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Stress Investigation of Aluminium Alloy and Composite Material for Unmanned Aerial Vehicle Application via Simulation Analysis

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Abstract: Composite material offers excellent properties such as lightweight, high strength to weight ratios, and excellent corrosion resistance. Universiti Tun Hussein Onn Malaysia successfully developed a Cargo Drone (C-Drone) using aluminium alloy as its structure. The future enhancement is looking at the potential of composite material for C-Drone application. Therefore, this research aims to study the stress properties of aluminium alloy and glass fibre composite for C-Drone application via simulation analysis. The scope of this study focuses on the landing gear part of the C-Drone. The drawing of C-Drone was analysed through SolidWorks software to obtain the result of the material reacting to stress, strain, and displacement. The result shows that glass fibre with brittle properties can withstand a high amount of stress, acceptable strain rate, acceptable deformation and reduced weight up to 10% compared to aluminium alloy. This research proves that composite material such as glass fibre reinforced plastic can become an alternative to the current aluminium alloy 6061-T6.

Keywords: Composite material, glass fibre reinforced plastic, C-Drone, stress analysis

1. Introduction

Unmanned aerial vehicle (UAV) has been a game-changer in various fields such as military, courier service, plantation and even hobbies. Much extensive research has been done to increase the performance by increasing the payload, flight time, or reducing the structure weight[1]. Several materials such as carbon fibre reinforced composites (CRFCs) [2], [3], biomaterial [4], glass fibre [5], and aluminium alloy [6], [7] has been applied to reduce the structure weight and increase the structural strength. The materials focus on an excellent strength-to-weight ratio, lighter, and easy to shape into complex parts [8]. Composite materials can be defined as a material structure consisting of two macroscopically identifiable materials that work together to accomplish a superior result and consist of relatively strong, stiff fibres in a tough resin matrix and produce unique composite properties [4], [5], [9]–[11].

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Universiti Tun Hussein Onn Malaysia (UTHM) took this opportunity in building the first cargo drone prototype, as in **Fig. 1**. The structure is mainly made of aluminium alloy 6061 -T6 expected to carry 180 kg. The weight of aluminium alloy 6061-T6 is too significant and could affect the flight time and reduce the expected payload of the C-Drone. Lighter material will be proposed, and this study will focus on the landing gear part as in Fig. **2** and consider other composite materials such as carbon fibre and fibreglass.

Fig. 1 - Image of C-Drone UTHM

Fig. 2 - The landing gear of C-Drone UTHM labelled in red

Glass fibre shows promising tensile strength compared to other materials with a range of between 1500 to 4500 MPa. Since the aviation and aerospace industry mostly uses aluminium alloy, the data in Table 1 shows significant differences in the strength of both materials, with aluminium alloy tensile strength only between 248 to 330 MPa.

Table 1 - The strength comparison between different materials

Material	Tensile strength (MPa)	Reference
Spectra fibre	2600 - 3700	[12]–[14]
Kevlar	2500 - 3600	[15], [12]-[16]
Carbon fibre	3500 - 5500	[15], [12], [14], [17], [18]
Glass fibre	1500 - 4200	[12], [14], [17], [19]
Steel alloy	500 - 745	[20]–[22]
Aluminium alloy 6061-T6	248 - 330	[12], [23], [24]

Table 2 shows that the glass fibre has an approximate range of between 100 to 328 MPa. The value is close to an aluminium alloy with lower density which could be advantageous in reducing the weight with the same compressive strength.

Table 2 - The compressive strength of different material

Material	Compressive strength (MPa)	Reference
Carbon fibre	396 - 869	[25]–[27]
Glass fibre	100 - 328	[25], [27], [28]
Aluminium alloy 6061-T6	100 - 483	[29]–[31]

Table 3 shows the impact test being conducted among the composite materials. It shows that glass fibre can absorb energy higher, between 10.4 to 11.43 J and have the highest average Charpy impact test, which is between 260.34 to 285.70 kJ/m^2.

Table 3 - The comparison of absorbed energy and average Charpy impact strength for each material composite [32]

Material composite	Post Curing Temperature (°C)	Absorbed energy (J)	Average Charpy impact strength ($\mathrm{kJ/m^2}$)
Carbon fibre	25	2.83	79.79
	62.5	3.08	86.75
	100	3.13	88.15
Glass fibre	25	10.4	260.34
	62.5	10.7	267.39
	100	11.43	285.70
Hybrid fibre (woven)	25	6.5	162.69
	62.5	6.98	174.58
	100	7.195	179.88

Table 4 shows that fibreglass can receive a high amount of impact force 4500 N compared to carbon and Kevlar-Carbon. With that, the data indicates that fibreglass composites absorb impact energy about 3.6 times greater than carbon and other types of composites [32].

Table 4 - The comparison of impact force being encountered by different composite [33]

Material	Impact Force (N)
Fibreglass	4500
Carbon	4200
Kevlar-Carbon	2000

In most of the research reviews, the outputs cover only general applications. However, the application of composite for C-Drone application needs further investigation. Therefore, this research aims to study the stress properties of aluminium alloy and glass fibre composite for C-Drone application via simulation analysis

2. Materials and Method

Analysis from the SolidWorks software reported Von Mises Stress, strain, and displacement results. For this specific design, the load is applied on the body structure's top surface, which assumption be made where the load will be distributed to the landing gear as shown in **Fig. 3**. The load being applied is the current maximum takeoff weight of the C-Drone which is 833 kg (8172 N) to be applied as the force that the landing gear needs to support.

For the fixtures, an assumption is made where the landing gear components meet the ground that is spade as the fixed fixture (as shown in **Fig. 4**). Material properties of the S-glass and the aluminium alloy 6061-T6 fibre as tabulated in Table 5 and **Table 6**, were inserted into the SolidWorks analysis.

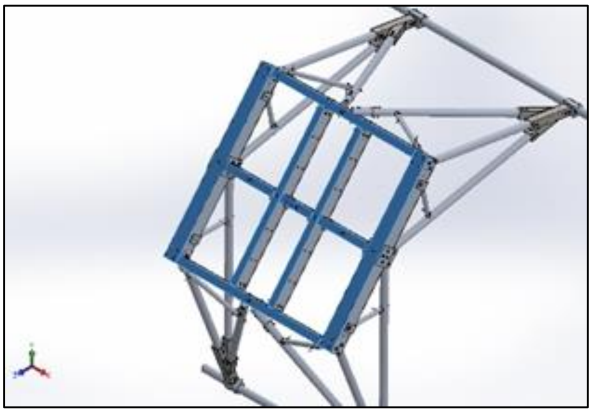


Fig. 3 - Forces being applied at the surface indicated in blue colour

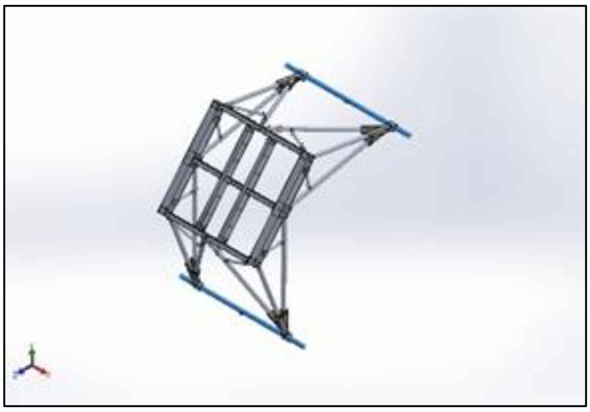


Fig. 4 - Fixture being applied at spade

Table 5 - The properties of glass fibre inserted into SolidWorks [34]

Property	Value	Units
Elastic Modulus	3.79×10^{10}	N/m^2
Poisson's Ratio	0.27	N/A
Shear Modulus	6.89×10^9	N/m^2
Mass Density	1992.95	kg/m^3
Tensile Strength	7.93×10^8	N/m^2
Compressive Strength	3.44×10^7	N/m^2

Table 6 - The properties of aluminium alloy 6061-T6 inserted into SolidWorks

Property	Value	Units
Elastic Modulus	6.90×10^{10}	N/m^2
Poisson's Ratio	0.33	N/A
Yield strength	2.75×10^8	N/m^2
Mass Density	2700	kg/m^3
Tensile Strength	3.1×10^8	N/m^2

3. Result and Discussion

3.1 Weight Reduction

From SolidWorks, the mass properties of the landing gear structure can be obtained when implementing two different types of material: aluminium alloy 6061-T6 and glass fibre. The mass obtained can be referred to in Fig. **5** for the landing gear part with glass fibre and Fig. **6** for aluminium alloy 6061-T6.

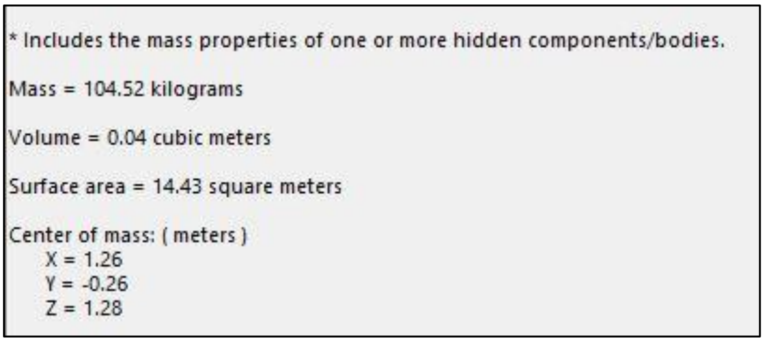


Fig. 5 - The mass properties of landing gear structure with glass fibre

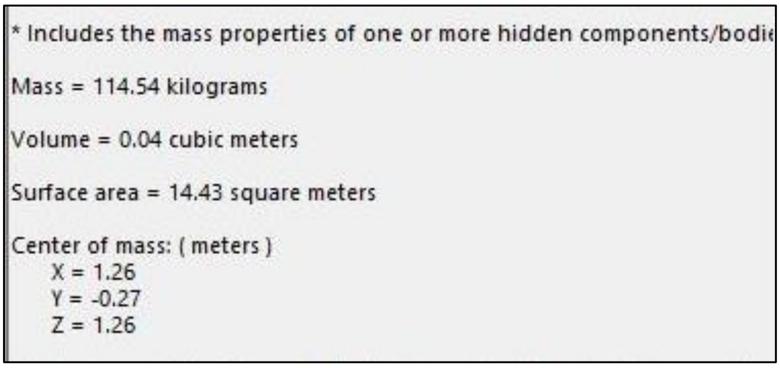
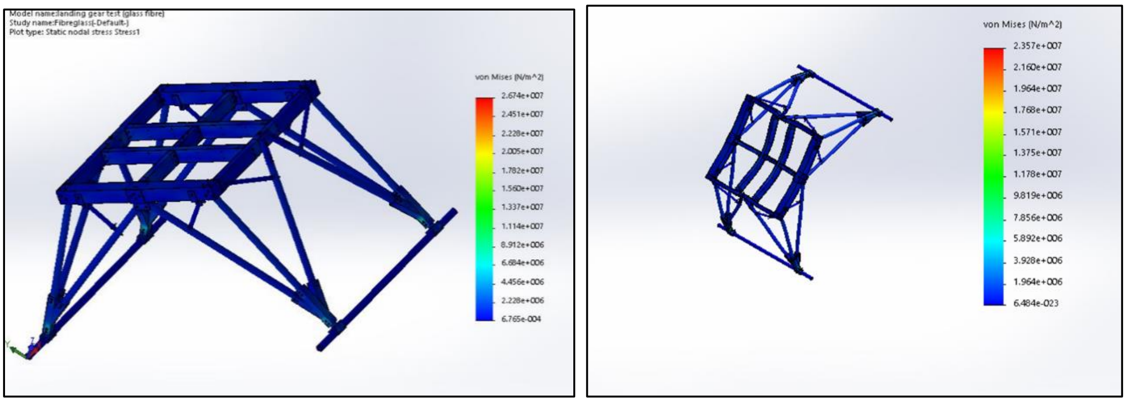


Fig. 6 - The mass properties of landing gear structure with aluminium alloy 6061-T6

The value obtained shows a significant weight reduction of landing gear structure by using fibreglass compared to aluminium alloy. By using fibreglass, the mass of the landing gear structure is 104.52 kg, while for aluminium alloy 6061-T6, the weight can reach up to 114.54 kg, which is heavier. The estimated weight reduction of the landing gear structure by using fibreglass can reach up to 10% less than the initial material, contributing to the lighter frame of the C-Drone. This result supported the statement by Gameros and Borchardt that using composite material can reduce the weight of the structure up to 15% to 45% compared to steel or alloys [1], [9].

3.2 Von Misses Stress

Based on Fig. **7**, the landing gear made of fibreglass has the lowest Von Mises stress at $6.765 \times 10^{-04}\ \mathrm{N/m^2}$ (As shown in **Fig. 7**(a)) while landing gear made of aluminium alloy $6.484 \times 10^{-23}\mathrm{N/m^2}$ (As shown in **Fig. 7**(b)) indicated in dark blue for both materials. Most of the landing gear structures experienced Von Mises stress approximately at $2.228 \times 10^{6}\ \mathrm{N/m^2}$ for fibreglass which is below the yield criterion of the material while $1.964 \times 10^{6}\ \mathrm{N/m^2}$ for aluminium alloy. Only a specific part of the structure experienced a higher value of Von Mises stress for both materials at approximately $1.337 \times 10^{7}\mathrm{N/m^2}$ for fibreglass and $1.178 \times 10^{7}\mathrm{N/m^2}$ for aluminium alloy indicated in green colour for both materials due to the existence of a fastener exist at that particular area, which can increase the stress value. This report supported the theory by J. Sanjeev and K. J. N. Sai Nitesh, stating that composite materials such as glass fibre imposed high strength to weight ratio [8] and proving the strength of the glass fibre in **Table 2** is close to the aluminium [25], [27], [28].

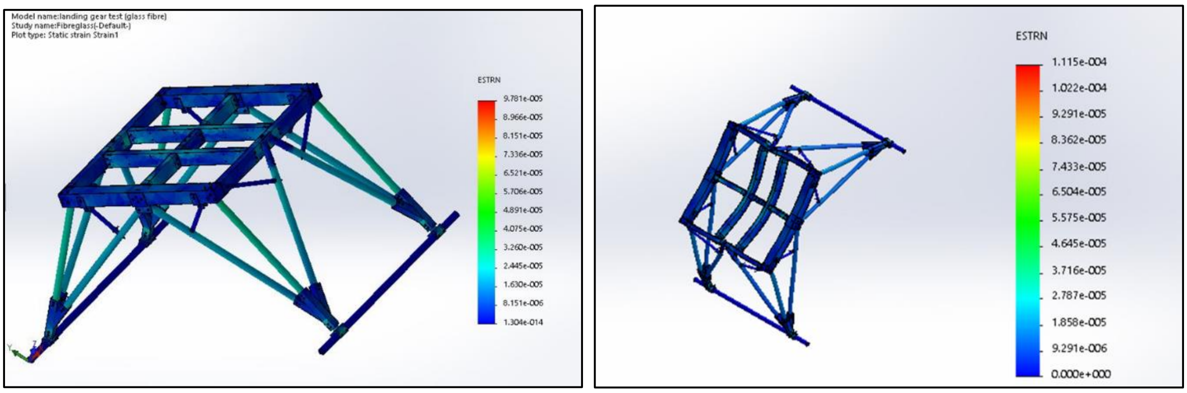


(a) (b)

Fig. 7 - Result for Von Misses Stress of (a) fibreglass (b) aluminium alloy

3.3 Strain

Based on Fig. **8**, the spade experienced a minimum strain of 1.304×10^{-014} for fibreglass (As shown in **Fig. 8**(a)) and 0 strain (As shown in **Fig. 8**(b)) for aluminium alloy indicated in dark blue for both materials due to the design fixed at that particular part. For the landing leg, most of the parts experiencing strain approximately at 2.445×10^{-05} indicated in light green colour for fibreglass while 2.787×10^{-05} indicated in light blue for aluminium alloy. Certain areas are experiencing higher strain at about 3.26×10^{-05} for fibreglass while 1.115×10^{-04} for aluminium alloy indicated in red colour for both materials. This is due to the joiner that connects between the leg and the spade, increasing the structure's strain at that particular area. This result proved the glass fibre able to withstand high strength as in **Table 1** [12], [14], [17], [19] without collapse and also could receive a high amount of impact as in **Table 4** without damaging the material [33].

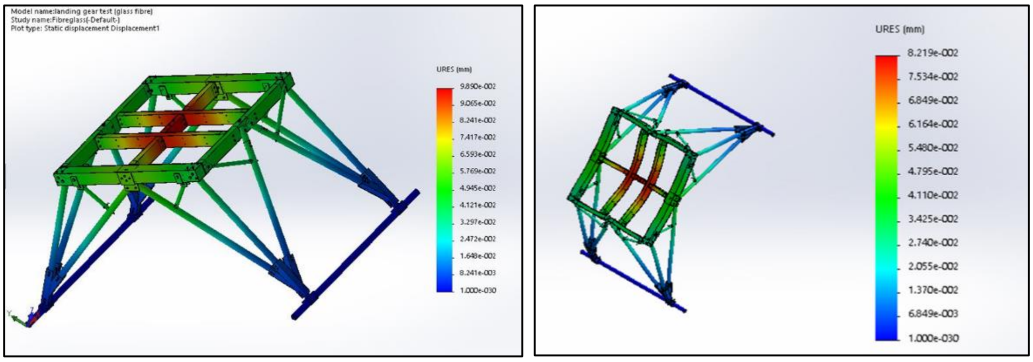


(a) (b)

Fig. 8 - Result for strain of (a) fiberglass; (b) aluminium alloy

3.4 Displacement

Fig. **9** shows that the minimum displacement of 0 mm for both materials is indicated in dark blue at the fixed part and increased up to the location where the load is exerted in the body structure. The highest displacement experienced by the landing gear structure is approximate 5.769×10^{-02}mm for fibreglass (As shown in **Fig. 9**(a)) while 4.11×10^{-02}mm for aluminium alloy (As shown in **Fig. 9**(b)) indicated in light green on top for both materials due to the location of the leg close to the surface of the load being applied. This result proved that the displacement that occurred within the material let the fibreglass withstand high tensile strength as in **Table 1** compared to aluminium alloy [8], [12], [14], [17], [19] and also supported the finding by C. Zweben that composite material has greater number of cycles to failure compared to other materials [35]. This happened because the composites are typically not fatigue critical since their fatigue threshold is a large percentage of their static or damaged residual strength [36].



(a) (b)

Fig. 9 - Result for displacement of (a) fibreglass (b) aluminium alloy

4. Conclusion

This research proves that fibreglass could be a potential material to be substituted with the current material, aluminium alloy 6061-T6. Most of the parts experienced Von Misses stress below the yield criterion of the material. Aluminium alloy and composite indicate an acceptable strain rate and deformation. For the current material, aluminium alloy 6061-T6, the weight of the landing gear structure is 114.54 kg, while glass fibre could reduce weight up to 104.52 kg. The weight reduction is 10%, thus increasing the flight time, and a higher payload can be carried.

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