Drone Frame Design using Autodesk Fusion 360: A Generative Design Approach

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Introduction

Generative design is a computer-aided design (CAD) process that uses generative algorithms to produce a range of possible solutions for a given problem. The generative design process starts with a set of design criteria and objectives, which are then fed into generative algorithms. The generative algorithms generate a set of possible solutions for the criteria. AI can be used to identify the 'optimal' design from the generated solutions.

Generative Design Requirements

Two geometry types of bodies, preserve geometry and obstacle geometry are to be included in the generative design process. Bodies to incorporate in the final shape of the design is defined as the preserve geometry and bodies that are to be excluded from the final shape are called obstacle geometry.

Constraints and loads are applied to the generative model as design conditions. Constraints are applied to the model to prevent it from moving in response to applied loads. At least one constraint to a preserved geometry, usually fixed constraint, is to be applied to prevent movements in selected directions and by default, all three global directions are constrained.

Use loads to define the external forces that cause the design to work. Apply a point load as force to simulate the action of the load on the model and it is to be applied to the preserve geometry. A load and constraint can't be on the same face, edge, or vertex.

The selection of materials is a very important part of the design requirements in a generative study. The Yield Strength value of the material is used to calculate the safety factor. The Poisson's ratio and Young's Modulus of the material are the main values used to solve the linear stress problems when generating outcomes. The material density is used to calculate the outcome mass when a gravity load and/or frequency constraints are applied. The material density must be different from zero for gravity to affect the outcome.

This document present frame design procedure for two components, the central body which accommodates all the electronic parts except the ESCs and motors, and the 4 arms of the quadcopter which carry the motors propellers and the ESCs.

Making an Arm for Quadcopter via Generative Design

For the arm design, two preserved geometries are considered, one for fixing the arm to the centre body of the frame (**mid-frame-mount**) and other, **the motor-mounting-hub**, for connecting the motor assembly with the arm.

The design for the **mid-frame-mount** depends on the **central body** made to accommodate the bulk of the drone electronic components. The mid-frame mount can either be vertical or horizontal. In the present design, a horizontal mid-frame mount (Fig.1) with a vertical wall is chosen considering the ease of assembly and the high strength generative designs generations with the help of the vertical wall as shown in Fig. 1a. Remember to give all the mounting holes in the initial design as the generative design will create designs considering the mounting hole positions. The dimensions were chosen keeping in mind the distance between the wall and the central body as shown in Fig. 1b. Also design Arches as shown by red arrow (Fig.1c) to increase the strength of mid-frame mount.

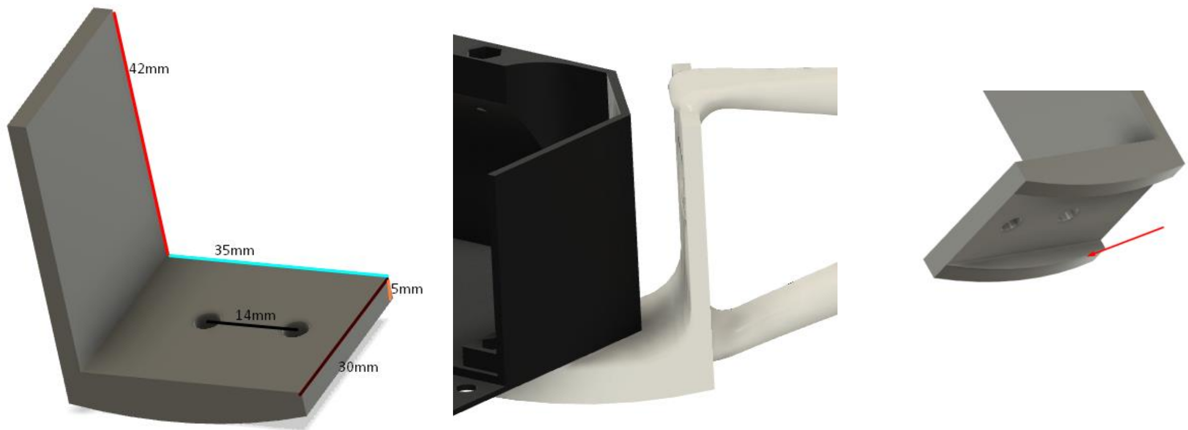


Fig. 1a. Horizontal mid-frame mount with vertical mount

Fig. 1b. Distance between the vertical walls and central body cover

Fig. 1c. Red arrow illustrating Arch ribs for enhanced strength

Fig. 1. Design of Mid Frame Mount

Next is to design the **motor mounting hub** (Fig 2) for the motor. The **DXF** file for the mounting hub will be shared, just extrude that sketch by 3mm to make the mounting hub as shown in Fig. 2a. Extra strength to the mounting hub can be obtained by modification as shown in Fig. 2b. Enough space for resting the screw heads is to be provided as shown in Fig. 2c.

Fig. 2a. Motor Mounting Hub Extruded from DXF

Fig. 2b. Motor Mount Hub with extra strength

Fig. 2c. 3D Printed Model showing importance of giving space for resting Screw Heads

Fig. 2. Design of the Motor Mounting Hub

Now arrange the two components (mid-frame mount and the motor mounting hub) such that the centre-to-centre distance between them should be within the range of 10-12cm, shown in Fig.3. The distance is arrived at considering the space requirement for the propeller rotation and the limitation of printable area of the 3D printer.

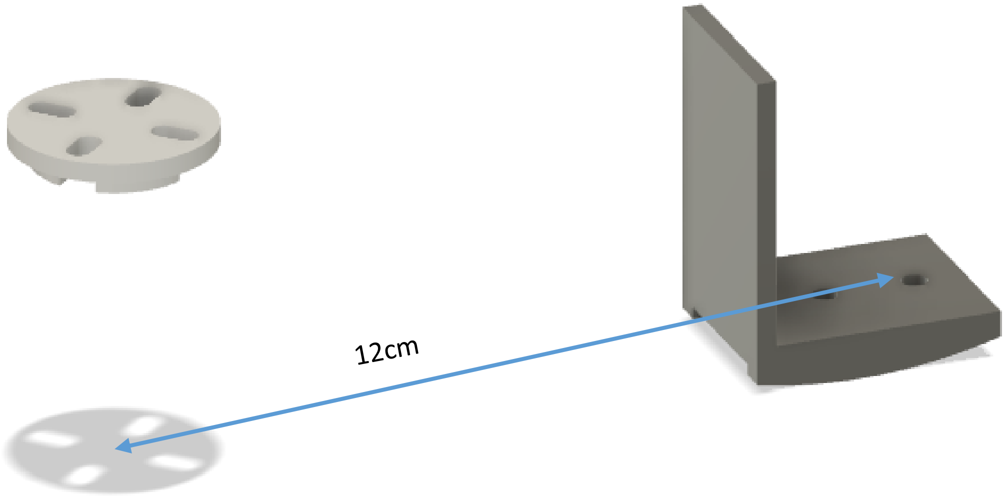


Fig.3. CAD Model showing the Appropriate Distance which should be kept before working on Generative Designing

Now with the two preserve geometries are ready, next step is to proceed with the generative designing.

Open generative design workspace by selecting drop down from top left as shown in Fig. 3a.

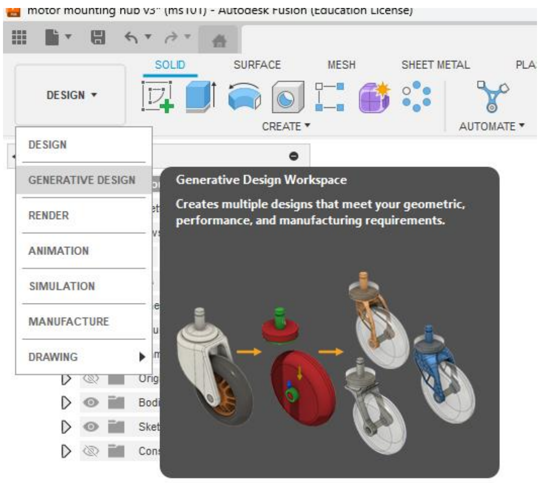


Fig. 3a. UI for Selection of Generative Design

The screen shot of the UI of generative design workspace is shown in Fig. 4, which will open after clicking on create study in the popup menu.

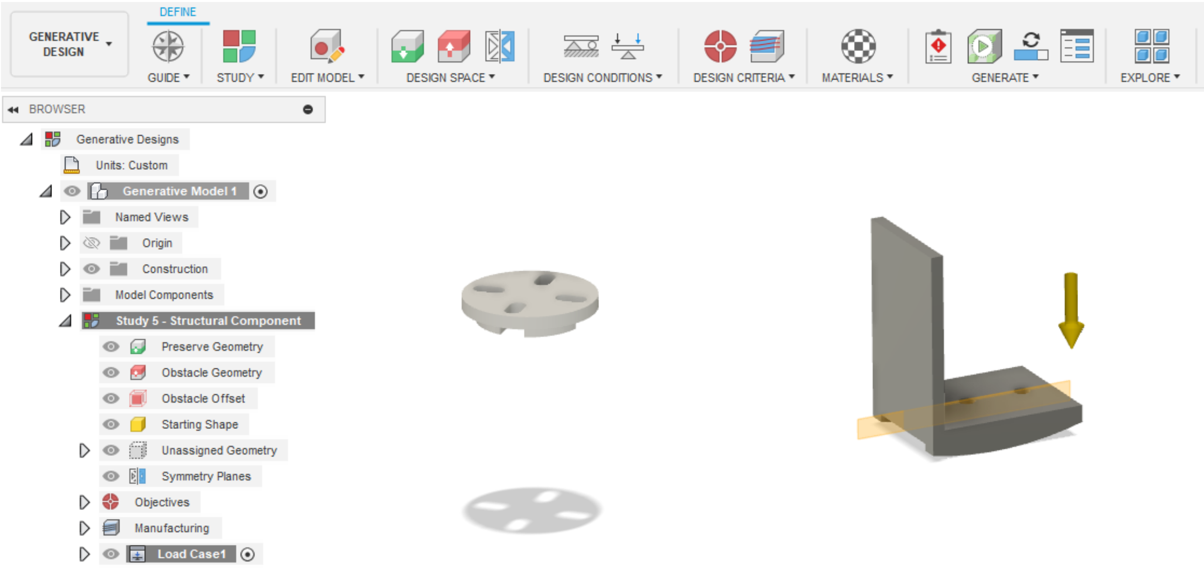


Fig. 4. UI of Generative Design Workspace

Click on Edit model tab to create required obstacle geometries. Remember the obstacle geometry designs made in edit model of generative design won't reflect in the actual design, it just stays in generative design workspace. Create some geometries around the preserved components using simple solid modelling same as in the design workspace as shown in Fig. 5 and Fig. 6. Then click on finish edit model to return to the generative design workspace.

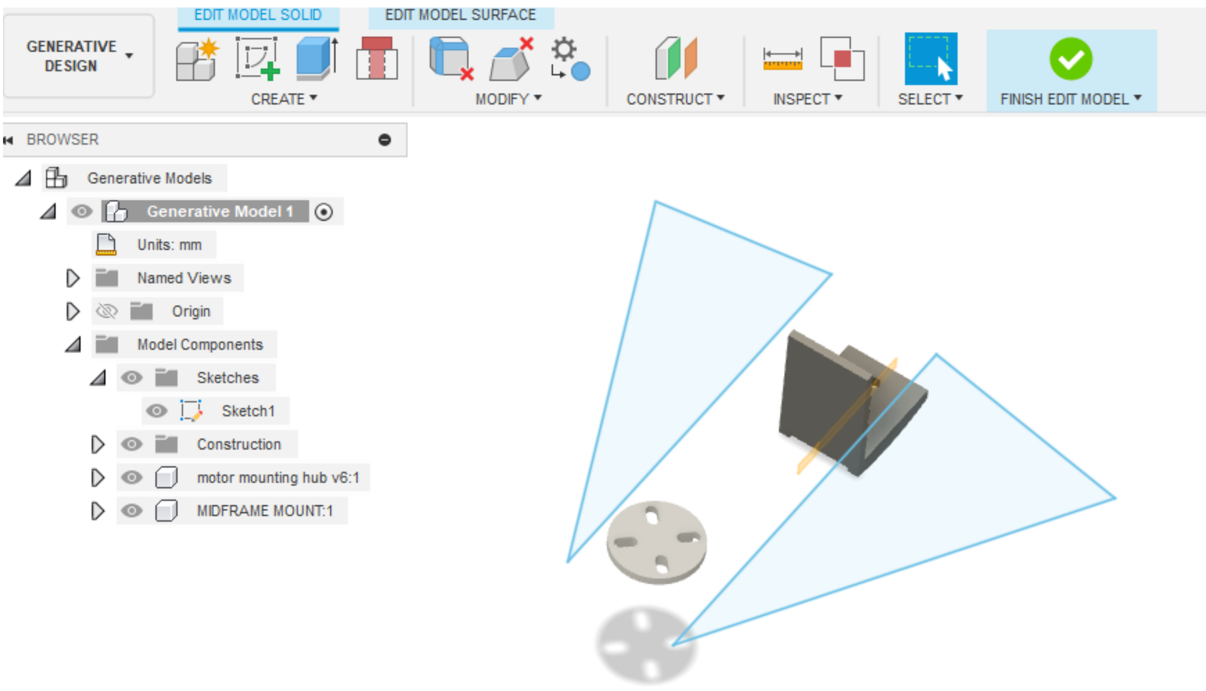


Fig. 5. Draw Sketches for Obstacle Geometries

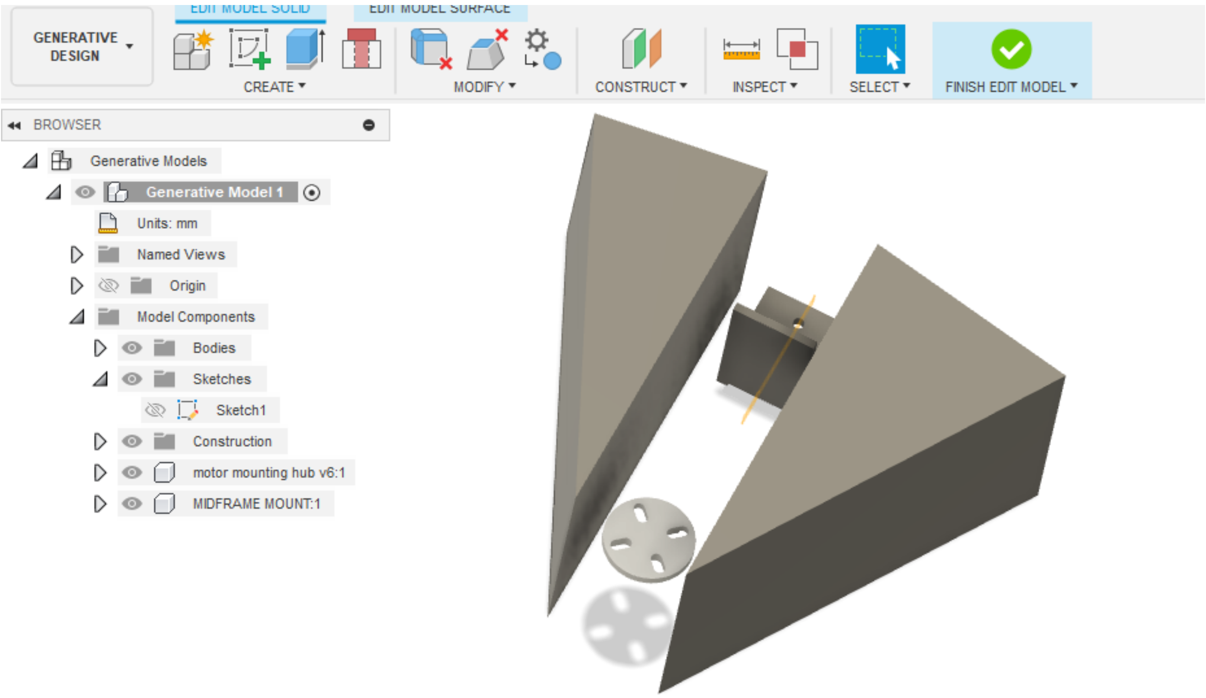


Fig. 6. Obstacle Geometry after Extruded from Sketch

Now click on green cube in design space tab as shown in Fig. 7 and select the mid-frame mount and motor mounting hub as preserve geometries and click on red cube and select two geometries around the preserved geometries as obstacle geometries.

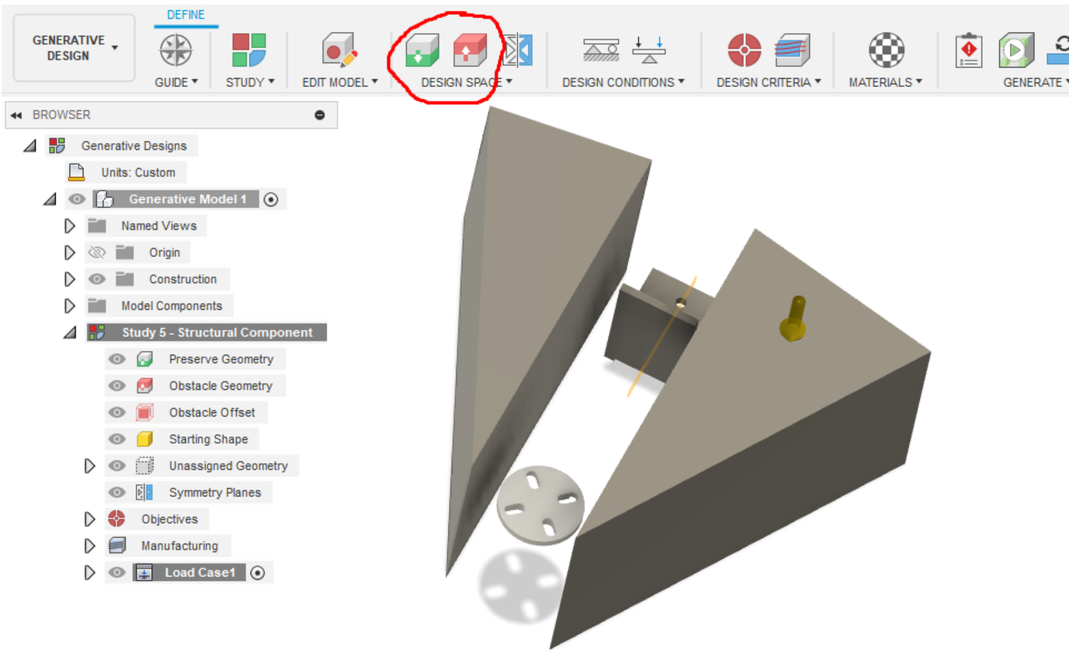


Fig. 7. Red mark shows location of Preserve and Obstacle Geometries Feature

Once the preserved and obstacle geometries are assigned as highlighted in Fig. 8, next step is to set the required design conditions.

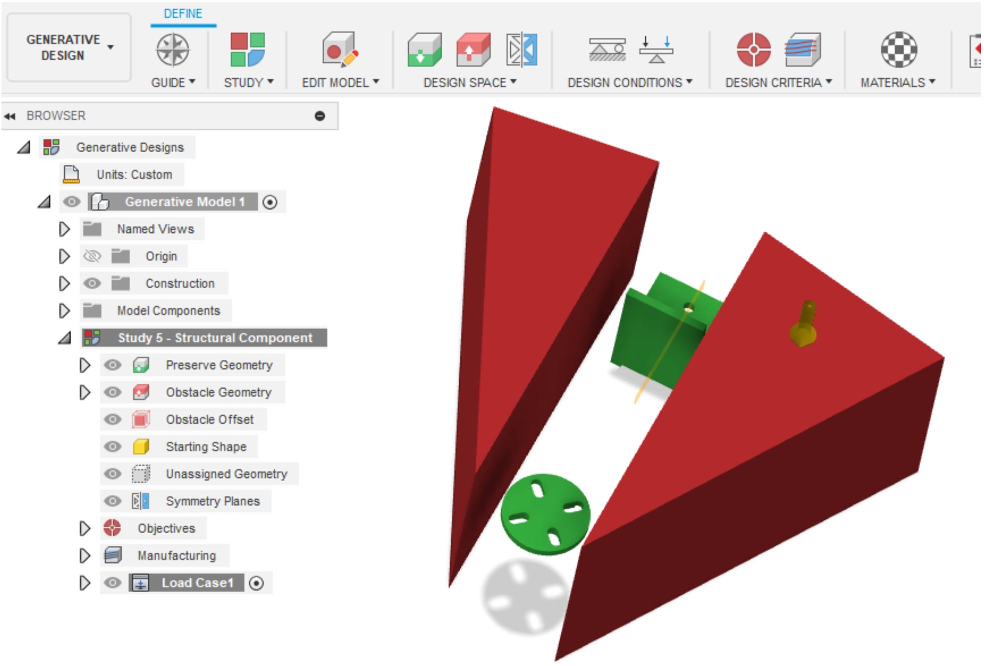


Fig. 8. After Assigning Preserve Geometry turn Green and Obstacle Geometries turns Red

Go to structural constraint under design conditions tab and click on the two faces of **Mid-frame mount** (our preserved geometry) and click ok to assign it as the fixed structural constraint as shown in Fig. 9.

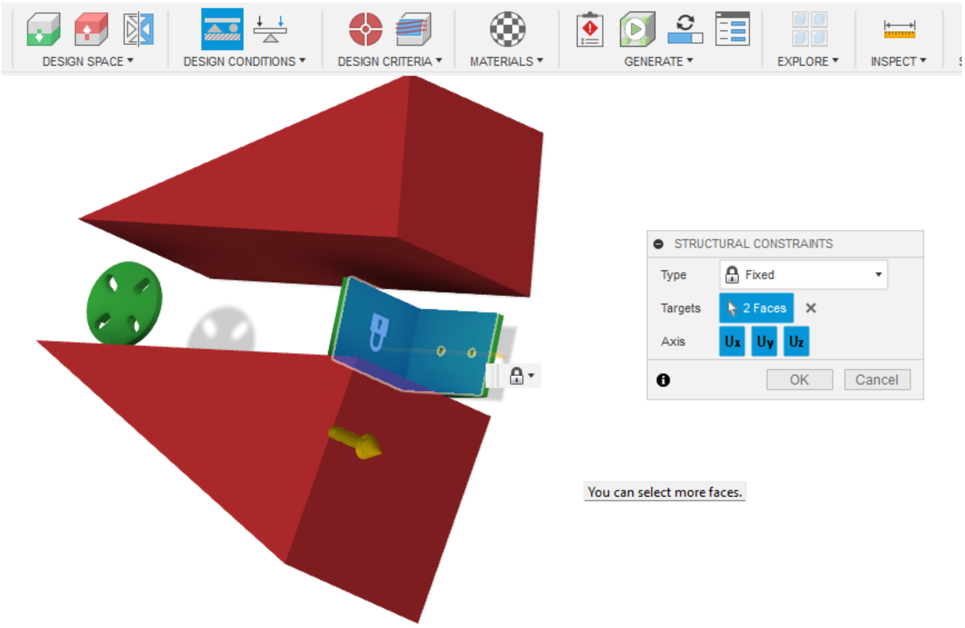


Fig. 9. Surfaces to be Selected for Fixed Constrain

Then assign structural loads by clicking on the top face of the motor mount hub. Assign magnitude of force 10 N as shown in Fig. 10, which will be around 1kg load and keep the rest of the settings as it is and click ok. The last design requirement is to assign the material for the design.

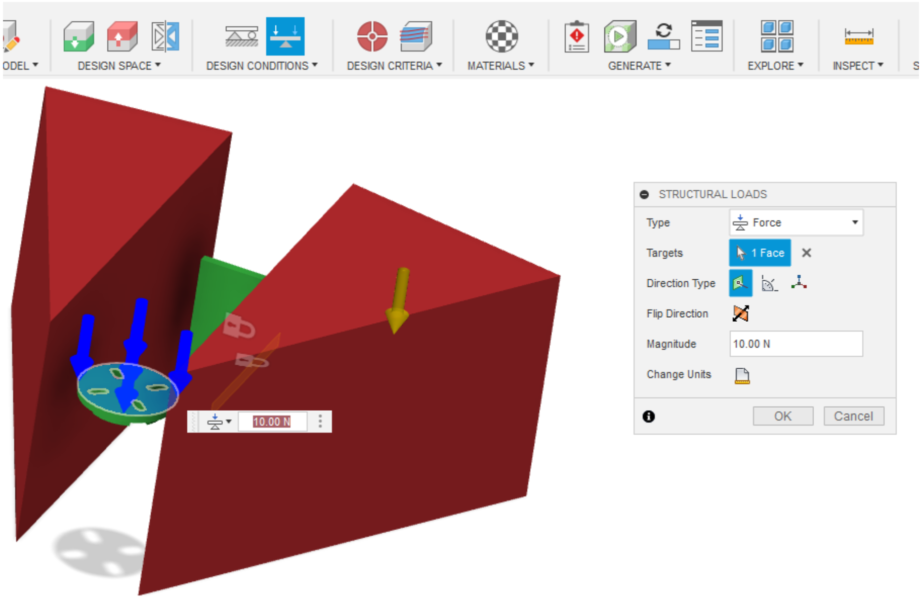


Fig. 10. Surface to be Selected for Structural Load

Click on materials and in study materials library, select Fusion material library from drop down menu. Then right click on ABS plastic (As PLA is not available in library) and click on add to all methods as shown in Fig. 11. Now, the model is ready for the generative design study to be executed in the cloud platform which will give various feasible designs based on the set design parameters and constraints.

NOTE: ABS material is selected as the study material even though the final 3D printing is to be done with PLA material as the PLA is stronger than ABS in temperature less than 50°C. So, the overall structure is going to be much stronger than what is designed by generative design.

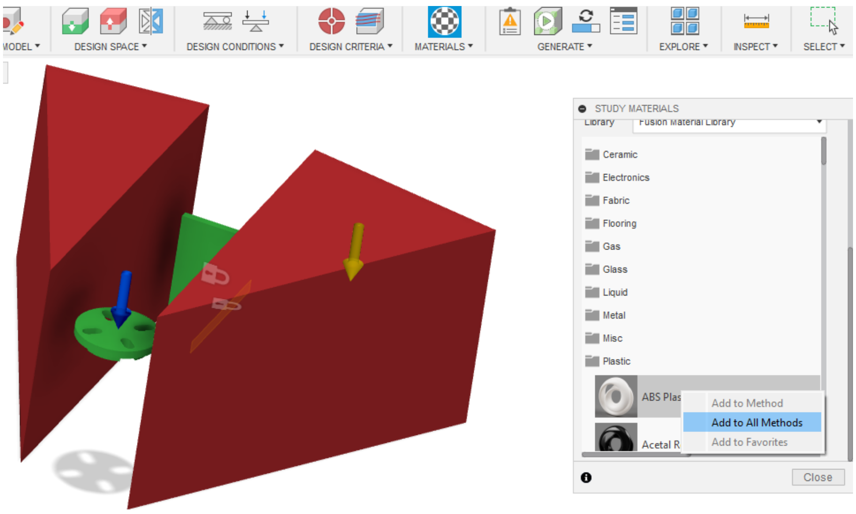


Fig. 11. Selecting the Material for the Study

The generative design study is initiated by clicking on generate option and then once the window as shown in Fig.12 shows up click on Generate 1 study and let it process, it will take around **10-15 mins** depending on the complexity of the study. An option will pop up saying **"Thumbnails for your outcomes will appear when they are processing"** just click ok and let it process. The user can close the Job status window or just drag it away to see the processing results.

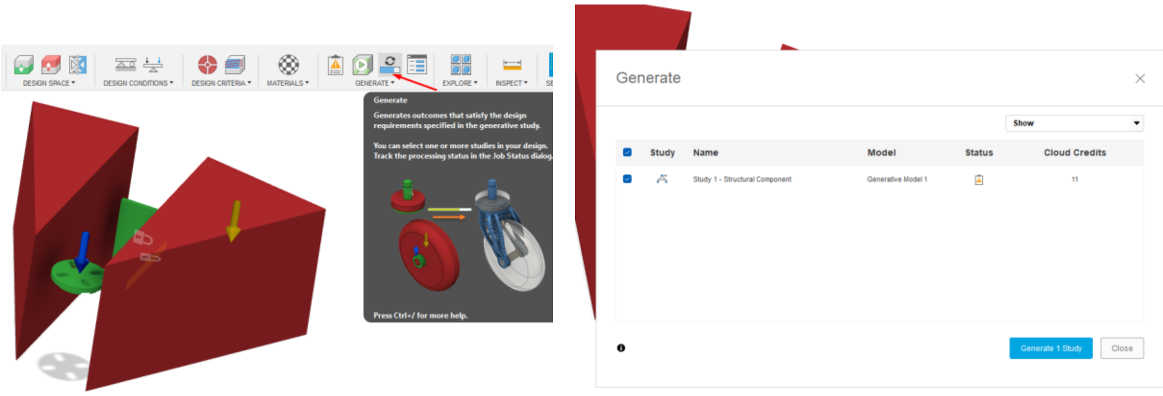


Fig. 12. Window showing Cloud Credits required for study to be processed, as a Student Licence you will have unlimited Cloud Credits

After the processing is done 3-4 designs will appear on the screen as shown in Fig. 13. Double click on a selection as per the user choice as shown in Fig. 14 and then click create design from the outcome and it will take another 1-2 min before it is ready for final modifications if any.

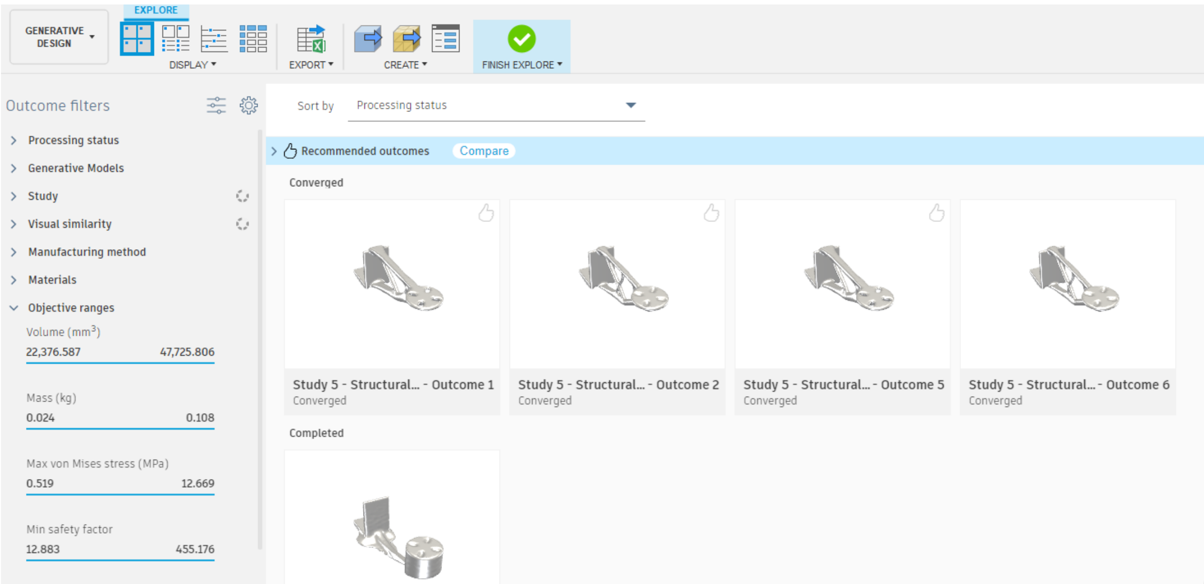


Fig. 13. UI of Generative Design study results after the Generations are completed

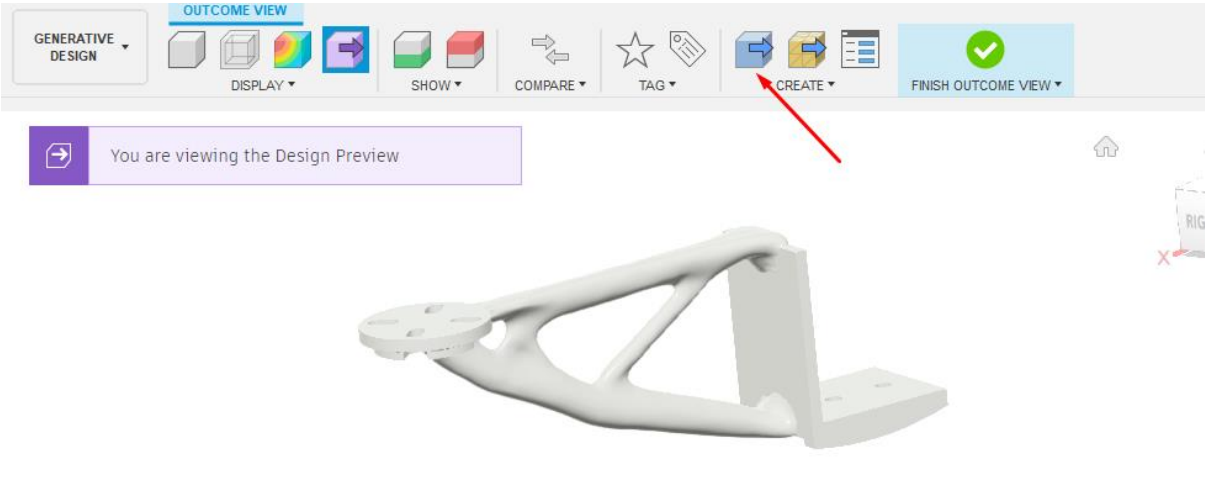


Fig. 14. Red arrow indicates option to convert the Generated Design into Regular Solid Body

For further modifications, click to continue and click on open design as shown in Fig. 15 and the design will open in the normal design workspace as shown in Fig. 16 and the final touches can be given by using normal solid modelling tools. Some of the finishing touches required are: mounting holes may need to be cut again; rough plan surfaces can be made smooth etc.

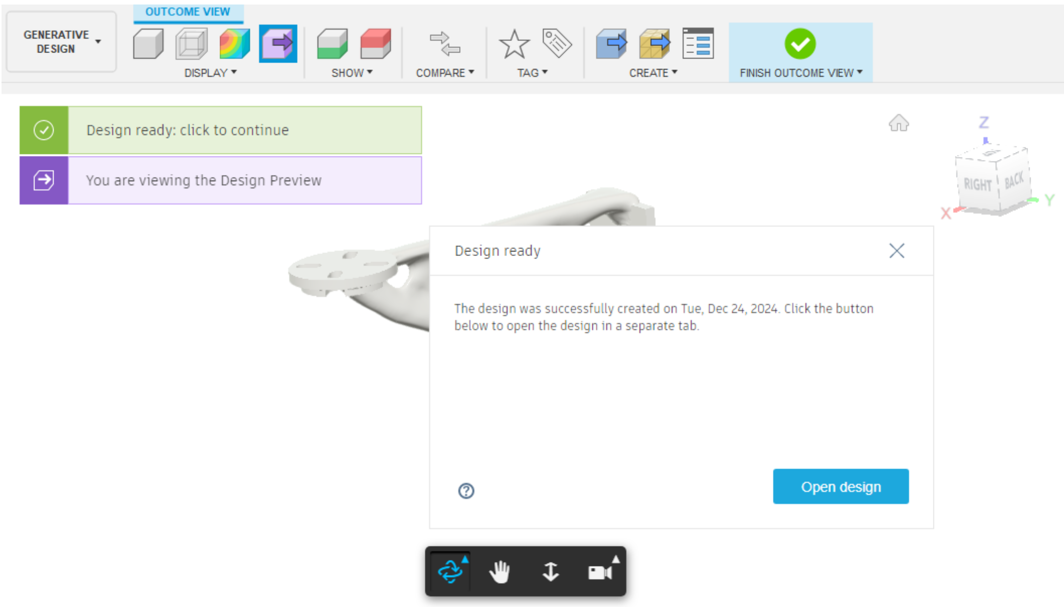


Fig. 15. When the processing is complete click Open Design

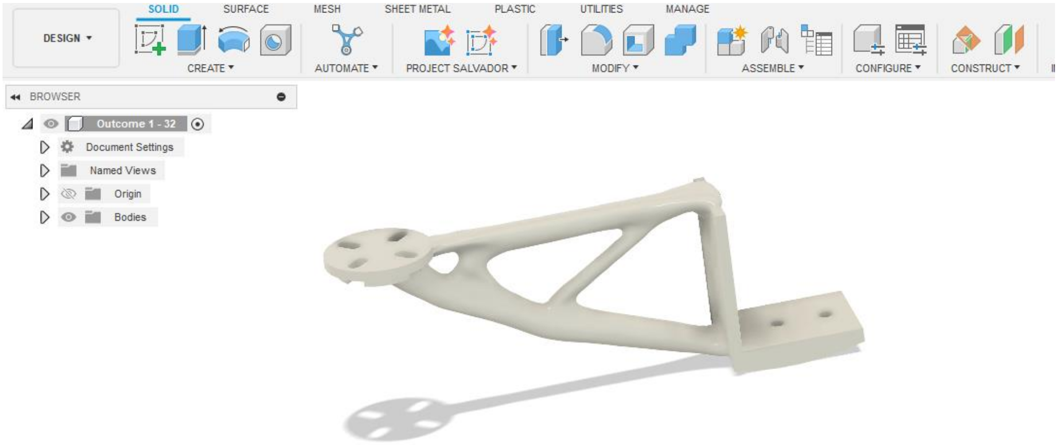


Fig. 16. Generated 3D Model of the Drone Frame Arm

Extra strength to mid-frame mount can be obtained by applying fillets at the intersection line of wall and mid-frame mount. Also providing ribs can add extra strength to the structure as well as reduce the overall flexibility. These modifications are illustrated in Fig. 17 and Fig. 18.

Fig. 17. Fillets for increased Strength at Intersection

Fig. 18. Ribs for Decreasing Flex in the Structure

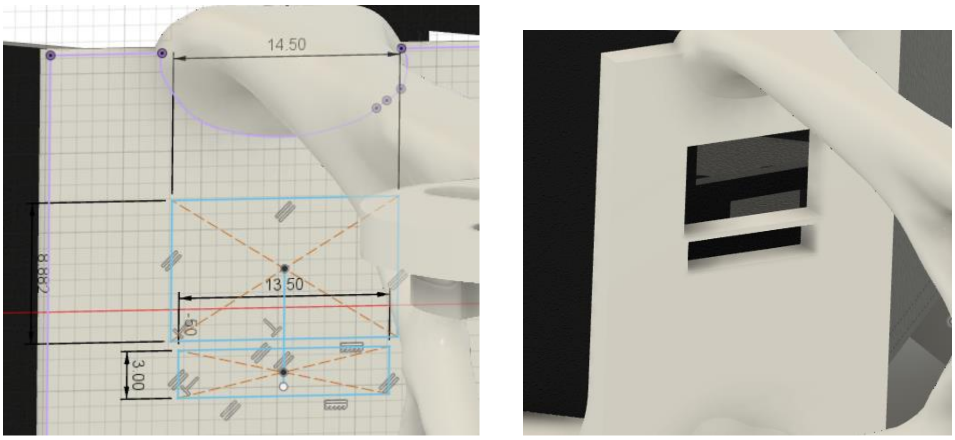


Fig. 19. Openings for the ESC's Signal and Power line (In latest PCB design the ESC power line's opening may have to be given from different end)

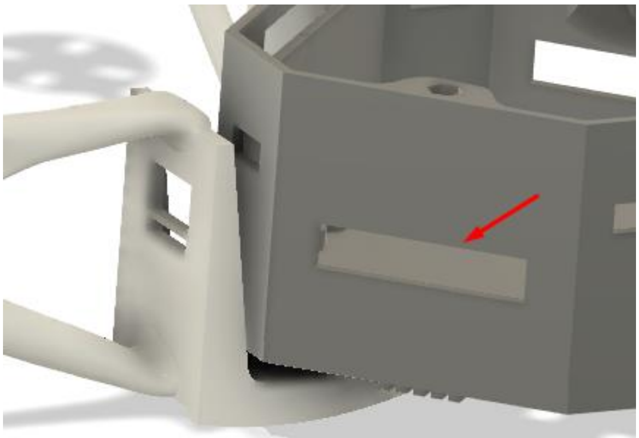


Fig. 20. Red arrow indicates opening for Latest PCB in Central Body

Now the arm is ready to be attached to the central body.

Central Body Frame Design

The central body is made in three parts for easy assembly. Part One is the base plate and other two are 3D printed parts, as coverings for the electronics. Initially import the PCB from easy EDA software to Fusion 360 workspace as seen in Fig. A.

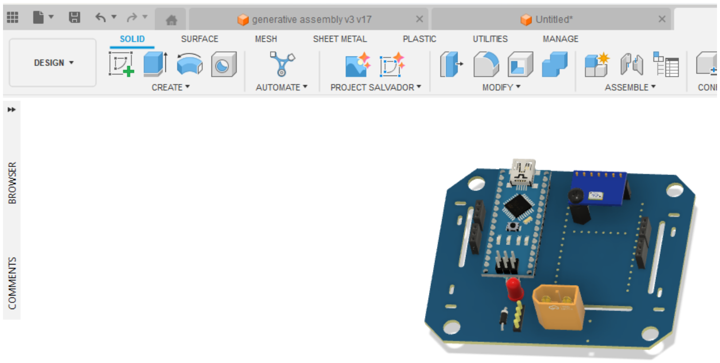


Fig. A. PCB after Importing into Fusion 360 from Easy EDA

Next step is to create the base plate, Select, create new component. Create a sketch and project the PCB. Now create an offset sketch around the boundary of PCB. Give an offset of 6mm as shown in Fig. B, at least, and extrude the sketch by 3mm to create the solid plate as shown in Fig. C.

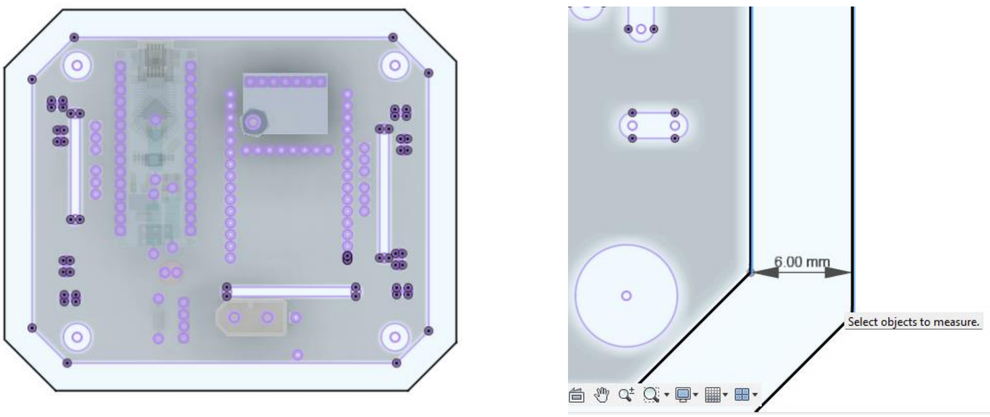


Fig. B. Sketch after Projecting the Outer Boundary and then Offsetting the it by 6mm

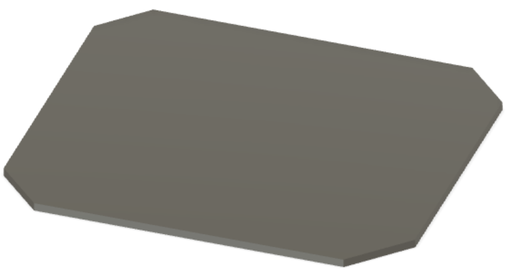


Fig. C. Base Plate after Extruding the Sketch by 3mm

Select the top face of the base plate, right click and create another sketch as shown in Fig. D. The openings for mounting the arms the drone PCB are created as the following. Take the centre point of the octagon and create a square (not rectangle, this is to create a plus configuration of the arms). The dimensions of the square may vary, just make sure that they are close to the boundary of the octagon. Then create two circles of 4 mm diameter on the square diagonals (the distance between them should match with the mounting holes in the mid-frame mount) and replicate them via circular pattern. Also project the 6 mm mounting holes from PCB and extrude all the circles, as operation cut, to create the opening as shown in Fig. D(a).

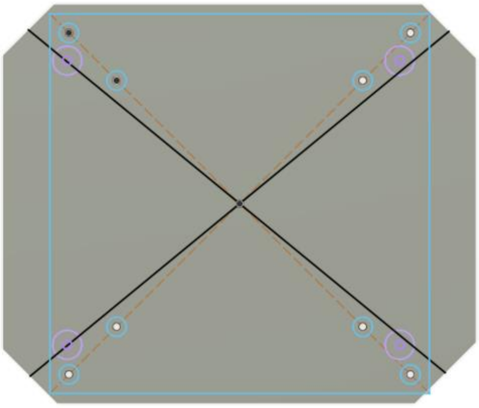


Fig. D. Sketch for creating Mounting Holes

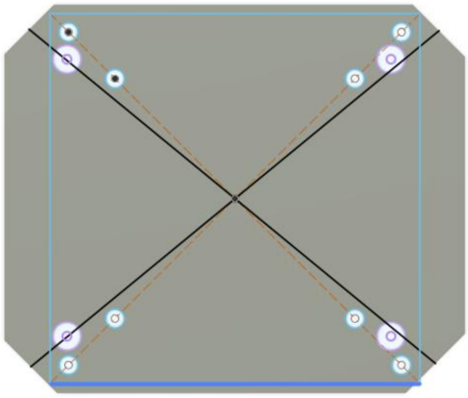


Fig. D(a). 3D model with Arms Mounting Holes

Now once again create a new sketch by selecting the top face. Give an offset of 2mm inside and create a centre line as shown in Fig. E(a). Extrude one-half of the sketch by around 43mm as shown in Fig. E(b).

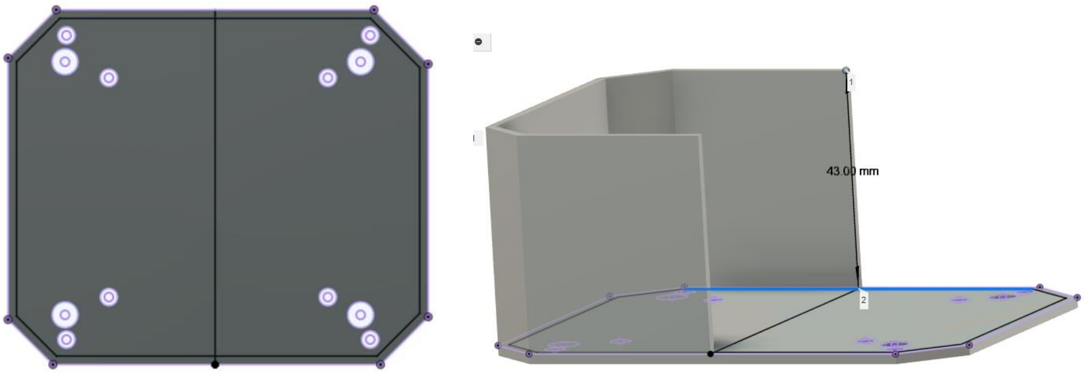


Fig. E(a). & E(b). Offset of 2mm for making the Cover walls and later Extruded by 43mm

Next is to make "**cover - base plate"** mounting point. Make a sketch similar to as shown in Fig. F1 and extrude it by 3.5 mm. This is to attach the 3M nut with internal threading to it so that it can be attached to the base plate with a screw. Make a 4 mm through hole for the screw as shown in Fig. F3 and mirror the entire thing about the symmetrical plane to make the mounting point for the opposite side as in Fig. F3.

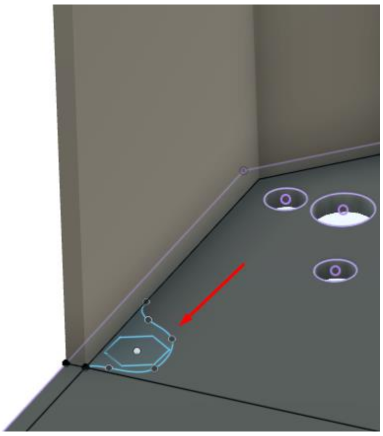


Fig. F1. Sketch for Making Mounting Point

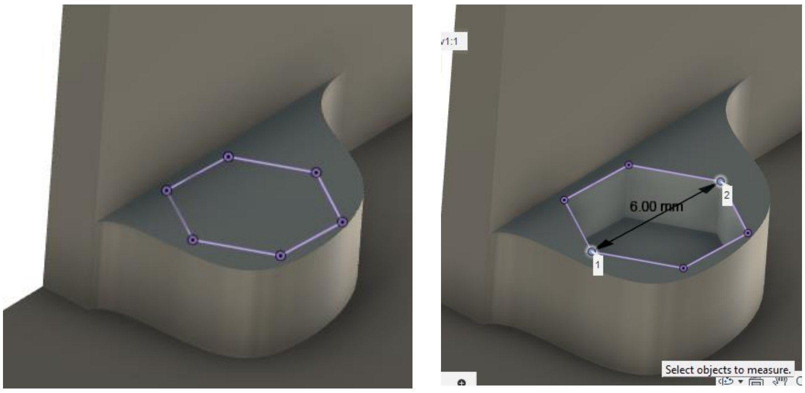


Fig. F2. Mounting point after Extruding the Sketch

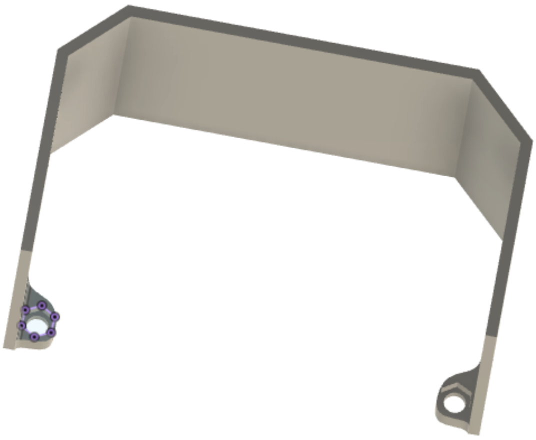


Fig. F3. Mounting points after Mirroring about the Symmetrical Plane

Next step is to create opening for the ESC power and signal line. Create a sketch as shown in Fig. G1 and extrude cut it as shown in Fig. G2 and similar to previous step mirror it as well.

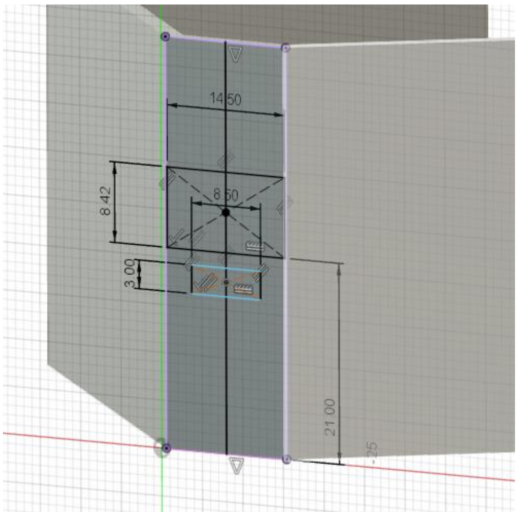


Fig. G1. Sketch for making opening for ESCs powerline, (In the latest circuit ESCs powerline opening may need to be made on other side for XT 30 connector)

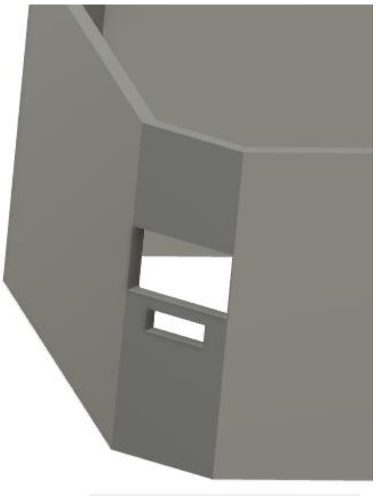
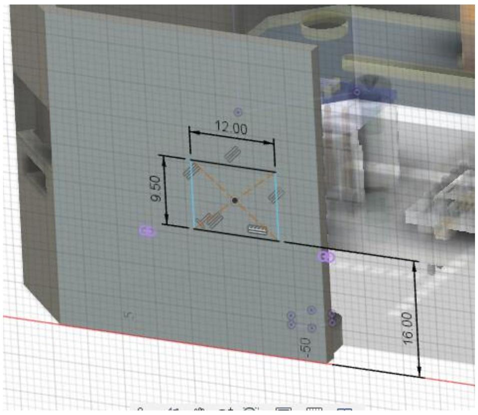


Fig. G2. Openings after being Extruded from the Sketch

Next we have to create openings for port. Create a sketch as shown in Fig. H1 and extrude as operation cut as seen in Fig. H2. Make sure to check the location of ports according to the placement of NANO/ ESP board CAD model.



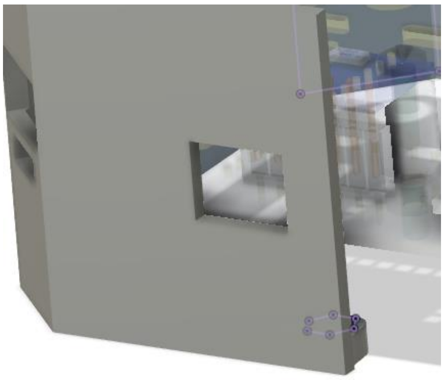


Fig. H1. Sketch for Nano/ESP32 USB port

Fig. H2. Port Opening

The last step is to create mounting point for top cover plate, as shown in Fig. I. The dimensions of the hexagon will stay similar to the previous step described for the base plate.

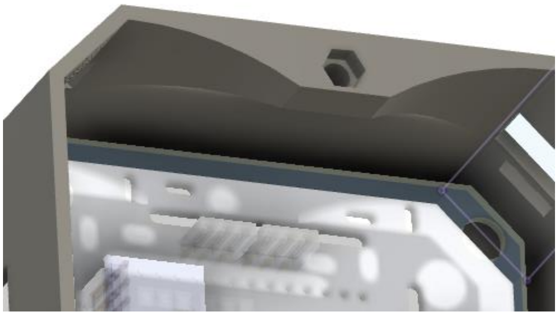


Fig. I. Mounting point for the Top Plate

The finished part is shown in Fig. J, after 3D printing and attaching the nuts at locations indicated by red arrows.

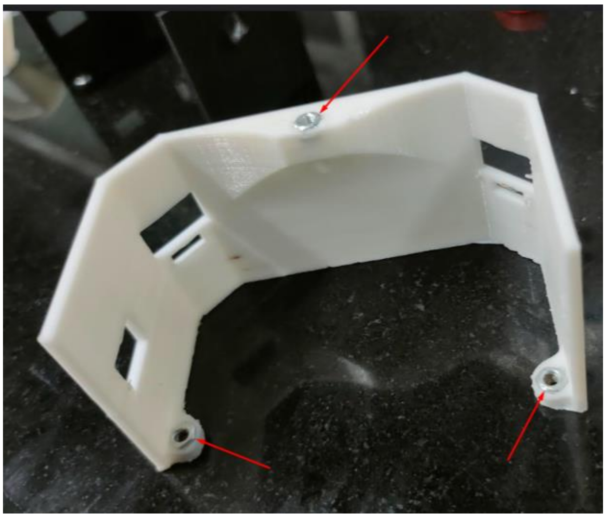


Fig. J. 1 3D printed model after Attached with the 3M nuts at the mounting points

One last step is remaining i.e to create the holes in our base plate for the bottom nuts shown in Fig. J. Project the holes of the bottom nuts and extrude cut them as shown in Fig. K.

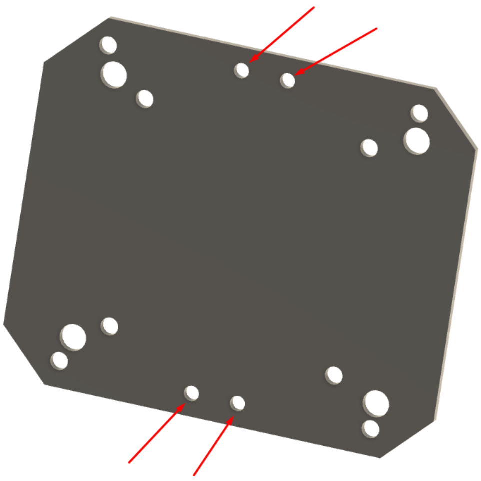


Fig. K. Red arrows showing the Openings for Mounting the Cover Walls

Create ribs structure to reduce the flexibility in base plate (Fig. L). Make sure to leave enough space between screw openings and covering. After all the assembly, the completed Central body is shown in Fig. M/N.

Fig. L. Ribs Structure to Reduce flex in the Base Plate

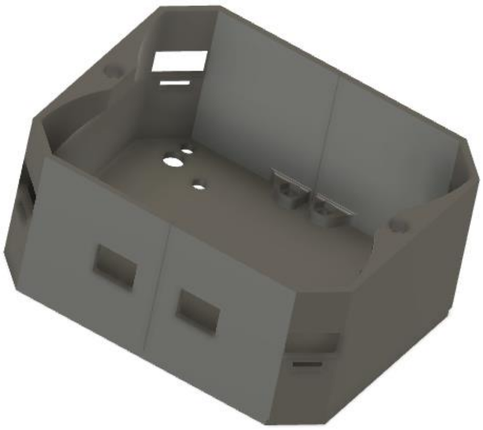


Fig. M. CAD model of complete Central Body of Drone Frame

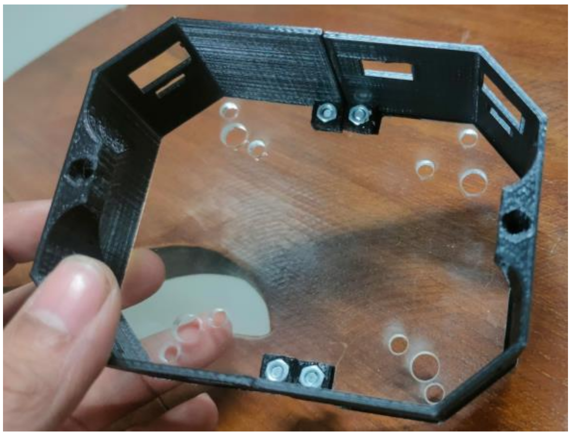


Fig. N. Central body after Being manufactured

Landing Gear Design

The design of the landing gear is such that it should support the drone's weight and its impact on landing. Some examples of landing gear designs are shown in Fig. 21 and Fig. 22a, 22b.

Fig. 21. Landing Gear with Strong Ribs for better Impact Protection

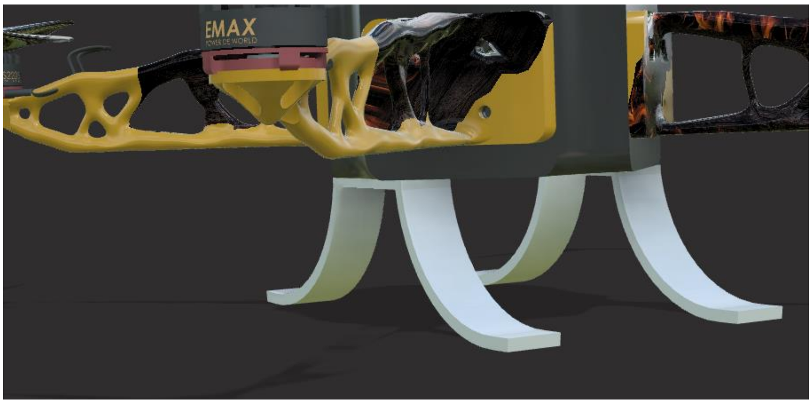


Fig. 22a. Landing Gear with inbuilt spring effect

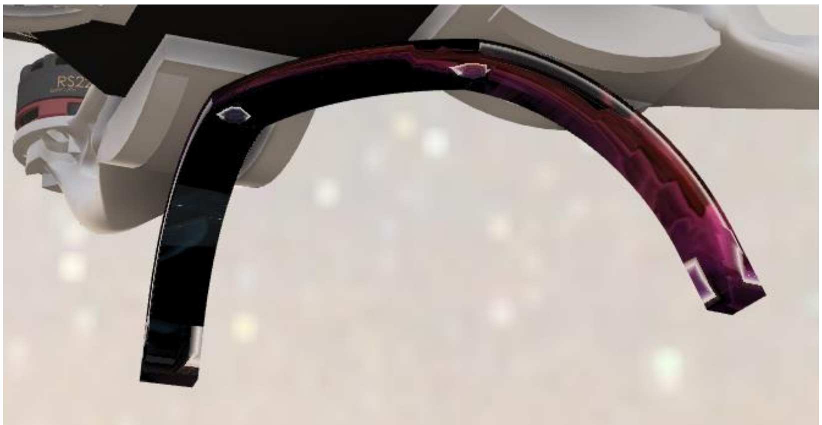


Fig. 22b. Landing Gear made by 3D sketch

Assembly

Now for the assembly of parts, it is recommended to use 3mm screw of **18mm** length, and the thickness of mid-frame mount, arm and base plate are chosen, based on the required strength safety factor.

For horizontal mid-frame mount, keep the thickness of the part around 5mm, for the Landing gear the thickness of mounting part should be 3mm maximum and the base plate which will have thickness of 3mm as shown in Fig. 23. Thickness values are arrived at based on simulation study.

Fig. 23. Showing Cross Section of Base plate- arm- Landing gear, arranged one over the other

Tentative time required for 3D printing for all the components

Make sure the project planning is done properly keeping in mind the time required for getting the parts printed.

The parts can be given to 3D print in 2 batches, details are shown in Fig. 24 and Fig. 25

- Batch 1- All the 4 Arms: Material consumption 80gms, Time required ~11 hrs

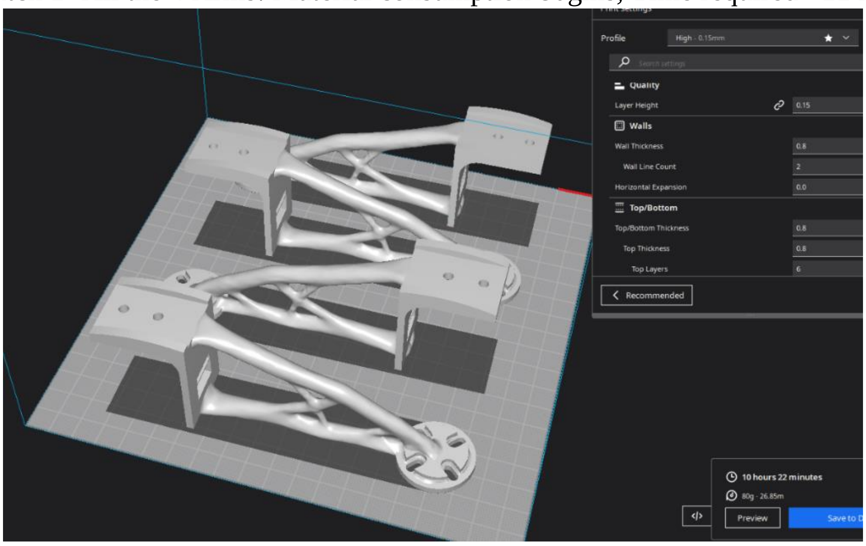


Fig. 24. Batch 1-Printing the 4 Arms of the Drone Frame

- Batch 2- Two landing gears, Base plate, two coverings (with proper arrangement on virtual build plate). Material consumption- 80gms, Time- ~10 hrs

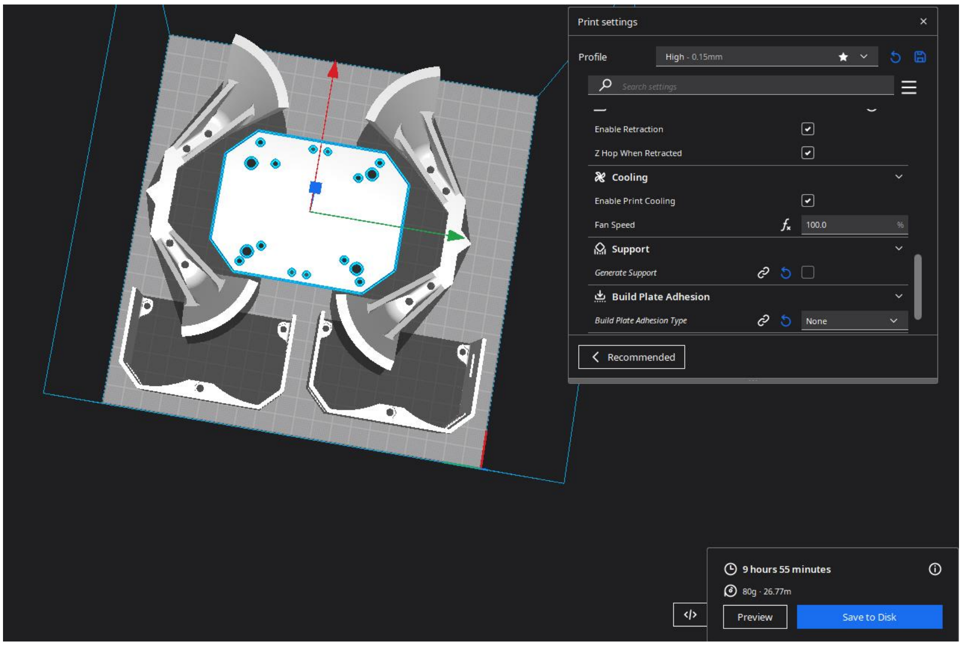


Fig. 25. Batch 2- Printing Frame Components

Make sure to arrange the components properly on build plate as shown for accommodating components on single build plate.

Stress-Strain Analysis of the Designed Part

The stress-strain analysis is a process done before finalizing the design for manufacturing. The design is subjected to the virtual loads and the system calculated the strains and stresses on the part based on the constraints given. This process can be initiated by selecting the simulation environment located in the top left drop down menu as shown in Fig. 26 (Similar to generative design).

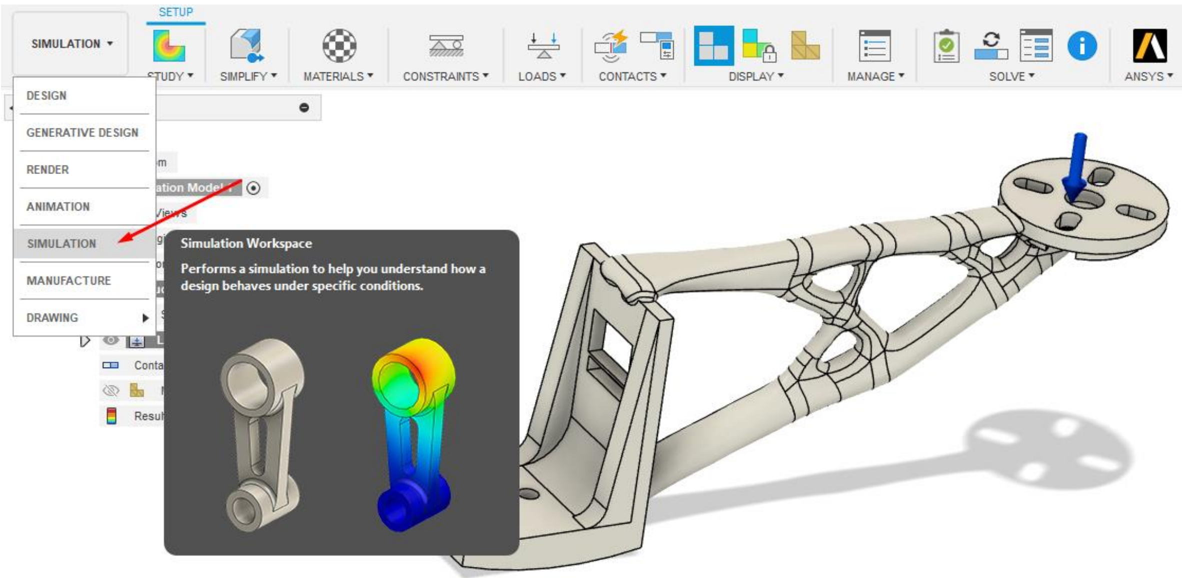


Fig. 26. Stress analysis Environment in Fusion 360

Once the new study is created, structural constrains are to be set. The material need not to be selected again as it was already selected during generative design. Click on constrain tab and select the base surface as fixed point and click ok as shown in Fig. 27. Then, set 10 N force on the motor mount hub in – Z direction as shown in Fig. 28.

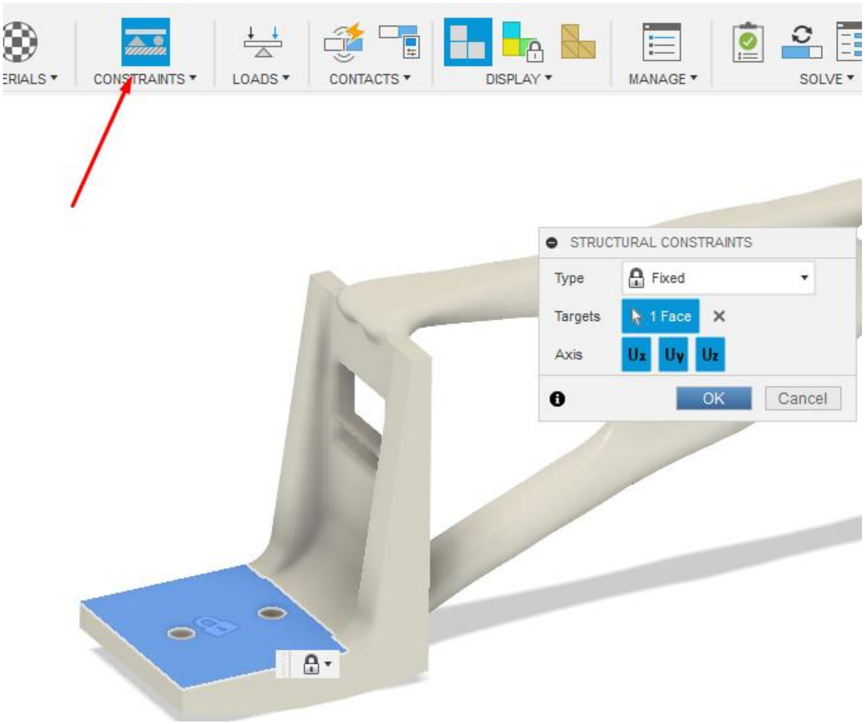


Fig. 27. The shaded surface will be the fixed point for our study

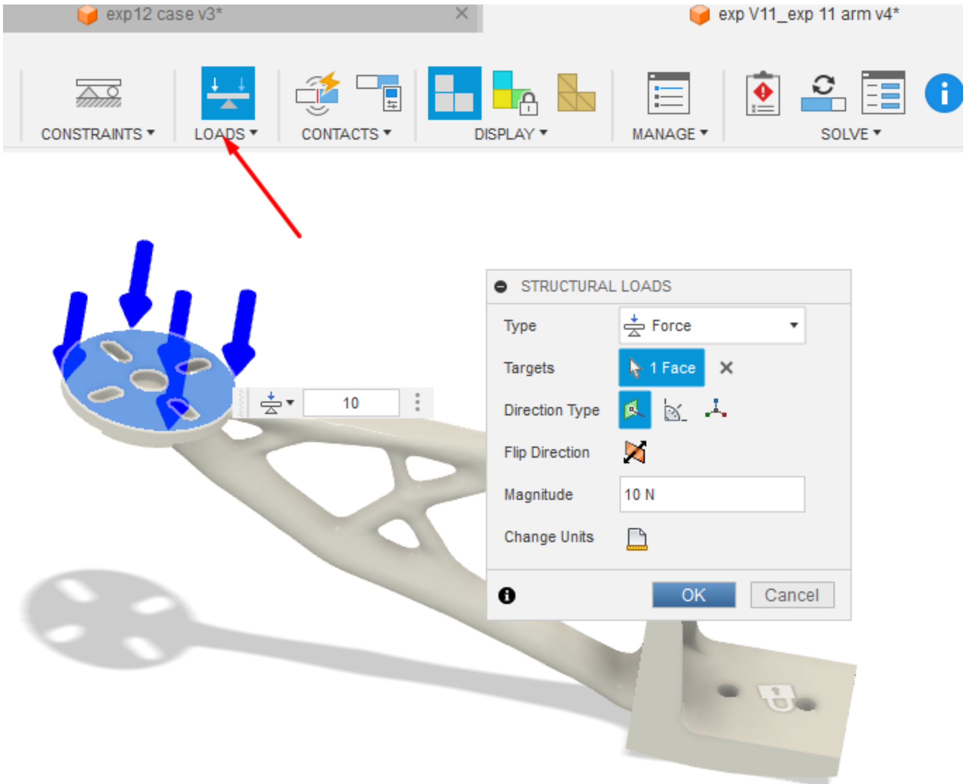


Fig. 28. 10N Force which translates to 1KG to be applied on Motor Mount Surface

Initially, the meshing is set to default setting as shown in Fig. 29. If the study requires more precision the meshing can be easily changed to finer. Remember finer mesh will take more time to process. But for most of the cases, the default setting is found to be enough. Click on solve to initiate cloud processing of the study. The screenshot of the same is shown in Fig. 30.

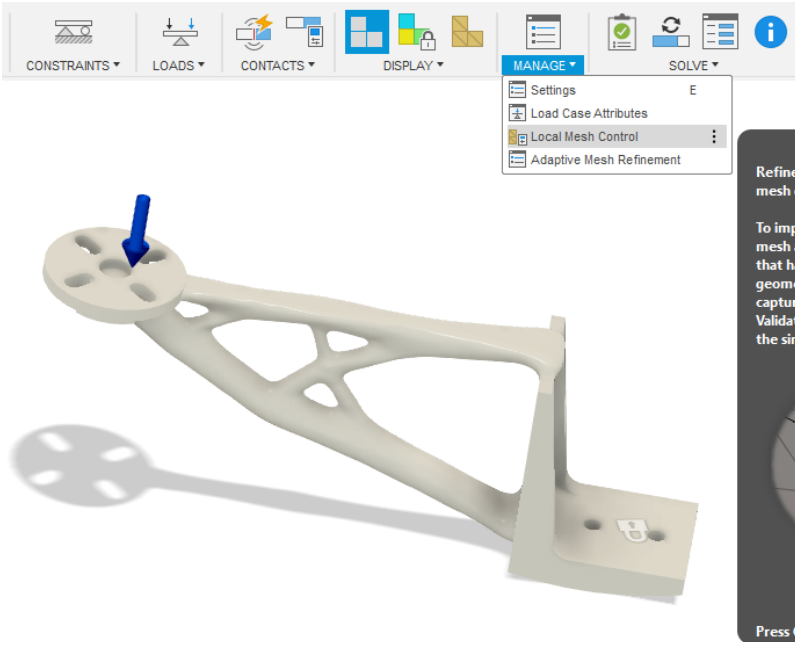


Fig. 29. Setting for Controlling Meshing Parameters

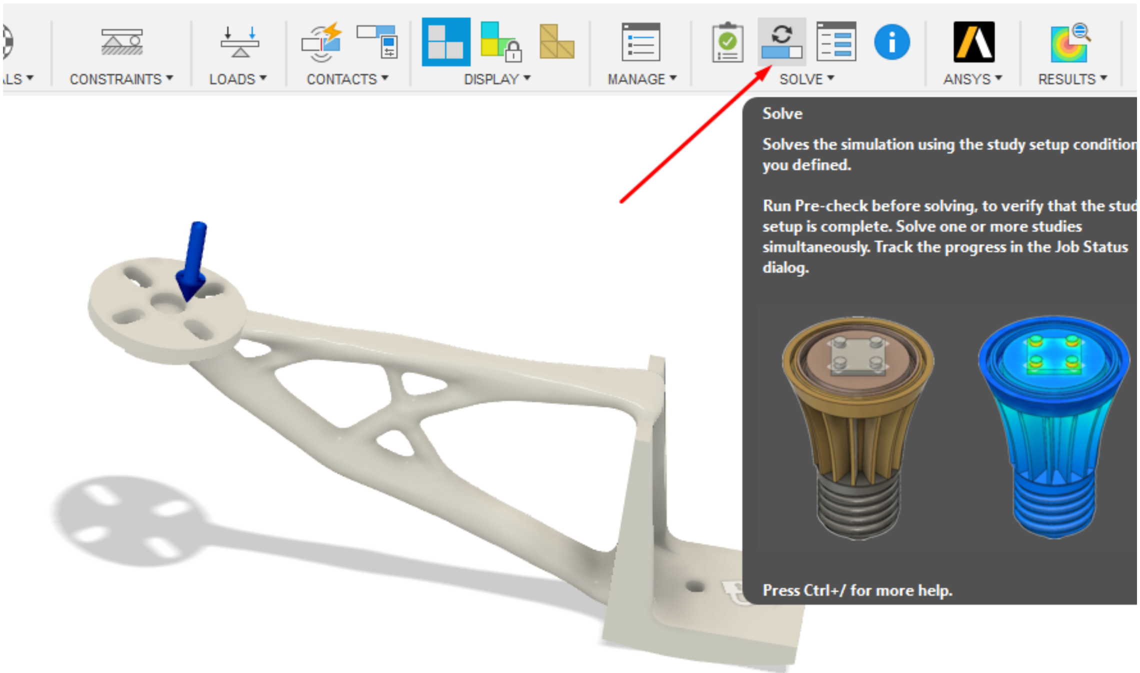


Fig. 30. Red arrow shows option to send the study for Solving

After the processing is completed, the screen shot of the UI is shown in Fig. 31. Just select stress from the drop down menu to locate the point which has the maximum stress.

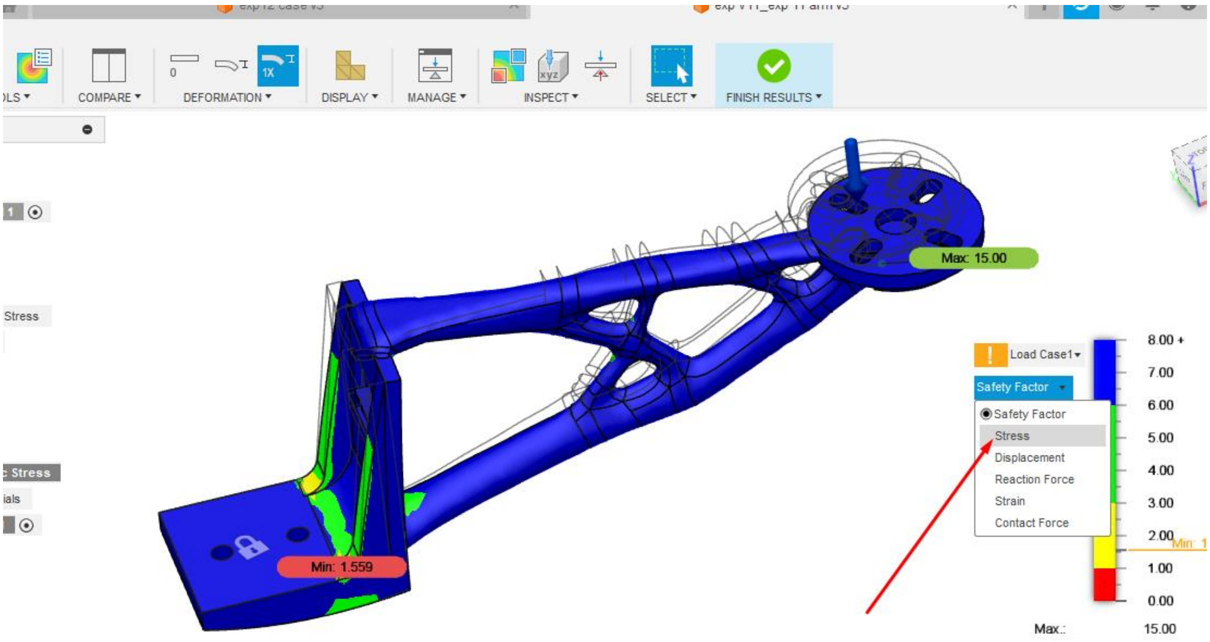


Fig. 31. After the study have solved we can see coloured structures over model showing different Stress and Strain Areas

For example, Fig. 32 shows, max stress as 12.88Mpa and the yield strength of ABS is 20Mpa. Which gives a safety factor of around 1.5. For ABS plastic the designed safety factor would be in the range of 1.5 to 2.0.

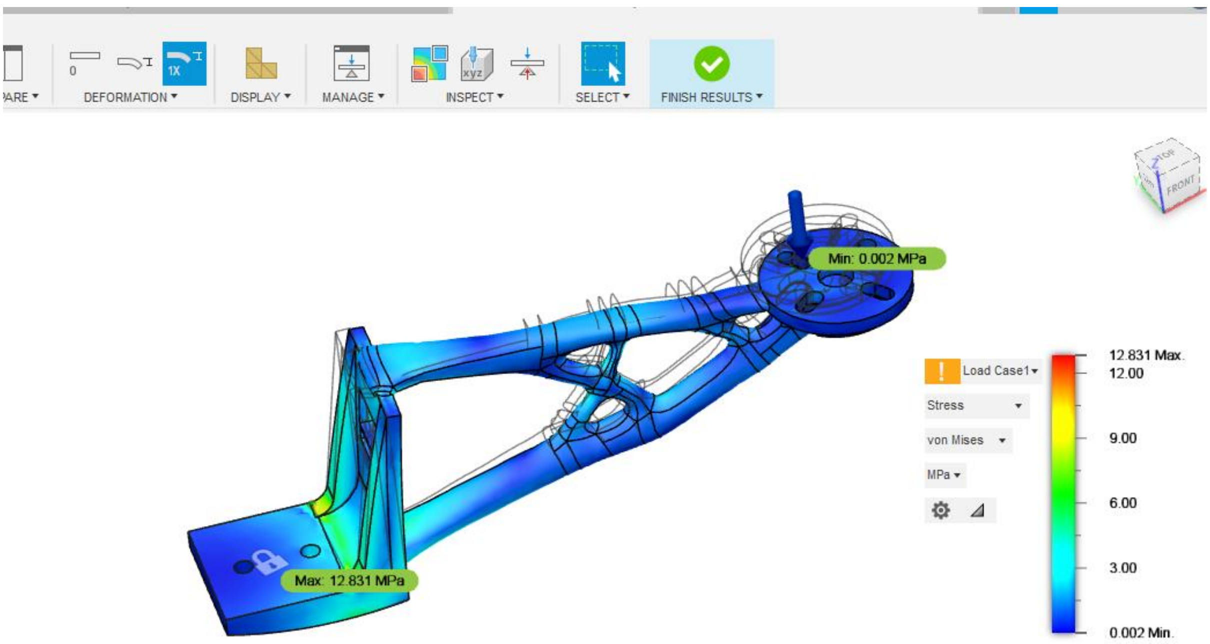


Fig. 32. Colourful Representation of Von Mises Stress on Generated Arm

Overall deformation and various other parameters can also be obtained from the study output as seen in Fig. 33. But the main goal is to keep the safety factor above 1.5.

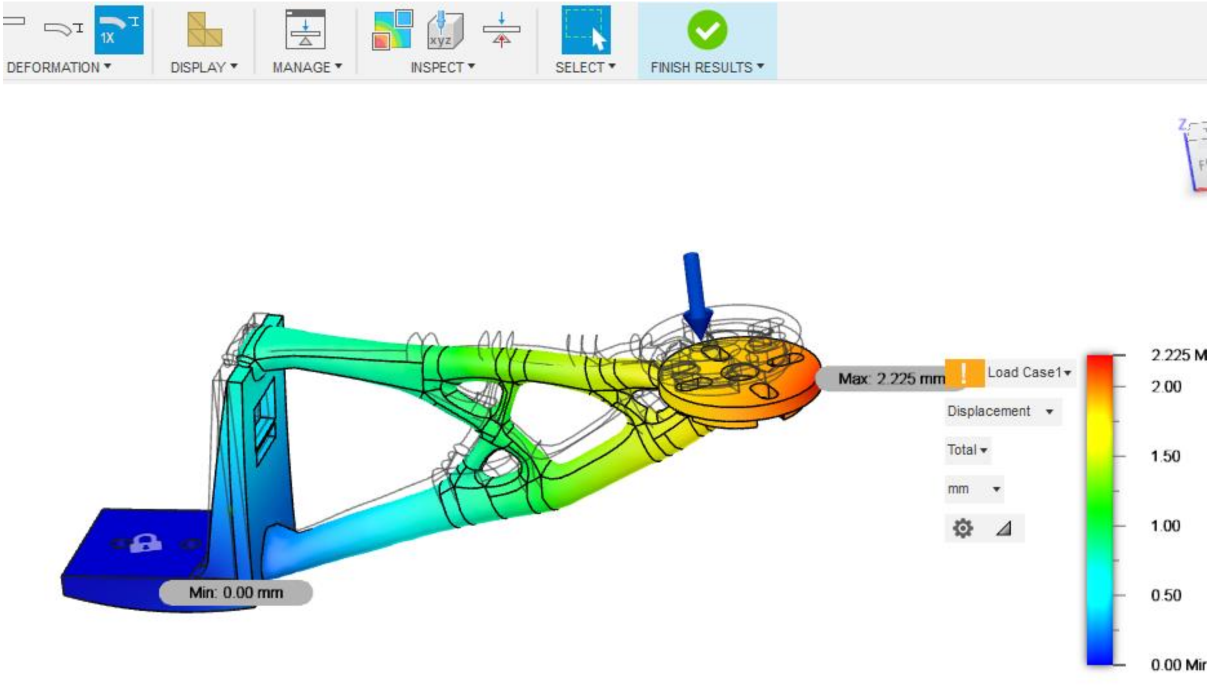


Fig.33. Colourful representation of Deformation occurred due to Virtual Stress on Generated Arm

Components Assembly

For the assembly M3 nuts and screw are to be used (3mm diameter) to screw two parts together. Two types of M3 screw will be required to make the assembly, short one (6mm length) and longer one (18-25mm length).

For most of the assembly the short M3 screws can be used. Longer M3 screw will be used for the assembly of landing gear, arm, and base plate together. So, make sure to keep the distance between the two mounting holes same in all the three parts (in this example it is 14mm Fig. 35).

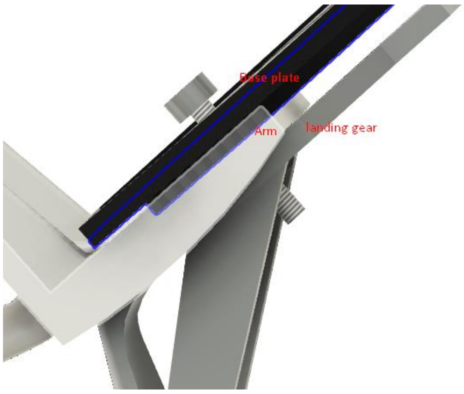


Fig. 34. Cross section of Base plate- Arm- Landing Gear, arranged on Top of Each other

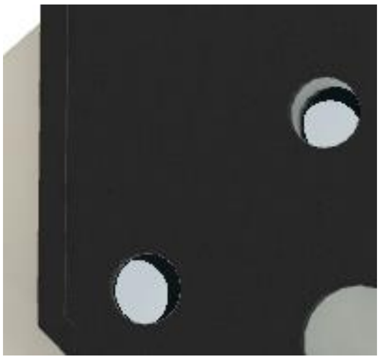


Fig.35. Two Mounting Holes for Arms placed at Distance of 14mm from Each other

For simplified assembly give hexagonal cavity in the landing gear mounting holes as shown in Fig. 36, and lock nuts will be used instead of normal nuts. For normal nuts use 6mm as the dia and 5.8mm for lock nuts.

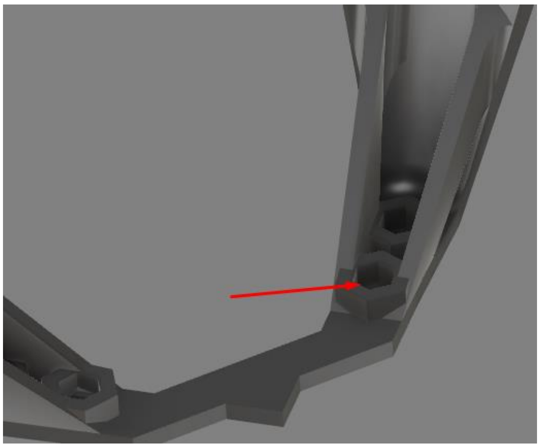


Fig. 36. Red Arrow showing the Hexagonal Cavity made to inset Lock Nuts

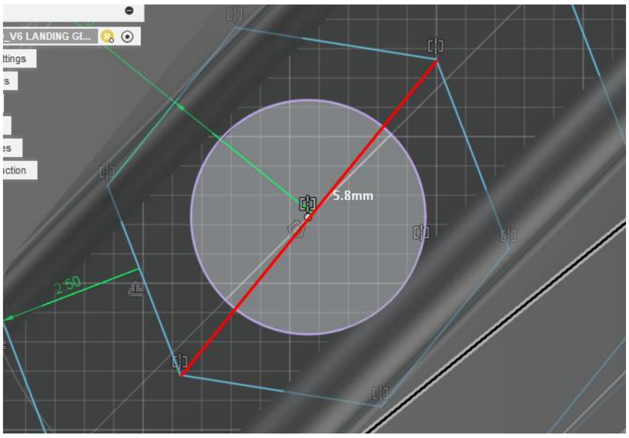


Fig. 37. Sketch of Hexagonal Cavity, with Vertex to Vertex Distance 5.8mm

Note: A little heating may required during inserting the nut in desired slot. A soldering iron can be used in this case to heat the PLA material and expand the cavity. If the nut is loosely fit in the cavity use superglue to stick it.

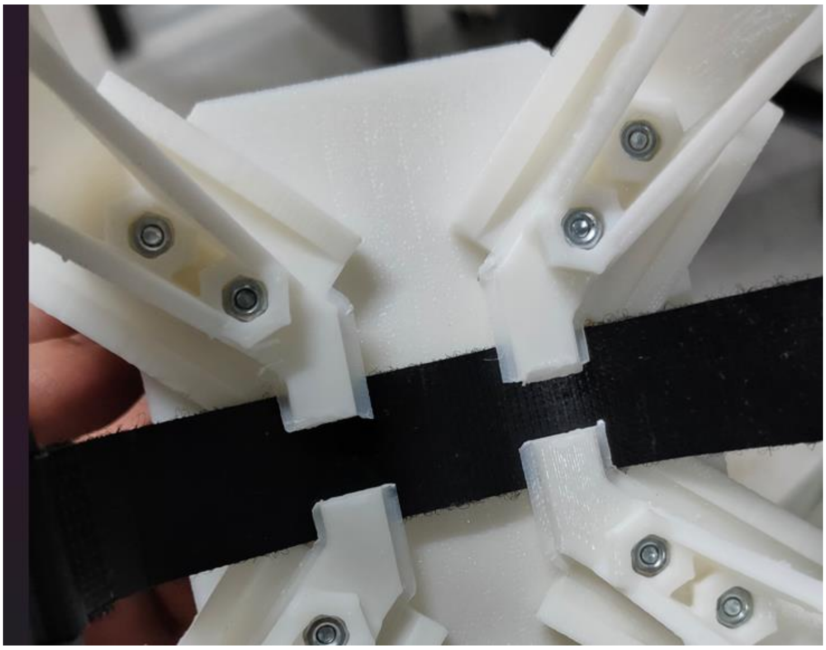


Fig. 38. Assembly after Attaching Baseplate- Arms- Landing Gears together using 3M Screw

The assembly looks as similar to the one shown in Fig. 38. The gap between the landing gear and the base plate may act like a place to insert Battery strap, else a dedicated battery strap holder may require to be designed and 3D printed. Don't forget to give the hole in middle of the motor mount Hub as shown in Fig. 39, as some motors may have a bit of extended shaft.

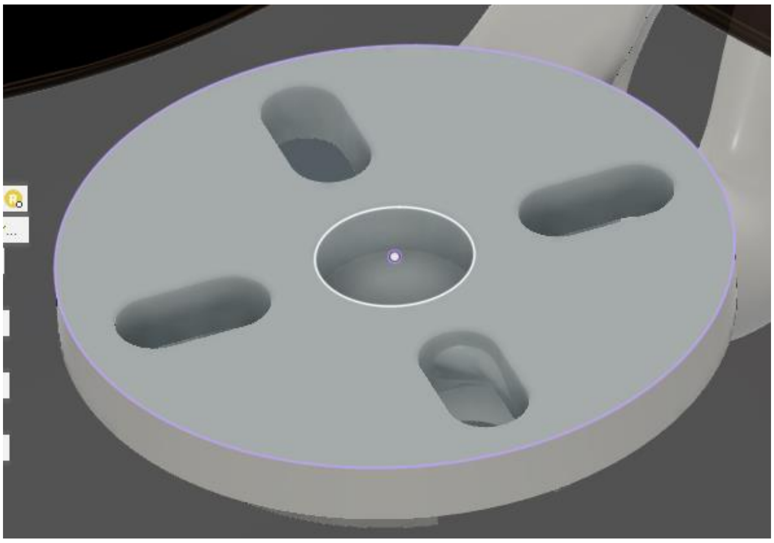


Fig. 39. Hole in Middle of the Motor Mount Hub

The overall finished assembly of frame may look something similar to Fig. 40, Fig. 41, Fig. 42 and Fig. 43. Figure 44 shows the completed drone assembly without the central covers.

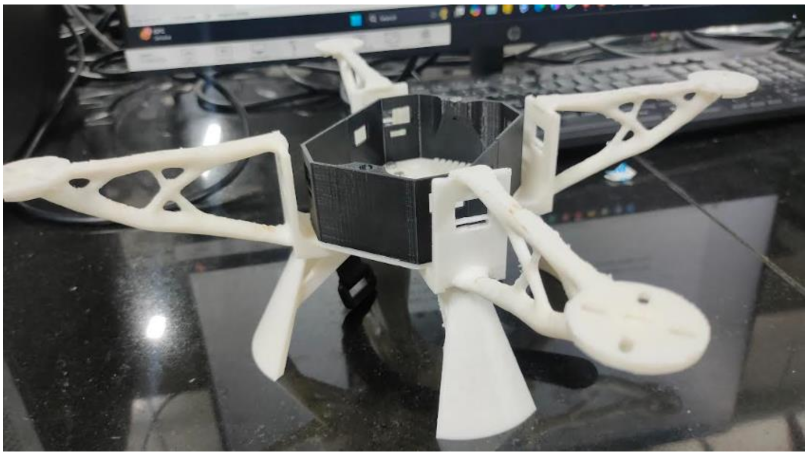


Fig. 40. Side view of Complete Manufactured Drone Frame

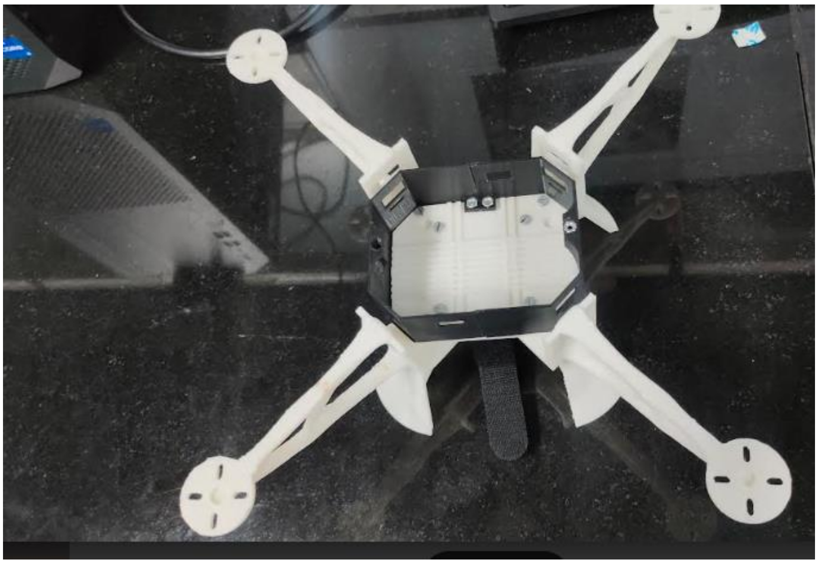


Fig. 41. Top View of Complete Manufactured Drone Frame

Fig. 42. Bottom view of Complete Manufactured Drone Frame

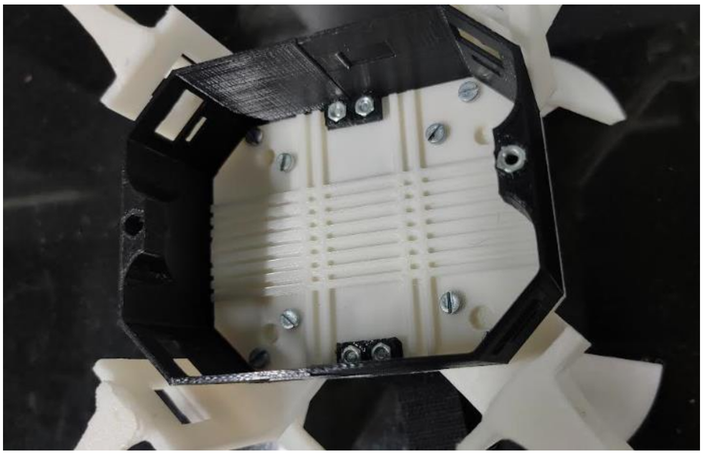


Fig. 43.

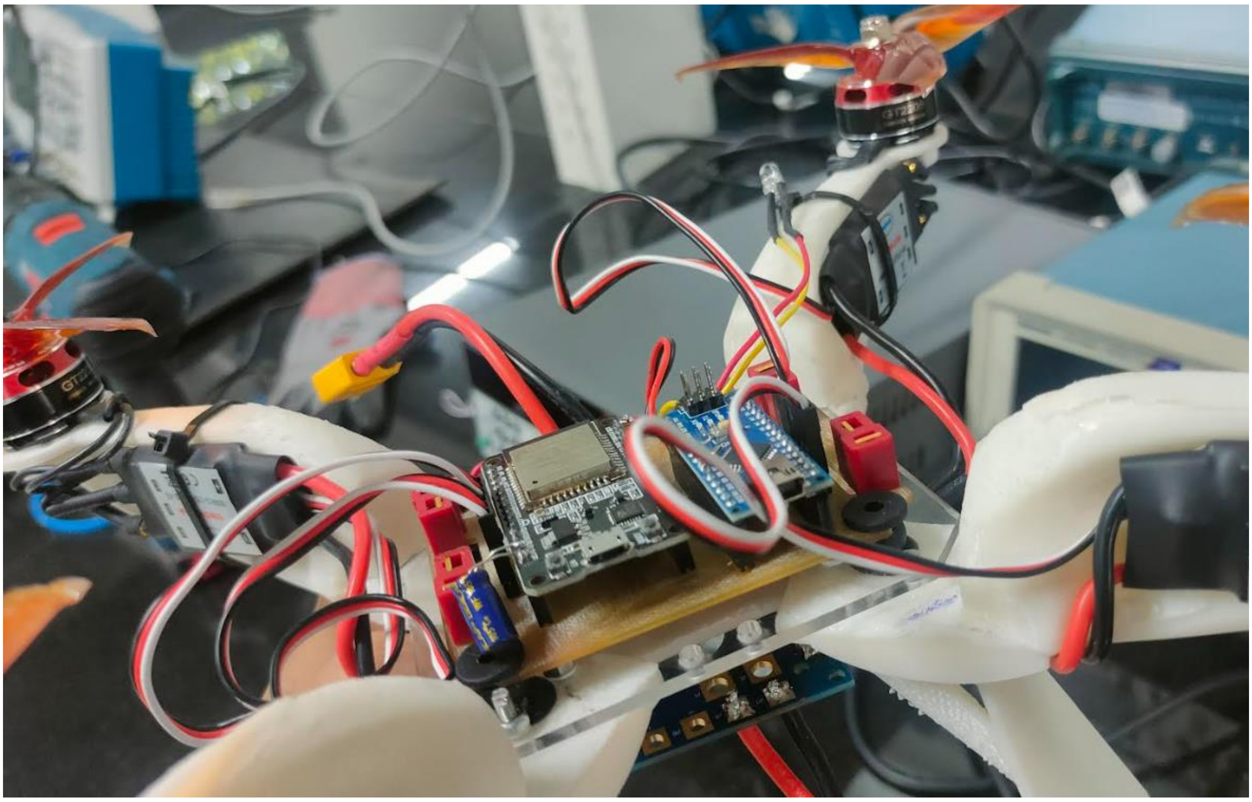


Fig. 44. Complete Drone Assembly, with Arms with Motors, Propellers and Electronic Components without the central Cover

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We, the authors, would like to express our sincere gratitude to the management of the Makerspace for giving us the opportunity to be part of the Makerspace, an innovative learning environment.

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