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PAAT

http://penerbit.uthm.edu.my/ojs/index.php/paat
e-ISSN: 2821-2924

Progress in Aerospace and Aviation Technology

Weight Reduction of C-Drone Body Structure

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DOI: https://doi.org/10.30880/paat.2023.03.01.005
Received 27 March 2023; Accepted 21 June 2023; Available online 31 July 2023

Abstract: UTHM has successfully developed a high payload cargo drone, namely the C-Drone, with a weight of over 400 kg. Although this drone has successfully passed the hovering test, it is believed that the weight of the drone can be reduced or optimized. The purpose of this research work is to reduce the weight of the C-Drone's main body structure. Therefore, tensile tests on Aluminium 6061 are reviewed to obtain the actual mechanical properties of the current C-Drone material. This study will run a structural analysis of the current C-Drone design and run topology optimisation on the current C-Drone structure for weight reduction using the software SolidWorks. To achieve the objectives of this project, the topology optimisation focuses on the main body of the C-Drone structure. Before the optimisation can be done, the input material properties need to be defined beforehand. The mechanical properties of the Aluminium 6061 were obtained from experimental data that involved the tensile and flexural tests of the material. These values are inserted into the simulation software, SolidWorks, and structural analysis for the current design. From this analysis, the critical part or area caused by the loads and internal stress was determined. From the result obtained, in order to ensure the weight is reduced without reducing the structural rigidity, the area is excluded from part removal for the topology optimisation. The topology process runs the analysis again if the results from the optimisation show the structure is unable to withstand the total load. The best results have been obtained from the series of simulations, and they show the suggestion for the most suitable modification strategy. It also shows the comparison of the current design of the body structure of the C-Drone with the software SolidWorks. The result of the stress, deformation, displacement, and safety factors of the construction is within acceptable limits. From this study, it can be concluded that the current design of body structure C-Drone is overdesigned because when the support of the current body structure C-Drone has been discarded, the result is still in the range of yield strength.

Keywords: Cargo drone, weight reduction, topology optimisation

1. Introduction

A new generation of autonomous delivery vehicles the size of planes is capable of moving hundreds of pounds over long distances of hundreds of kilometers. They are referred to as cargo drones in the industry. They are more efficient, more ecologically friendly, and have the potential to completely transform the cargo industry [1]. They are also more affordable. When considering a cargo UAV, one of the most crucial elements to consider is its ability to carry a significant amount of weight [2]. When this cargo drone is successfully completed, it will go down in history as the first large-sized cargo drone to be produced in Malaysia. Based on the problems faced by the group at Universiti Tun Hussien Onn

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Malaysia, the weight of the drone cargo is too significant. More weight will require more thrust to launch the drone and more power to increase the flying time [3]. The main purpose of this research is to reduce the weight of the C-Drone's main body structure.

The details for this objective are, firstly, to review tensile tests on Aluminium 6061 to obtain the actual mechanical properties of the current C-Drone material. Besides, the researcher wants to run a structural analysis of the current C-Drone design and perform topology optimization on the current C-Drone structure for weight reduction. The scope of this study is the material that will be used in this research, which is Aluminum 6061. Moreover, the structural analyses include the stress, strain, and deflection of the structural component. Using the SolidWorks topology optimisation tool, the first estimate of the body structure of the C-Drone design based on the selected area or part can be obtained. According to [4], to determine that the stress, deformation, displacement, and safety coefficient of the structure are within acceptable parameters, a finite element study was performed with the goal of validating the optimally obtained conception of the body structure through SolidWorks topology analysis.

2. Related Works

2.1 Evaluation of Mechanical Properties in Tensile

According to [5], the best mechanical properties in tensile strength were found in 6061-T4 samples, reaching 117.48 MPa, in contrast to the 6061-T6 sample processed with similar conditions, which reached 73.57 MPa. Aluminium is commonly machined with HSS, carbide, and PCD tooling [6]. While methods for bending, stamping, welding, deep drawing, and spinning are used, 6062 is more easily worked and retains its corrosion resistance even when the surface is abraded. Besides, referring to [5], they said that the dimension of the specimen is a gauge length of 33 mm and a diameter of 5.8 mm, with a total length of 67 mm for 6061 alloy, which has been used for experimental analysis. The tensile test has been carried out on a UTM of 20 KN capacity at an across head speed of 2 mm/min, where the load deflection curve was obtained for each specimen [7]. The value of the young modulus that can be used is 128 GPa. Table 1 shows the Young’s modulus result.

Table 1 - Young’s modulus result

Material Properties	Unit	$AlMgSi_{0.5}F_{22}$ (AA 6060)	HE 20 (6061)
Young modulus	N/mm^2	185	128
Yield stress	N/mm^2	306	154
Ultimate tensile	N/mm^2	374	194
Tensile Strength at Fracture	N/mm^2	321	160
Total Elongation	%	15	21
Rockwell Hardness	HRF	76.8	36.2

2.2 Evaluation of Fracture Toughness Measurement for Aluminium 6061-T6

Based on [8], the tensile testing for both the smooth and notched specimens was performed on an INSTRON 3369 dual column table-top testing machine, which had a rating of 50 kN. The rate of applied loading was 2 mm/min. The material used for the present work in this test was a solid round bar 25.4 mm (1 inch) in diameter and 4 m in length. The literature on the mechanical properties of aluminium 6061-T6 alloy is shown in Table 2.

Table 2 - Literature mechanical properties of aluminium 6061-T6 alloy

Property	Al 6061 – T6
Young’s modulus	68.9 GPa
Poisson’s ratio	0.33
Tensile yield stress	276 MPa
Ultimate tensile strength	310 MPa
Elongation at break for 12.7mm (1/2 in.) diameter	17%
Brinell hardness	95
Fracture toughness K_{IC} (T-L orientation)	29 MPa/m

3. Methodology

3.1 Flowchart

Fig. 1 illustrates the flowchart of the project's research. In this research, the topology optimisation focuses on the main body of the C-Drone structure. Before the optimisation can be done, the input material properties need to be defined beforehand. The material used for the main body structure is Aluminium 6061. The mechanical properties of the Aluminium 6061 are obtained from experimental data that involved the tensile and flexural tests of the material.

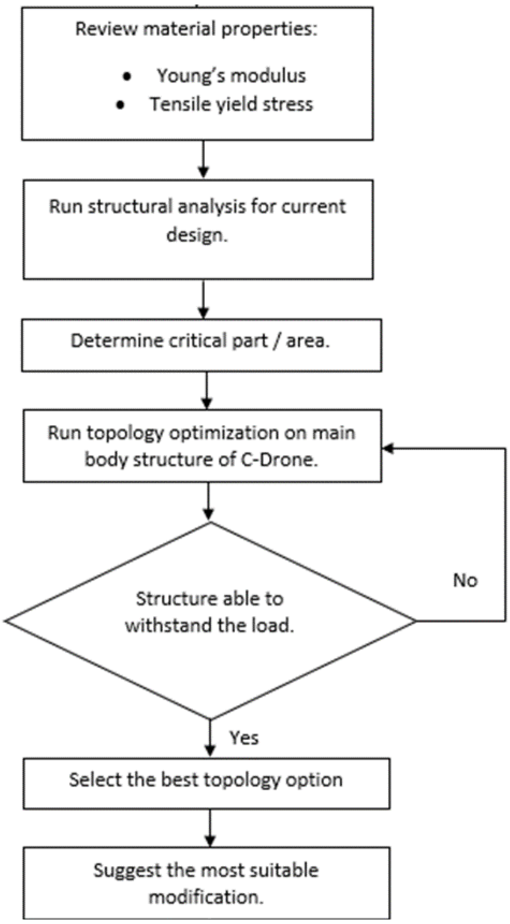


Fig. 1 - Topology optimisation process

The outcome parameters required from these experiments are the Young modulus and shear modulus of Aluminium 6061. Later, these values are inserted into the simulation software, SolidWorks, and structural analysis for the current design will be run. From this analysis, the critical part or area caused by the loads and internal stress will be determined, and this area will be excluded to ensure the weight can be reduced without reducing the structural rigidity. Results from the optimisation will be analysed and if the structure is unable to withstand the total load, the topology process will be run again. If the criteria are met, then the design will be included in the database. A series of simulations will be performed until the best results are obtained, and from the results, the most suitable modification strategy will be suggested.

3.2 Static Analysis

The static analysis was done on all five designs. Fig. 2 shows the front view and isometric view of fixed geometry sets for C-Drone design. All of the designs were fixed to the bottom of the C-Drone body to simulate as if the C-Drone were in the landing phase. Then, the impact force was applied to the designs as shown in the table to simulate the force due to empty weight and gravity. Table 3 shows the force applied to the current design of the body structure of the C-Drone.

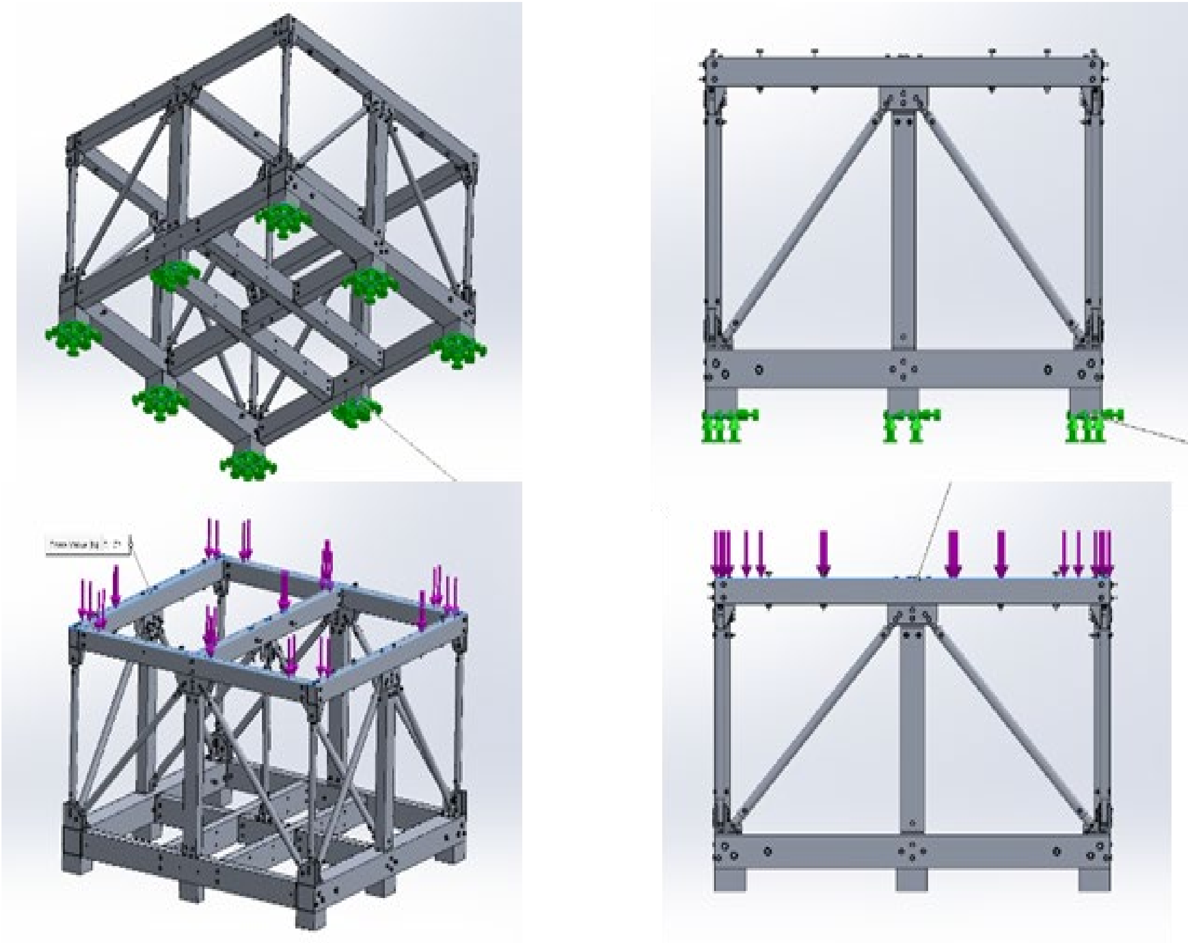
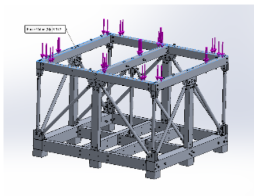
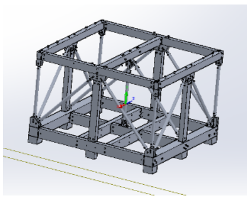
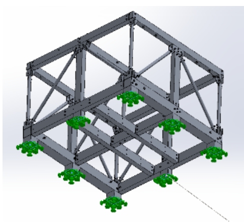


Fig. 2 - Front view and isometric view of fixed geometry sets for C-Drone design

Table 3 - The force applied on the current design of body structure of C-Drone

Load name	Load apply	Load Details
Force due to top body (downward force)		Entities: 4 face(s) Type: Apply normal force Value: 8172 N
Centre of gravity		Reference: Face<1> Values: -9.81 Units: SI
Fixed due to bottom body		Entities: 8 face(s) Reference: Face<1> Type: Apply Fixed

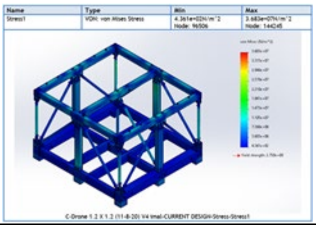
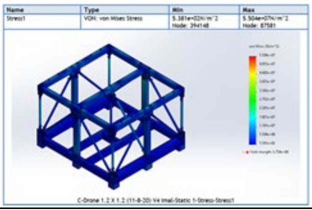
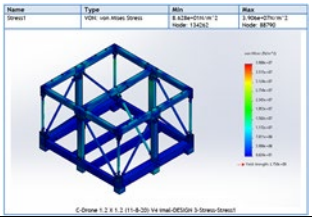
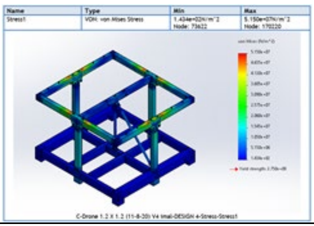
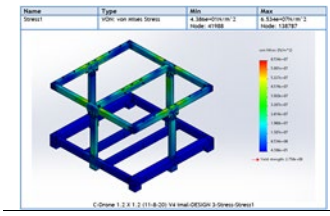
4. Results and Discussion

The results of these studies show how the designs behave under a different design to reduce weight. Hence, the discussion of the results is explained below.

4.1 Von Mises Stress

The Von Mises stress results from Table 4 shows that Design 4 is obviously the best design out of the other designs. It can withstand much more of the impact force, up to 63.54 MPa, which is 42.05% more than the initial design. The current design has the lowest stress than other designs. This would give the current design an advantage when the body structure is static on the ground compared to the other designs. This would result in a much safer design than the other design. In addition, the maximum stress for every design has been multiplied by the factor of safety of the aircraft, which is 1.5 [9]. The result will multiply by 1.5, and the result will still be within the range of the yield strength of the material.

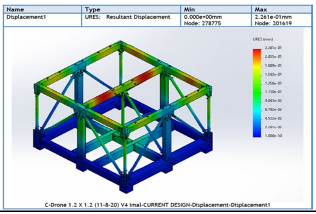
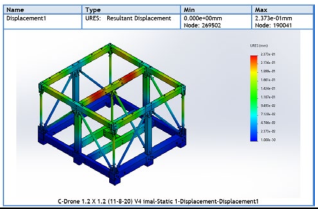
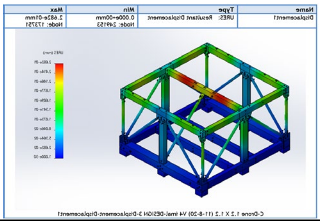
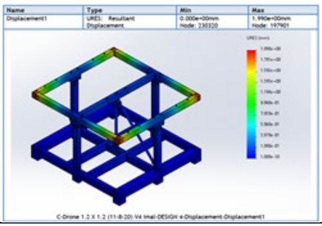
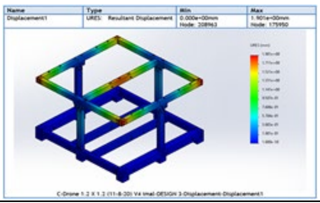
Table 4 - Von mises stress result

Simulaton result	Design	Minimum stress (N/m^2)	Maximum stress (N/m^2)
	Current design	4.361x10^2	3.683x10^7
	Design 1	5.381x10^2	5.504x10^7
	Design 2	8.628x10^1	3.906x10^7
	Design 3	1.434x10^2	5.150x10^7
	Design 4	4.386x10^1	6.354x10^7

4.2 Resultant Displacement

This analysis shows how much the designs will be deformed when the force is exerted on them. Table 5 shows that the displacement for the current design is 2.261×10-1 mm, design 1 is 2.373×10-1 mm, design 2 is 2.682×10-1 mm, design 3 is 1.990×100 mm, and finally, design 4 is 1.901×100 mm. The outcome of these results shows that the current design has the lowest displacement among the other designs, while design 3 has the worst displacement. Therefore, the current design is the most suitable design to choose based on this analysis.

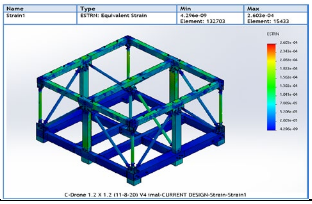
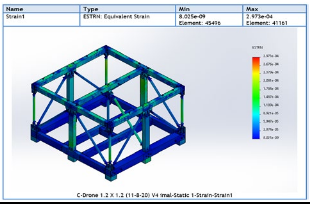
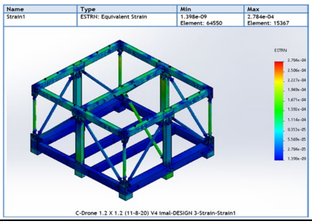
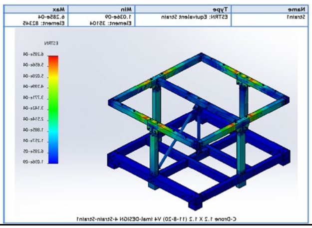
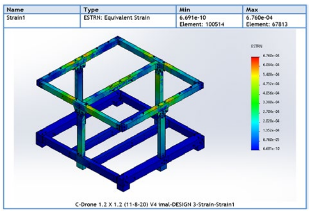
Table 5 - Resultant displacement result

Simulation result	Design	Minimum (mm)	Maximum (mm)
	Current design	$0.000x10^{0}$	$2.261x10^{-1}$
	Design 1	$0.000x10^{0}$	$2.373x10^{-1}$
	Design 2	$0.000x10^{0}$	$2.682x10^{-1}$
	Design 3	$0.000x10^{0}$	$1.990x10^{0}$
	Design 4	$0.000x10^{0}$	$1.901x10^{0}$

4.3 Maximum Deformation

From the results in Table 6, the current design has the lowest maximum deformation at 0.00026, while design 4 has the highest value at 0.000676. Therefore, the best choice here is the current design because it has the lowest strain value, meaning that the design would not elongate too much and cause any problems. The elongation of the design is so insignificant that it can hardly be noticed.

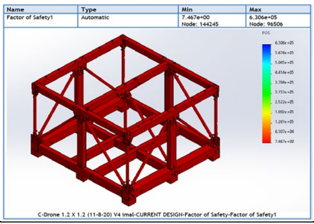
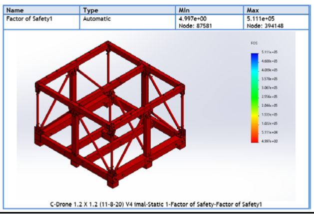
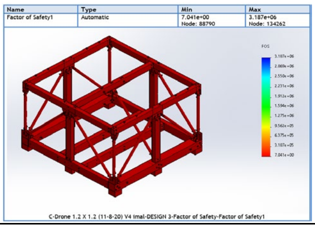
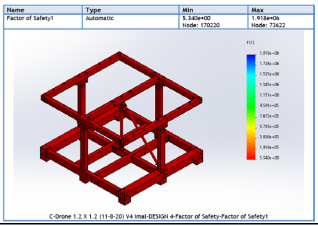
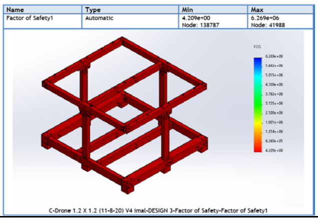
Table 6 - Maximum deformation result

Simulation result	Design	Minimum	Maximum
	Current design	4.296×10^{-9}	2.603×10^{-4}
	Design 1	8.025×10^{-9}	2.973×10^{-4}
	Design 2	1.398×10^{-9}	2.784×10^{-4}
	Design 3	1.036×10^{-9}	6.285×10^{-4}
	Design 4	6.691×10^{-10}	6.760×10^{-4}

4.4 Safety of Factor

The result of the factor of safety for each design is shown in Table 7. The result for all designs is not less than 1. It is because when the result of the factor of safety is lower than 1, the design fails. If the result of the factor of safety is equal to 1, the result almost fails, and when the result of the factor of safety is greater than 3, the result is over design, which means the design is very safe. All designs do not fail because all types of designs are within the range of yield strength.

Table 7 - Safety of factor result

Simulation result	Design	Minimum	Maximum
	Current design	$7.467x10^{0}$	$6.306x10^{+5}$
	Design 1	$4.997x10^{0}$	$5.111x10^{+5}$
	Design 2	$7.041x10^{0}$	$3.187x10^{+6}$
	Design 3	$5.340x10^{0}$	$1.918x10^{+6}$
	Design 4	$4.209x10^{0}$	$6.269x10^{+6}$

4.5 Mass Reduction

From the result in Table 8, design 4 has the highest percentage to reduce the weight of body structure C-Drone without changing the original size. Fig. 3 show the bar graph weight comparison for C-drone design.

Table 8 - Mass reduction

Body structure C-Drone	Initial mass	Final mass (kg)	Percentage (%)
Current design	91.27	91.27	0
Design 1	91.27	88.14	3.43
Design 2	91.27	85.59	6.22
Design 3	91.27	78.63	13.85
Design 4	91.27	75.58	17.19

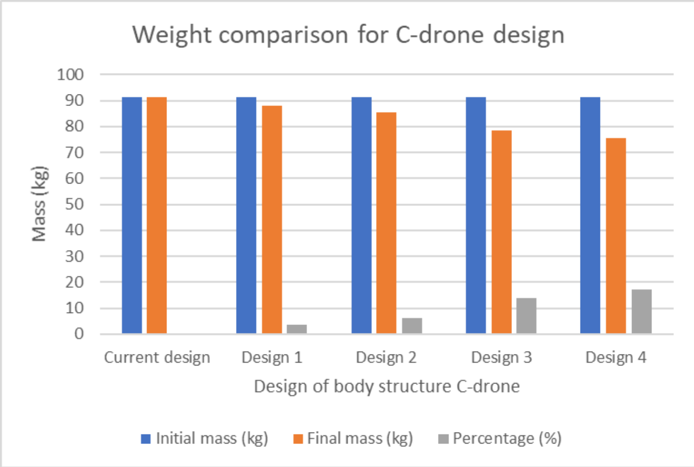


Fig. 3 - Bar graph weight comparison for C-drone design

4.6 Topology Optimisation

The design of the model was carried out using the software SolidWorks with the help of topology optimisations tools [10]. The result from the topology optimisation tool in SolidWorks in Table 9 shows the initial value and optimal value for three parts of the body structure. The weight reduction for this part can be reduced from 81.84 kg to 73.21 kg, which is equivalent to a 10.54% reduction from the initial value. Fig. 4 shows the parts that have been chosen for the weight reduction, which indicates the location of areas Base 1, Side 1, and Base 2 in this analysis.

Table 9 - Result of the topology optimization

Design Study 3				
Scenarios/Iterations:	12			
Parameter Constraint or Goal	Format	Unit	Initial Value	Optimal Value
Base 1		mm	1301.6	650.8
Side 2		mm	622.537	311.268
Base 2		mm	1187.3	593.65
Mass1	Minimize	g	81847.03	73206.57

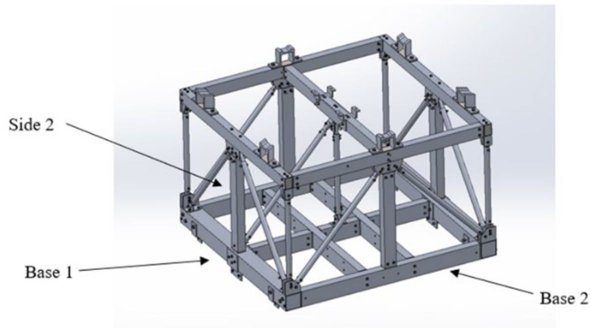


Fig. 4 - The part selected

5. Conclusion

In conclusion, there are three (3) main objectives stated in the study, which are to review tensile tests on aluminium 6061 to obtain the actual mechanical properties of the current C-Drone material; to run structural analysis of the current C-Drone design; and to run topology optimization on the current C-Drone structure for weight reduction. As part of this research, researchers gathered and compared the parameters required: the Young Modulus and shear modulus of aluminium 6061. The Young's modulus for aluminium 6061-T6 alloy is 68.9 GPa, and the tensile yield stress is 276 MPa. This value is used to make a comparison with the results achieved. The results also show that the maximum stress, the maximum deformation, the displacement, and the safety factor have been collected. From these results, design 4 is obviously the best design out of the other designs. It can withstand much more of the impact force, up to 63.54 MPa, which is 42.05% more than the initial design. The current design has the lowest stress compared to other designs. Besides, the maximum stress for every design has been multiplied by the factor of safety of the aircraft, which is 1.5. The result will be multiplied by 1.5, and the result for design 4 is 95.31 MPa. The tensile yield stress for aluminium 6061-T6 is 276 MPa, which means the result for design 4 is 95.31 MPa, and the result after removing some parts is still in the range of the yield strength of the material. To conclude, the current design of the body structure of the C-Drone is overdesigned because when the support of the current body structure has been discarded, the result is still in the range of yield strength. All the objectives were achieved successfully.

Acknowledgement

The authors would like to express their gratitude to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for their assistance.

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