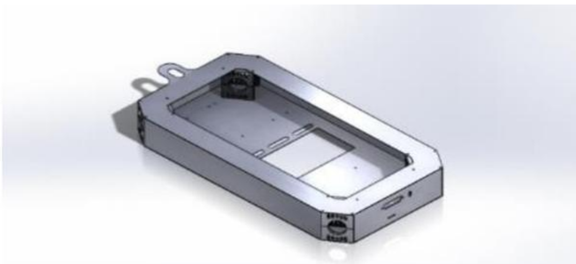


Fig 80. Plate-CAD Model.

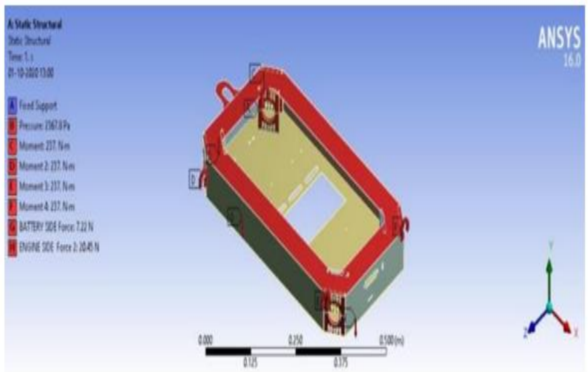


Fig 81. Plate-Boundary Conditions (Forces and Moments).

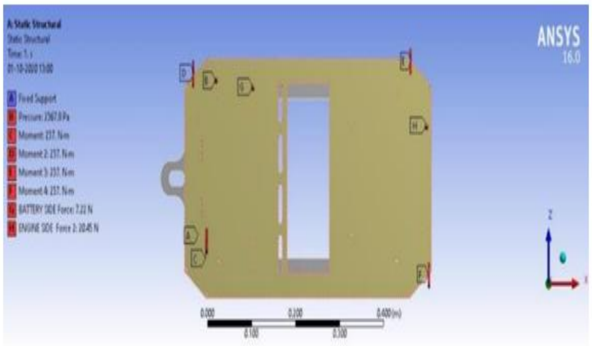


Fig 82. Plate-Boundary Condition (Fixed Support).

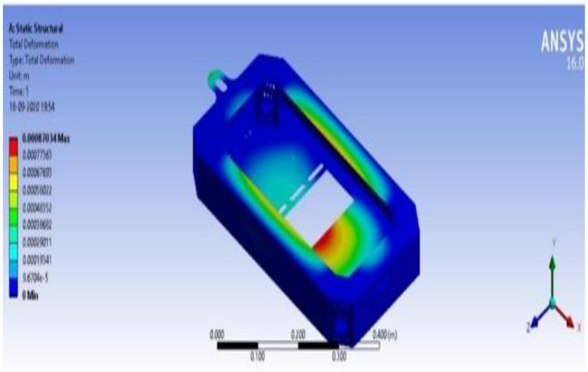


Fig 83. Plate-Total Deformation.

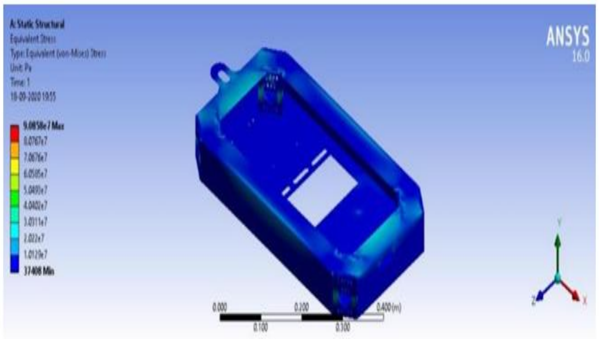


Fig 84. Plate-Equivalent Stress.

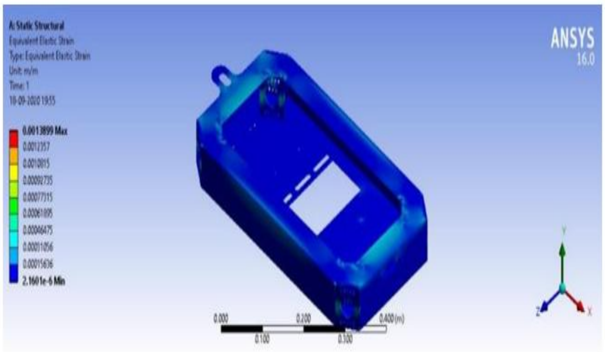


Fig 85. Plate-Equivalent Strain.

15. Analysis of Landing Gear:

Fig 86. Landing Gear-CAD Model.

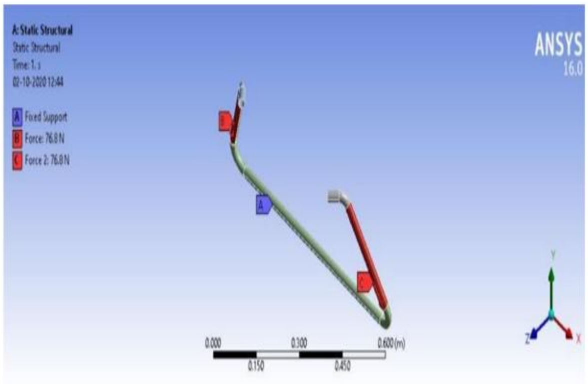


Fig 87. Landing Gear-Boundary Conditions (Forces and Fixed Support).

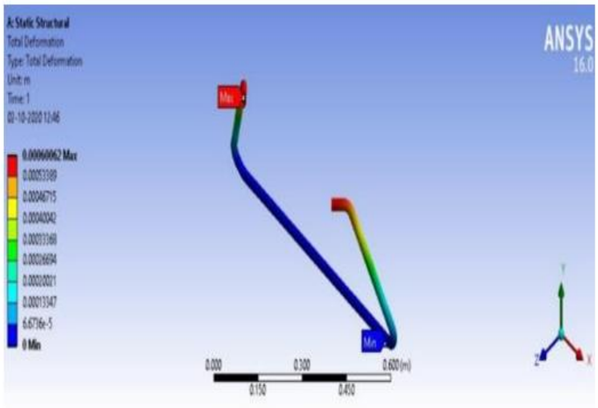


Fig 88. Landing Gear-Total Deformation.

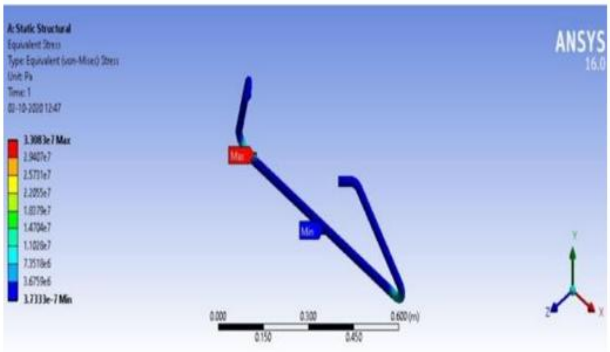


Fig 89. Landing Gear-Equivalent Stress.

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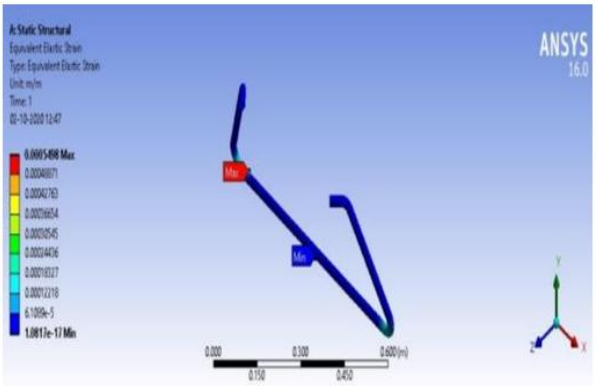

Fig 90. Landing Gear-Equivalent Strain.

16. Analysis of Fuel Tank:

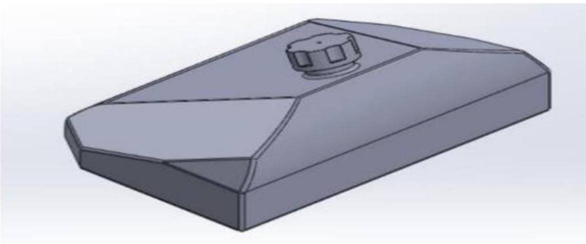

Fig 91. Fuel Tank-CAD Model.

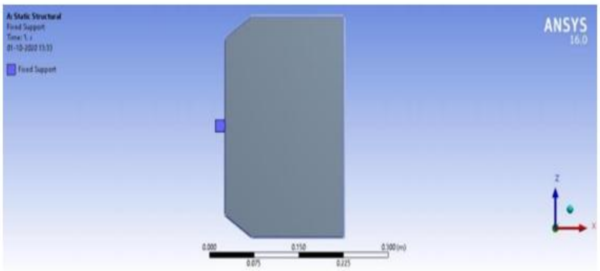

Fig 92. Fuel Tank-Boundary Condition (Fixed Support).

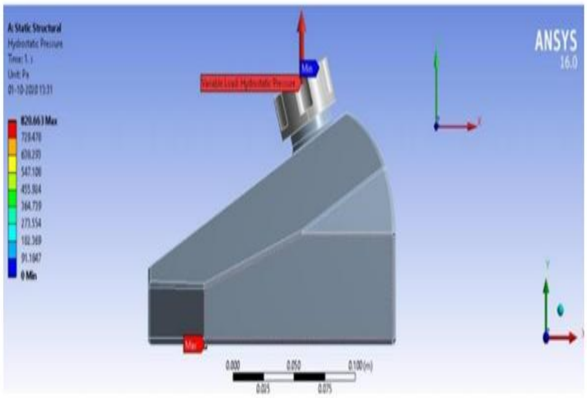

Fig 93. Fuel Tank-Boundary Condition (Hydrostatic Pressure).

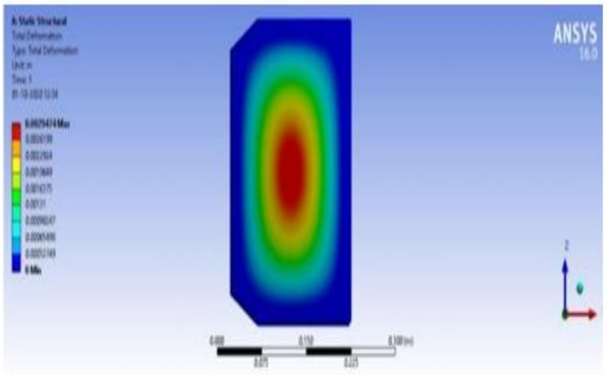

Fig 94. Fuel Tank-Total Deformation.

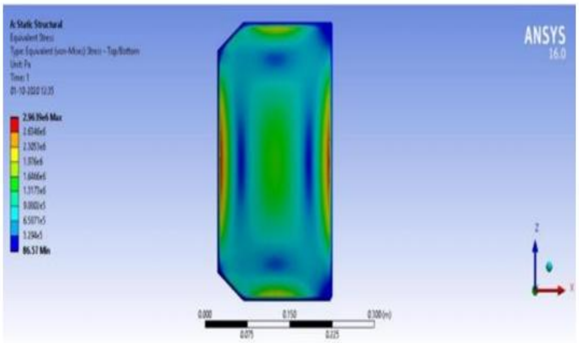

Fig 95. Fuel Tank-Equivalent Stress.

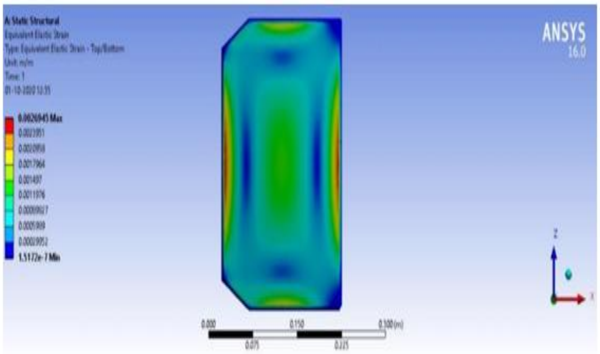

Fig 96. Fuel Tank-Equivalent Strain 6.3.14

17. Analysis of Agricultural Matter Tank:

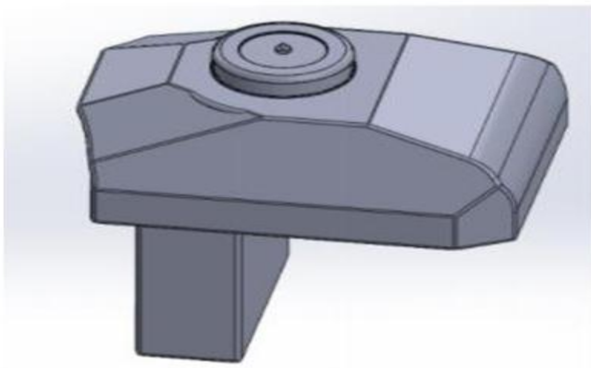

Fig 97. Agricultural Matter Tank-CAD Model.

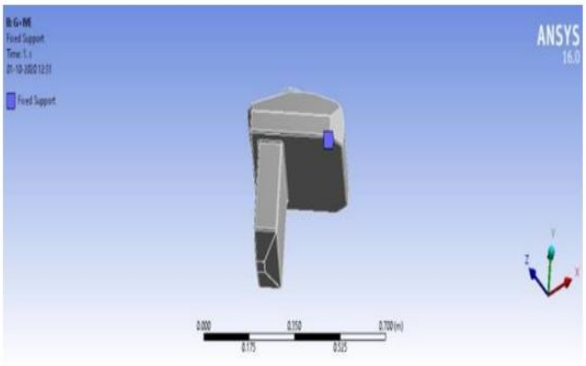

Fig 98. Agricultural Matter Tank-Boundary Condition (Fixed Support).

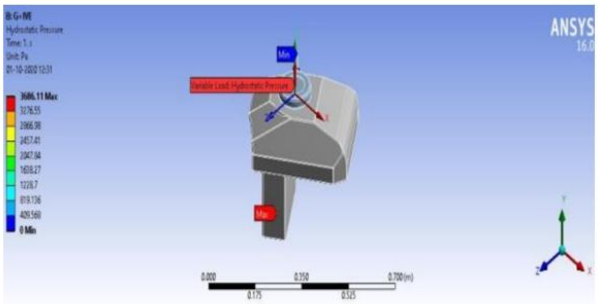

Fig 99. Agricultural Matter Tank-Boundary Condition (Hydrostatic Pressure).

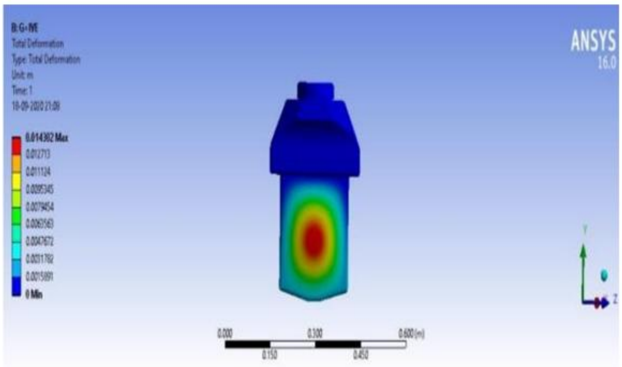

Fig 100. Agricultural Matter Tank-Total Deformation (Front View).

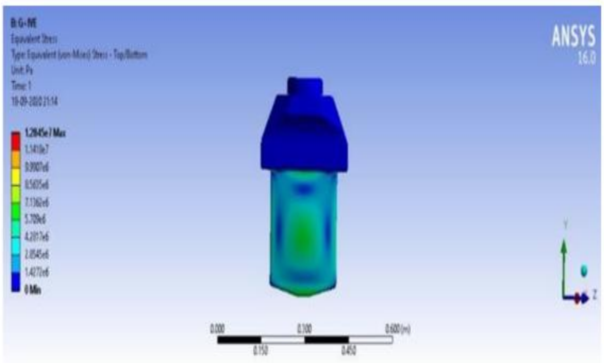

Fig 101. Agricultural Matter Tank-Equivalent Stress (Front View).

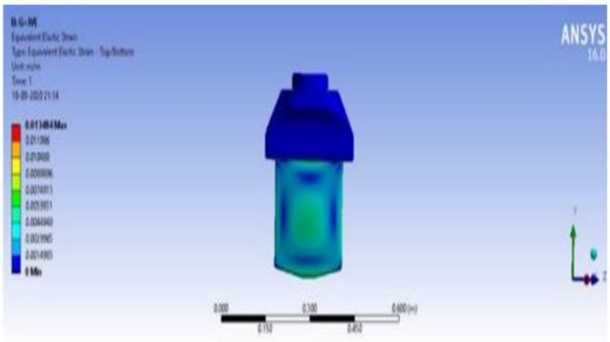

Fig 102. Agricultural Matter Tank-Equivalent Strain (Front View).

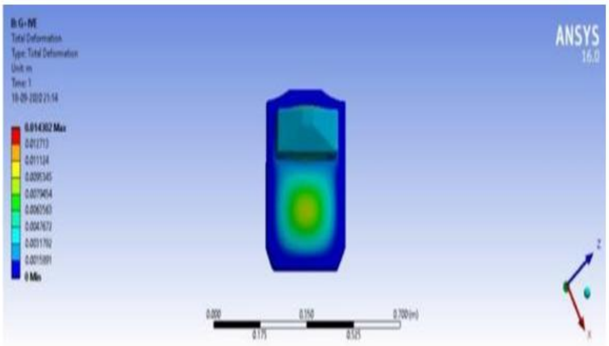

Fig 103. Agricultural Matter Tank-Total Deformation (Bottom View).

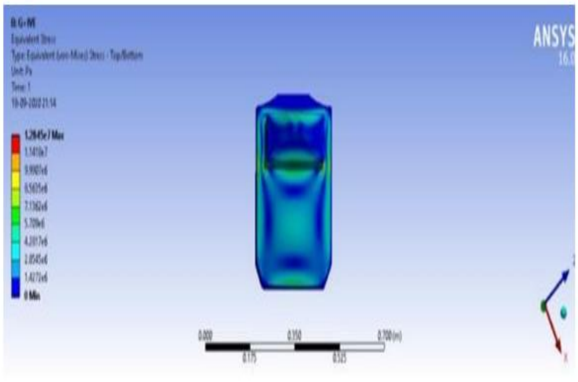

Fig 104. Agricultural Matter Tank-Equivalent Stress (Bottom View).

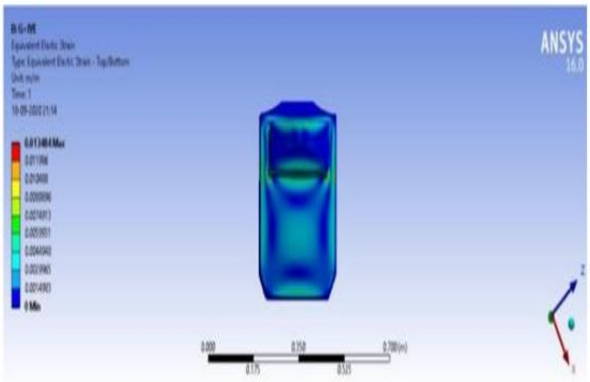

Fig 105. Agricultural Matter Tank-Equivalent Strain (Bottom View).

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VII. RESULT VALIDATION & DISCUSSION

1. Validation of Results:
FEM is a tool to simulate physical phenomena. If one has stewarded the physical load and boundary conditions (BC) appropriately, one can get reliable results. It is often impossible to exactly replicate load and BCs; then, you should pick one with the closest match.

It is usually told that FEM has 3 steps- pre- processing, solving, and post-processing. One must also validate the results obtained. There are various methods to validate the results. Since the above geometry is very complex theoretical analysis is tedious. One can also use a simple cantilever beam and compare it with the theoretical closed-form solution to validate the software result.

The validation is presented below:
Consider a cantilever beam of the circular cross-section with a tipping load of 100 N. The deformation values are compared for FEA and Theoretical results.
Taking,
E=2*10^5Pa
L=0.5m
D=40*10^-3m
FEA Solution:

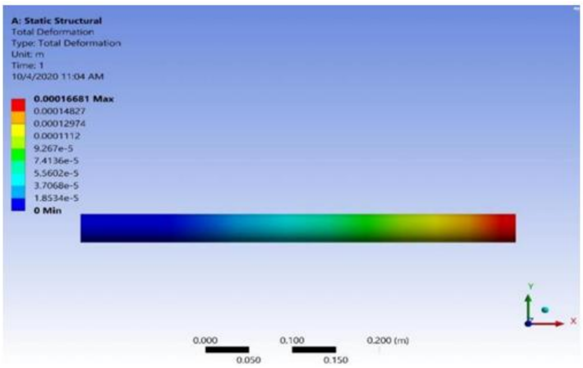

Fig 106. FEA Solution for Validation Model.

Tip Deflection, δ = 0.166 mm

2. Theoretical closed form solution:
Tip Deflection,

$$\delta = \frac{PL^{(3)}}{3EI}$$

Moment of Inertia,

$$I = \frac{\pi D^{(4)}}{64}$$

Substituting the values, the result obtained is Tip Deflection, δ = 0.1657 mm

Examining both the values, there is very negligible variation between the theoretical and the FEA solutions, and hence the software results could be treated as reliable.

2. Results Discussion
As per the above results, the maximum deformation of the UAV & its components is significantly less. This will not create any malfunction or permanent deformation to the structure.

2.1 The factor of Safety (FOS Calculation):

2.1.1 Complete UAV:

$$FOS = \frac{572 * 10^6}{373.85 * 10^6} = 1.53$$

2.1.2 Landing Gear:

$$FOS = \frac{572 * 10^6}{33.083 * 10^6} = 17.3$$

The maximum stress of the complete UAV also has a lesser value when compared to its material's allowable stress. The Factor of Safety (FOS) is 1.53, which is following the DGCA requirements.

The Landing gear is the major component of the whole assembly which supports the whole body's weight. The FOS for Landing Gear from the static structural analysis is 17.3, which is very high for static analysis.

Table 8. Static Structural Analysis Results.

Sl. No	Component	Tot.Def (mm)	Equiv.Stress (Mpa)		Equiv. Strain	
			Max.	Min.	Max.	Min.
0	Complete UAV	3.55	373.85	0	0.005	0
1	Arm-Short Part	0.47	451.28	0	0.006	0.001
2	Arm-Short Part Connector	0.43	771.3	0.29	0.012	0
3	Arm-Cylindrical Screw Lock	0.05	77.35	0	0.001	0
4	Arm-Long Part Connector	0.09	209.32	0	0.003	0
5	Arm-Long Part	1.53	59.15	0	0	0
6	Arm-ESC Unit Support 1	1.35	1466	0	0.020	0
7	Arm-ESC Unit Support 2	1.18	1268	0	0.017	0
8	Arm-Main Motor Housing	0.14	47.37	0.01	0.001	0
9	Arm-Main Motor Housing Underbody	1.27	282.27	0.03	0.004	0
10	Arm-Sprinkler Assembly	2.17	66.58	0	0.064	0
11	Plate	0.8	90.86	0.04	0.001	0
12	Landing Gear	0.60	33.08	0	0.001	0
13	Fuel Tank	2.90	2.96	0	0.003	0
14	Agricultural Matter Tank	14.30	12.85	0	0.013	0

So, higher FOS of the Landing gear will save the UAV during sudden impact also. The landing gear will not fail but may yield a static test showing its reserved energy absorption capacity. The higher FOS under static conditions may help to prevent failure during impact under free fall from table height only (1 to 1.5 m).

VIII. CONCLUSION AND FUTURE SCOPE

The UAV was initially analyzed using the Mechanics of Materials approach. (Shear Force and Bending Moment Calculation). The results obtained from the MOM approach were used as the input to the Finite Element Analysis carried out using ANSYS (Static Structural) for the complete UAV and the subcomponents. From the results obtained using the approaches above, we infer that. The physical behaviour of the UAV in terms of its deformation behaviour (static) satisfies the laws of Physics.

From the total deformation results obtained in ANSYS, we inferred that the deformation for the complete UAV and the subcomponents was within the negligible limits, demonstrating that the airframe structure shall be able to withstand flight limit loads without failure, malfunction, or permanent deformation. Thus, it satisfies the DGCA requirement.

The Factor of Safety of individual components gets compensated when it becomes a part of a complete UAV. Thus, their deformation characteristics and physical behaviour are of prime importance in the individual component analysis. The Factor of Safety for the complete UAV is 1.53, which is following the DGCA requirements. As per the design, clearance is sufficient from the structure and components and the ground, following DGCA requirements. This report's works can be extended to the dynamic analysis of the UAV to understand its dynamic behaviour (Vibration Etc.).

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