STRENGTH ANALYSIS OF MAIN LANDING GEAR STRUCTURE OF LSU 02-02

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Abstract
Main Landing Gear Structure (MLG) has essential role in landing phase of LAPAN Surveilance UAV (LSU 02-02). This structure became the main support of dynamic load subjected to LSU 02-02, so the performance of this structure affect the flight mission. Through analytical, experimental and numerical methods the preliminary studies have been conducted to determine the performance of MLG absorbs impact energy. MLG LSU 02-02 composite made of e-glass fiber with lycal resin. Based on the FEM simulation maximum stress on the critical area of MLG is 128.1 MPa, whereas based on static test maximum stress is 119.4 MPa. The difference is about 8.7 MPa or 6.7 %. The differenceoccursbecausethemanufacturingprocessduringthedesignstillneedstobe improved.
***Key Words**: Main Landing Gear Frame (MLGF), Composite, fiber eglass*

1. Introduction

Main Landing Gear Structure(MLG) 02-02 LSU plays an important role in the process of landing. This structure can with stand dynamic loads up to three times the load factor. MLG framework is made of e - glass composite material coated by carbon composite on the top and bottom of the structure. In this paper the research done by using e-glass material entirely. Utilizing of this material is to ensure that its desired performance fullfiled.The Cost of E-glass fiber ischeaperthan carbon fiber so we can suppress its cost.Therefore, the research of the MLG framework made of e-glass fiber to determine its strength subjected to static load is essential.Common manufacturing methods used in the manufacturing process of the composite structure are hand lay - up, resin transfer molding, filament winding, pultrusion, compression molding, injection molding, and autoclave forming. In order to obtain maximum economic value, hand lay - up method is used.

The study is examined the MLG structure subjected the continuous static load of weight by 3 kgs to 36 kgs. These load in accordance with MTOW of LSU 02-02 for 12 kg. This method applied to know how much load that the structure can be received. This study expected to be a reference for future studies when the MLG framework subjected to impact load with speed variations in accordance togiven landing angle.

2. Basic Theory

1. Tensile Strength Composite

Tensile strength of e-glass composite can be determined by tensile test. From the stress-strain curve all of the mechanical properties can be known. Load and elongation can be formulated as follows:

a. *Engineering Stress* (σ)[5)]

$$\sigma = \frac{F}{A_0} \tag{1}$$

F =load in the perpendicular direction to the cross section of the specimen (N)
Ao =initial sectional area of the specimen (m^2)
σ = *Engineering Stress*(Mpa)

b. *Engineering Strain* (ε)[5)]

$$\varepsilon = \frac{L_1 - L_0}{L_0} = \frac{\Delta l}{L_0} \tag{2}$$

where:
ε = *Engineering Strain* (mikrostrain)
L_0 =initial length(m)
Δl =lengthof deformation

Based on Hooke's law, it is applicable on the linear/elastic region[5].

$$\sigma = E\ \varepsilon \tag{3}$$

where:
E = Modulus elastisitas (MPa)

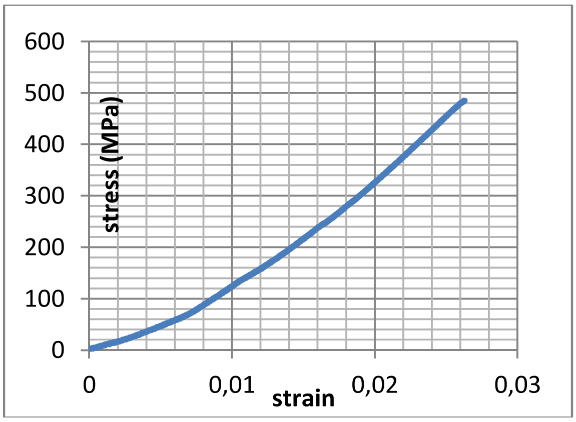


Fig. 1. Relationship stress - strain on tensile testing of e-glass composite UD 0^0

2. Flexural Strength

Flexural strength can be determined using three points bending method. Flexural strength or bending strength is the maximum stress occurs in the structure due to external load without over deflection or failure. The amount of flexural strength depends on the type material and boundary conditions. As a result, the top surface of structure experiences compression, while the bottom is tension.

Failure criterion of the composite occurs when a layer of composite structure ruptured. This is because the formed stress over its tensile stress of the material.

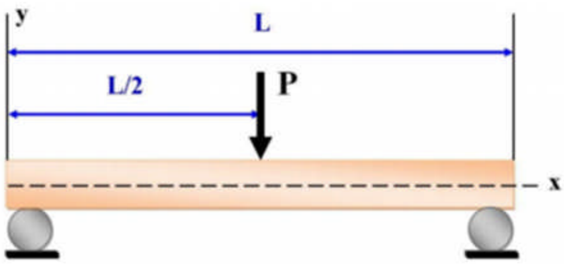


Fig. 2. Three point bending test

Three-point bending method is used in this study. Bending stress on the upper and lower surface is equal, it is depends on the boundary condition applied to it.

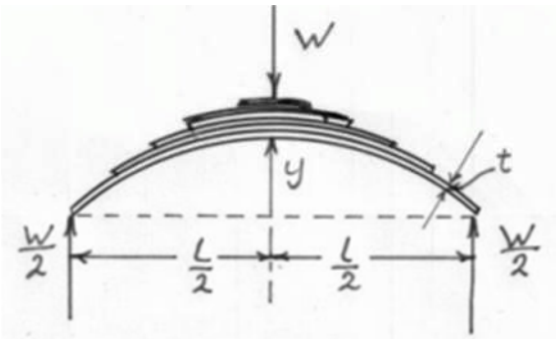


Fig. 3. Stress diagram*semi-elliptic leaf spring*[7]

Formulae in the calculation are[7] :

$$M = -\frac{wL}{4} \tag{4}$$

$$I = \frac{nbt^2}{12} \tag{5}$$

$$\sigma_b = \frac{3wL}{2nbt^2} \tag{6}$$

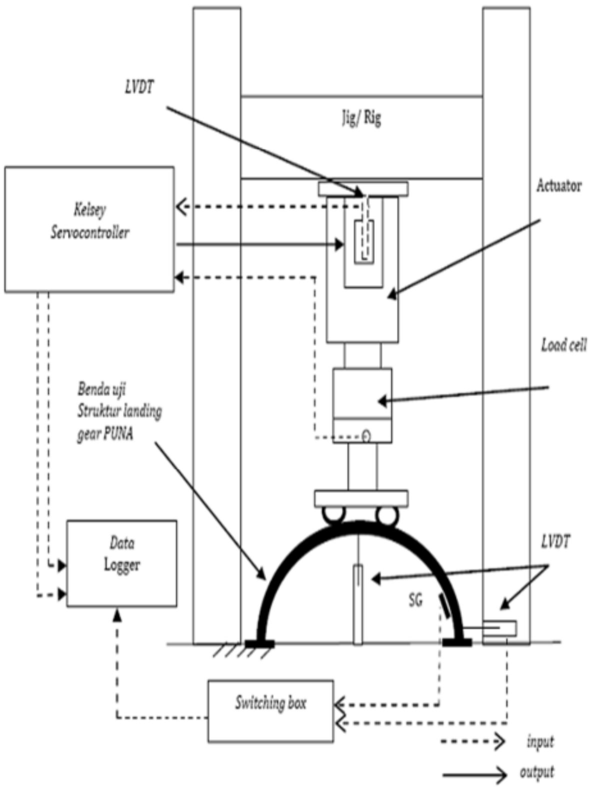
$$\delta = \frac{3wL^3}{8nbt^3E} \tag{7}$$

where :

M = Bending moment (Nmm)
L = Span length/Support span (m)
I = Moment of Inertia (mm^4)
b = Width (mm)
σ_b = Bending stress (N/mm^2orMPa)
n = Number of blades
δ = Deflection (mm)
t = Depth (mm)
w = Load (N)
E = Young's modulus (MPa)

To test the vertical static load / (full scale test) due to bending in the form of Main Landing Gear as can be seen as the image below

Vertical static load layout for MLG and the strain gage location can be shown at (Fig. 4) :



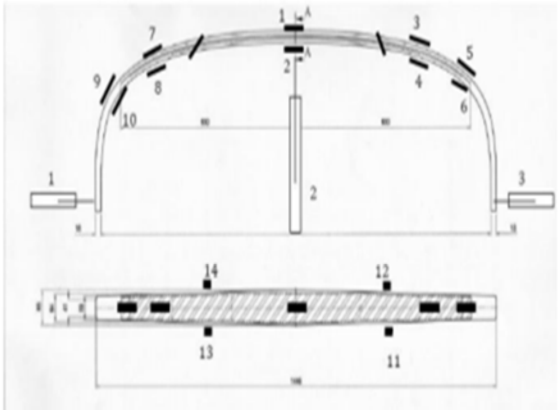


Fig. 4. Vertical static testing scheme's Main Landing Gear at BPPT[8)]

3. Testing Process

Table1. Mechanical properties of E-glass fibers and carbon

No	Material	σ_y (MPa)	σ_u (MPa)	E (MPa)	υ	ρ (gr/cm^3)
1	Carbon	116	586	58.062	0.24	1,141
2	Uni e-glass	54	303	21.057	0.34	1,518
3	45^0e-glass	31	174	15.382	-	1,330
4	Uni s-glass	57	536	27.905	0.32	1,360
5	45^0s-glass	33	232	16.290	-	1,421

source:Aplikasi Material KompositUntukPeningkatanKehandalanStruktur Landing Gear PesawatUdaraNirAwak (PUNA) – B2TKS – BPPT 2012

MLG dimensions of the MLG can be seen in the following figure (Fig. 5)

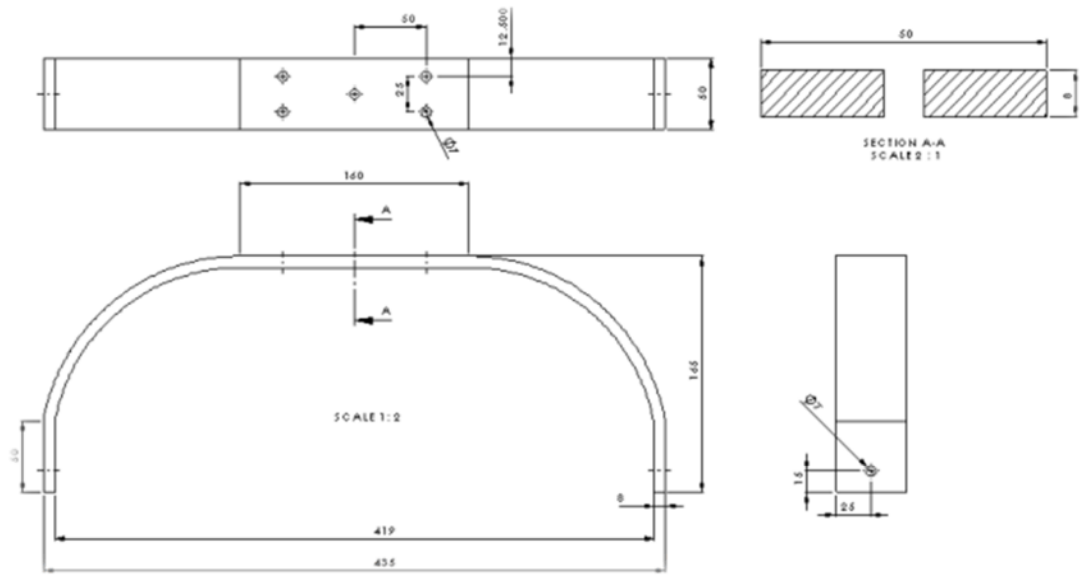


Fig. 5. Main Landing Gear Structure Dimension of LSU-02-02

Fig. 6. Strain gauge placement process on MLG

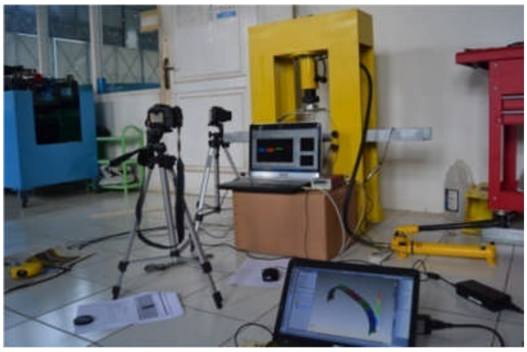


Fig. 7. Installation Unit of MLG Static Vertical Testing

4. Analysis

4.1. Analytical Calculations

Calculations theory to determine stress and deflection due to bending load are based to the testing scheme as the Fig. 8.

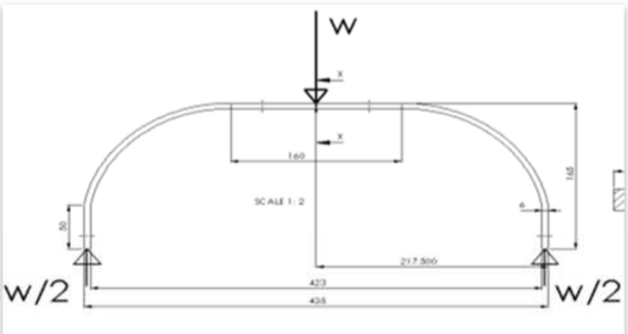


Fig. 8. Loads on the main landing gear LSU-02-02

analytical data is shown in the Table 2 :

Table 2.Dimension and Load Parameter

L	435	mm
½ L	217.5	mm
MTOW	12	kg
Load Factor	3.0	g (1 g = 9,81 m/s^2)
W	3-36 (increment loads 3kgs)	Kg
w/2	1.5-18	Kg

Width b = 50 mm, Depth t = 6 mm

Source : Data from LAPAN

Three time maximum load or three G's load factor in the calculation is to simulate or replace the expenses incurred due to dynamic load. Where, the value of the acceleration can be obtained from the assumption when MLG receive shock loads when the UAV landing.
The maximum load can be calculated by this equation:
F = m .a, where the value of a = 1 g = 9.81 m/s^2, so F = 12kgx3g =12kgx3x9.81m/s^2= 353.16 N or proportional to the static load 36 kg (3g).
So to calculate the bending stress, use Eq. (6) in Chapter 2, where:

$$\sigma_b = \frac{3wL}{2nbt^2}$$

$$\sigma_b = \frac{3.36.435}{2.50.6^2}\text{kg/mm}^2$$

$$\sigma_b = 13.05\ \text{kg/mm}^2$$

The bending stress due to 36 kg is 13.05 kg/mm^2 or 127.98 MPa. The maximum stress due to increment three kg load can be shown in Table 3 :

Table 3.Bending stress result of analytical Calculation

Load (kg) W	Analytics Calculation		
	Stress (kg/mm^2) σ_b	Stress (kg/cm^2) σ_b	Stress (MPa) σ_b
3	1.0875	108.75	10.668375
6	2.175	217.5	21.33675
9	3.2625	326.25	32.005125
12	4.35	435	42.6735
15	5.4375	543.75	53.341875
18	6.525	652.5	64.01025
21	7.6125	761.25	74.678625
24	8.7	870	85.347
27	9.7875	978.75	96.015375
30	10.875	1087.5	106.68375
33	11.9625	1196.25	117.352125
36	13.05	1305	128.0205

Source: processed from bending stress theory calculations based on[7)]

4.2. MSC. Patran NastranAnalysis

MSC.Nastran 2011 was used in this numerical simulation. This calculation based on the analytical calculation and the real test condition. There is difference in the boundary condition between numerical and analytical calculation. The load subjected to center line of the upper surface of the MLG in the analytical calculation, but in the numerical calculation the same amount of load applied on MLG top surface due to contact surface of the load cell.
This simulation uses linear static assumption, so if the variation of load applied in the model, the distribution of stresses still the same but its amount is different.
Based on table III-1 the material properties parameter B2TKS-BPPT of unidirectional e-glass the value of E = 21057 MPa, ν = 0.34, ρ= 1518 g/cm^3, σ_{ult} = 303 MPa. From this model the weight of MLG is 291.36 kg. This material is the lowest desnsity between aluminium and carbon fiber composite, but the strength is fair enough. The real weight of MLG structure is ± 320 grams, there is different in weight about 28.64 gram due to different density properties between data base model and the real model. The reason because of the different of mold dimension and the coating material such as paint and putty aren't include to the weight calculation.
Steps for calculation of bending sress can be done by following stages:
1. Simulations based on analytic calculations

Surface/shell type model is choosen to approach the experimental result. Surface/shell type model or 2D model is more representative for the analysis because the integration error will be minimized. It has lower cost calculation than use the solid or 3D model. Meshing and boundaray condition that applied to the model can be seen as the following Fig. 9 and Fig. 10 :

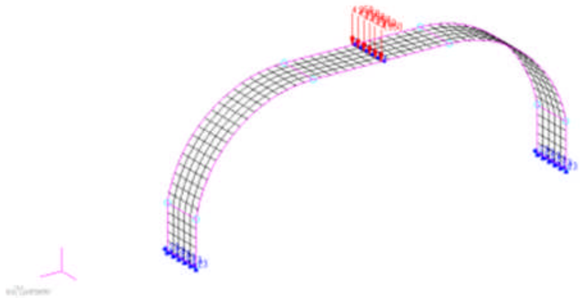


Fig. 9.Meshing and boundary conditions simulated loading

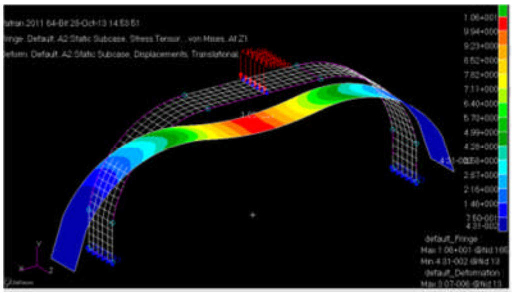


Fig. 10. Simulation results of 3 kg load

The variation of load is applied at the center line of the MLG. Y and Z direction of the model tip are fixed, so the X direction is free according to experimental test.

This result was used as the validation of the analytical calculation. Based on the result the error between simulation and analytical calculation is 0.1585%. This mean numerical prosedur to calcutate the real condition of the experimental test is valid.

2. Simulations based on test conditions

The top surface of the MLG along 60 mm length is subjected to the variation of load. Fig. 11 is described about the condition:

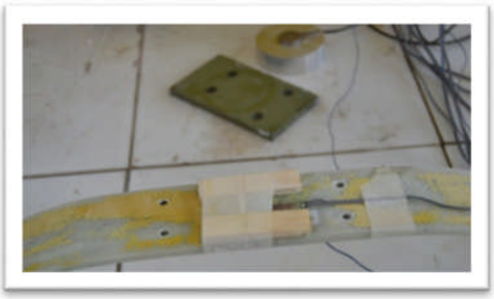


Fig. 11.Conditions of loading area when testing

This simulation result obtain the value of stress at the certain deflection as the following table:

Table 4. Simulation results MSC. Patran Nastran for Bending

Load (kg) W	Stress Vonmisses (MPa) σ_b
3	10.6
6	21.2
9	31.8
12	42.2
15	52.7
18	63.6
21	72.1
24	84.4
27	94.9
30	105
33	116.6
36	127

4.3. Analysis of Testing Results

Vertical static test result data can be seen on the minus graph for displacement. This is indicates the downward deflection suppressing the test model, this result appropriate with sensor displacement readings, as well as the SGcolumn 1,3, and 5 the minus sign indicates that compressive stress occurs in that area. Inversely, the SG 2 and 4 are indicates the tensile stress. Fig. 12 and Fig. 13 shows the comparison of the all the strain gage result.

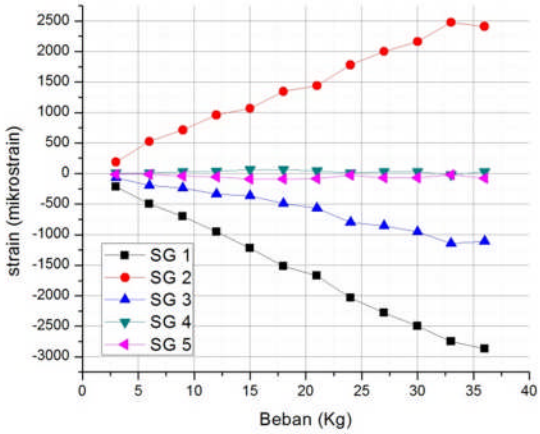


Fig. 12. Comparison of load and strain

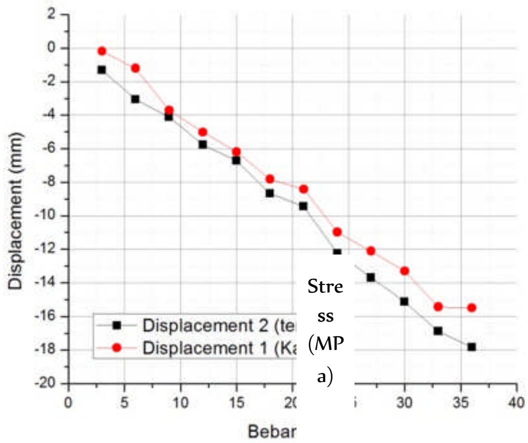


Fig. 13. Comparisson load vs Displacement

The corresponding equation between deflection in mm and strain values can be converted using this formula[5)]:

$$\sigma=E.\varepsilon \quad (8)$$

Based on the above Eq. (8) young's modulus can be obtain by maximum deflection formula due to bending equation[7)]

$$\delta = \frac{3wL^3}{8nbt^3E} \tag{9}$$

The maximum stress occurs on strain gage 1, this is appropriate to numerical simulation but different value for analytic simulation. Average young's modulus obtain by this experiment is 58.212 GPa. Maksimum stress due to 36 kg is 167.07 MPa, This result different from analytical data from B2TKS-BPPT. This difference because the manufacturing process of the composite material, ratio of fiber and resin, alignment of the fiber composite, type of resin. Measurement of reaction force due to bending moment can be done by force gage tool. This result experiment can be seen in table below:

Table 5. Load and side force due to bending moment

Load (kg)	Force (N)	Load (kg)	Force (N)
0	0	30	100.6
3	12.4	33	109.5
6	19.3	36	113.5
9	30.7	39	108.8
12	45.8	42	117.5
15	58.8	45	126.9
18	62.8	48	136.8
21	71.6	52	142.5
24	80.8	55	153.6
27	90.3	58	164.3

Source: The results of vertical static load test of MLG LSU 02-in Lapan-Pustekbang 2013

Whereas the comparison of analitycal, numerical and experiment test at the critical point can be seen in the Fig. 14 :

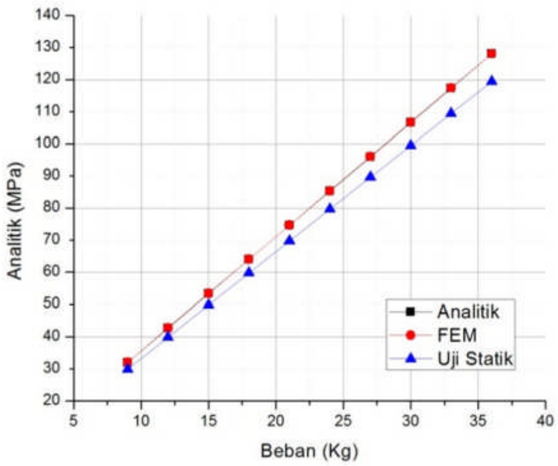


Fig. 14. Comparison of analytical, numerical(FEM), and experiment test

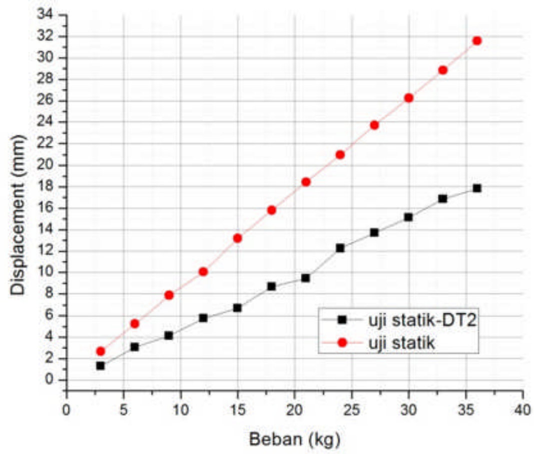


Fig. 15. Comparison of load and displacement

Fig. 15 show the maximum stress due to 36 kg vertical load do not exceed 303 MPa, this stress is the ultimate strength stress of the material composite. Maximum deflection obtain by 36 kg vertical in the experimental tes generate 167 MPamaximum stress. This is indicates that MLG structure can be optimized by reducing its thickness or other dimension in order to obtain efficient design. This structure also didn't failed subjected to 72 kg vertical load with maximum deflection on the DT-2 which its value is -46.81 mm and the strain value is 5201.356 με.

5. Conclusion

1. Based on numerical calculation and static testing result of the MLG structure subjected to vertical static load, its able to withstand 36 kg up to 72 kg vertical load.
2. MLG structure can be optimized so it can reduce its weight by decreasing the thinckness and widht of MLG. Optimizing can be done by numerical calculation only.
3. Manufacturing proses of composite structure influences to the mechanical properties of structure, so to obtain better experiment data the technician must have qualification in manufacturing proses and the manufacturing method must be improved to vacuum bagging method or other.

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8) http://pkpp.ristek.go.id/_assets/upload/feval/F1_134_Presentasi_Evaluasi.pdf
9) http://www.lapan.go.id/

Discussion

Question

1. Why not display the comparison result of a calculation, simulation and experimentation? (Agus Bayu Utama, LAPAN)
2. Why.... Not spread evenly over the surface? Load line on paper only.(Agus Bayu Utama, LAPAN)
3. Analysis that used to use what strength? When there should be listed on the title (Mabe S, LAPAN)
4. How many thickness reduced? (Mabe S, LAPAN)

Answer

1. Already shown the results of the comparison of analytical, simulation, and experimentation in the form of graphs and tables but not discussed in detail.
2. Contact force / bad made a line on the top surface MLG as a validation of the numerical calculation of whether the procedures used in the FEM has been irrelevant if not, so if the result is the same as the procedure used in the FEM can be applied on condition that occurs when the experimental test.
3. The method employed uses the comparison results of numerical calculations / FEM and the experimental. Numerical calculations / FEM are validated by analytical calculation according to the equation shown in the poster.
4. Based on FEM MLG structure can be reduced to 33% of its thickness, but for a more definite must be retested.