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MODELLING AND STATIC STRUCTURAL ANALYSIS OF FUSELAGE WITH LATTICE STRUCTURE BY USING ALUMINIUM ALLOYS

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ABSTRACT

The fuselage is the primary structural component of an aircraft, designed to accommodate passengers and cargo while withstanding various loads during flight and landing. This project focuses on the conceptual design and analysis of a lattice-structured fuselage for a small, 50-passenger aircraft. Using CATIA, a lightweight and efficient lattice structure is modelled to optimize structural performance. Static structural and modal analyses are conducted in ANSYS to evaluate stress distribution, deformation, and natural frequencies under operational and Static loading conditions.

The study investigates four materials - Aluminium Alloy 7075-T6, Aluminium Alloy 7068,Aluminium Alloy LM-25, and a standard Aluminium alloy - comparing their suitability based on strength, stiffness, weight, and fatigue resistance. The objective is to identify the optimal material for the fuselage structure while maintaining safety and minimizing weight. The results provide insights into the effectiveness of lattice structures in enhancing structural efficiency and offer recommendations for material selection in aircraft design.

Key Words: Structural Behaviour, Deformation, Stress, Strain, Fuselage with Lattice Structure, ANSYS , CATIA -V5.

1. INTRODUCTION

The fuselage serves a number of functions:

It forms the body of the aircraft, housing the crew, passengers or cargo (the payload), most of the aircraft systems - hydraulic, pneumatic and electrical circuits, electronics. It forms the main structural link between the wings and tail or fore planes, and holds these at the correct positions and angles to the airflow to allow the aircraft to fly as it was designed to do. The loads transmitted from these items, particularly the wings and tail, try to bend and twist the fuselage, and it must resist these forces. Engines may be installed in or attached to the fuselage, and the thrust and inertia forces generated by them can be very high. Most modern aircraft have some form of pressurization system in the fuselage. This is because they fly at such altitudes that the passengers and crew would find it uncomfortable or even impossible to survive. So, the inside of the fuselage is pressurized to simulate a lower altitude, of around 2,400 meters (8,000 feet) for transport aircraft, and up to 7,600 meters (25,000 feet) for military aircraft (with crew oxygen). These pressure forces try to burst the fuselage like a balloon. These many forces can all exist at once, and the fuselage needs to be strong and stiff enough to hold its shape for many flying hours. The fuselage is often blended into the wing to reduce drag. In some aircraft it is difficult to see where the fuselage ends and the wing begins.

Advantages of Fuselage with Lattice structure

ADVANTAGES:

- Improving safety and making repairs more manageable.
- Advanced materials, such as composites or lightweight metals, can be strategically used where needed.
- Minimizes material wastage and cost.
- Lattice structures are well-suited to additive manufacturing (3D printing), enabling complex geometries.

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Applications of Fuselage with Lattice structure

- Ultra-lightweight structures for extended flight duration.
- Structural frameworks for satellites, space probes, and launch vehicle payload sections.
- Lattice fuselages used in prototypes to demonstrate the feasibility of advanced designs and materials.
- Used in Hypersonic, Supersonic and Research aircrafts.
- Also used in transport, Cargo and Rescue aircrafts.

2. LITERATURE REVIEW

Aircraft structure is an area where in many researches are being carried out. It provides lots of research to the fellow researchers. Everyday there is a scope of improvement in the field of aircrafts, be it in the aircraft structure, its efficiency, and various other fields.

1. **Vijay raja L** and **A R Anwar Khan** [2015] Using ANSYS, Z-stringer splice joints in aircraft fuselages were analyzed with metallic, composite, and hybrid materials. Composite stringers showed superior strength and lower weight, making them the preferred choice.

2. **Basil Sunny** and **Richu Thomas** [2015] This study analyzes anxiety (stress) and predicts fatigue life to crack initiation in splice joints of an aircraft fuselage using composite materials. Composites enhance the strength-to-weight ratio, while aluminum alloys remain key in joint construction.

3. **Channabasavarj B. Dharani, Shivraj** and **Sai Sachin** [2016] This study presents stress analysis and fatigue life estimation of a critical splice joint in an aircraft fuselage under pressurization cycles. Fundamental joints are key structural elements, and analyzing their stress response is vital for ensuring airframe reliability.

4. **Adarsh Adeppa, K. E. Girish** and **Dr. M. S. Patil** [2018] This study conducts stress analysis and fatigue life prediction of a splice joint in an aircraft fuselage using the FEM approach, considering Aluminum Alloy 2024-T351 under cabin pressurization loads. A 2D finite element analysis examines stress distribution around bolt holes, identifying critical regions for fatigue crack initiation.

5. **Arunkumar K. N** and **Lohith N** [2019] This study analyzes the effect of rib and stringer spacing on reducing the weight of composite aircraft structures. It aims to optimize spacing and cross-sections for minimum weight while meeting buckling and manufacturing constraints.

6. **Dr. C. Udaya Kiran** and **Y. Vijaya Kumar** [2020] This study presents static and dynamic analysis of aircraft stiffened panels, which connect stiffeners to the skin for load distribution in the fuselage and wings. An I-section stiffened panel, more resistant to deformation than traditional T-sections, is modeled in CATIA, meshed in HyperMesh, and analyzed in ANSYS.

7. **Dr. C. Udaya Kiran** and **Y. Vijaya Kumar** [2020] This study analyzes aircraft stiffened panels, which connect the skin and stiffeners for load distribution, using an I-section for better resistance to deformation. The panel is modeled in CATIA, meshed in HyperMesh, and analyzed in ANSYS.

8. **William L. KO** and **Raymond H. Jackson** [2015] The study investigates buckling in cap-stiffened panels under uniaxial loading, finding that local buckling occurs at lower loads than predicted. Global buckling loads were higher than theoretical values, indicating local buckling is more prevalent. 4o mini

9. **D Quinn1 et al.,** [2016] This study explores the potential to introduce buckling control features without compromising panel toughness, aiming to generate experimental data for validating fracture propagation models. The results show that buckling control designs can improve both static strength and fatigue life by optimizing panel skin geometry.

10. **Mustafa Osaka et al.,**[2018] This study analyzes the post-buckling performance of panels with locally modified skin thickness using FE simulations and experiments, revealing that initial buckling loads were 30% lower than measured. Design optimizations could improve initial buckling strength by over 10%.

METHODOLOGY

DESIGN SPECIFICATIONS.

S. No	Name of the part in fuselage lattice structure	Dimensions
1	Hoop frame	100.946 mm
2	Lightening hole	3.91 mm
3	Stringer	180 mm
4	Floor frame	81.152 mm
5	Floor beam	188 mm
6	Floor braces	20.284 mm

TYPES OF MATERIALS OR MATERIAL DATA

1. Aluminium alloy 7075 – T6.

AL 7075-T6 > Constants

Density	2804 kg m^-3
Specific Heat Constant Pressure	848 J kg^-1 C^-1

AL 7075-T6 > Shock EOS Linear

Gruneisen Coefficient	Parameter C1 m s^-1	Parameter S1	Parameter Quadratic S2 s m^-1
2.2	5200	1.36	0

AL 7075-T6 > Shear Modulus

Aluminium alloy LM25

Shear Modulus Pa
2.67e+010

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Element	Percentage (%)
Aluminium (Al)	91.3 – 93.3
Silicon (Si)	6.5 – 7.5
Magnesium (Mg)	0.2 – 0.45
Iron (Fe)	0.1 max
Copper (Cu)	0.1 max
Manganese (Mn)	0.1 max
Zinc (Zn)	0.1 max
Titanium (Ti)	0.2 max
Others	0.05 each, 0.15 total max

This composition allows LM25 to retain excellent fluidity during casting while maintaining a good balance of mechanical properties and corrosion resistance.

Physical Properties of LM25 Aluminium Alloy

The physical properties of LM25 aluminium alloy contribute to its performance in various applications. Key physical properties are listed below.

Property	Value
Density	2.68 g/cm³
Melting Range	555 – 620 °C
Thermal Conductivity	150 W/m-K
Electrical Resistivity	0.034 μΩ-m
Coefficient of Thermal Expansion	21.5 x 10^-6 /K

2. Aluminium alloy 7068

Element	Weight percentage (%)
Aluminium, Al	85.43
Zinc, Zn	8.3
Magnesium, Mg	3
Copper, Cu	2.4
Iron, Fe	0.15
Zirconium, Zr	0.15
Silicon, Si	0.12
Manganese, Mn	0.1
Titanium, Ti	0.1
Chromium, Cr	0.05
Other (each)	0.05
Other (total)	0.15

TYPES OF ANALYSIS AND FORMULAS

The types of analysis that are applicable in this are described below:

Static Structural Analysis

Equivalent stress: Load/Area.

Equivalent strain:

Change in dimension / Original dimension.

Total Deformation (F): Proportionality constant * Change in length.

Modal Analysis

1. Total deformation node 1.
2. Total deformation node 2.
3. Total deformation node 3.
4. Total deformation node 4.
5. Total deformation node 5.
6. Total deformation node 6.

FORMULAS USED:

1. Lattice Geometry and Structural Analysis:

(i) Axial stress: $\sigma = F/A$

Where, F = Axial Force (N).

A = Cross-sectional area (m^2).

(ii) Shear stress in joints: $\tau = V/As$

Where, V = Shear Force (N). A_s = Shear Area (m^2).

2. Weight Estimation:

$W = \rho \cdot V$

Where, ρ = Density (Kg/m^3).

V = Total volume of material (m^3).

3. Global Stiffness Matrix (Finite Element Method):

$[K]\{u\} = \{F\}$

Where, u = Displacement vector.

F = Force vector.

K = Global stiffness matrix.

CATIA PROCESS:

open **Catia V5 R21.**

Select Mechanical Design And click on Part Design.

Open the part design select the plan and draw the section profile and click on exit work bench

Take pad option and a pocket option To Make Hoop Frame with Lightening Holes.

Using pad and linear pattern to create multiple

Finish the model

The Overview of Fuselage Component is designed

ANSYS PROCESS

- Select any 3D design software.
- Draw the object (Fuselage with lattice structure) in chosen 3D software.

- Now, select "File" and click on "Save (ctrl + S) or Save as". Then, select file format called 'igs (initial graphics exchange specification)'.
- Now, save the object in igs file format.
- Open "ANSYS workbench 2024 R2".

STATIC STRUCTURAL ANALYSIS

- Select "Static Structural".

Engineering Data:

- In this, "Engineering data" is in-built automatically.

Geometry:

- Select "Geometry". Then, click on "Import Geometry". Later, select "Browse".
- Select the igs file name of an object which has already drawn in CATIA V5 and saved in igs format. Then, Open the file.
- **"**Geometry" process is finished. Model:
- Now, select "Model". Then, give right click on "Edit". Later, the model of an object is displayed on screen.

(i) Mesh:

- Now, select "Mesh". Then, click on "Generate Mesh". The Nodes and Elements of an object are obtained.

(ii) Static Structural (A5):

- Select "Static Structural (A5)". Then, give a right click on "Insert". Then, select "Fixed support".
- Now, select the 'Face (ctrl + F)'. Later, click on the face of an object and then "Apply".
- Again, Select "Static Structural (A5)". Then, give a right click on "Insert". Then, select "Force".
- Now, select the 'Face (ctrl + F)'. Later, click on the face of an object which lies in opposite direction to the previously selected face.
- Now, assign the value of magnitude (depends upon object) in the table. Also, give direction and then "Apply".

(iii) Solution (A6):

- Click on "Solution (A6)". Now, select "Insert". Then, Click on 'Deformation' and then click on 'Total'.
- Again, Click on "Solution (A6)". Now, select "Insert". Then, click on 'Stress' and then select 'Equivalent (von-Mises)'.
- Again, Click on "Solution (A6)". Now, select "Insert". Then, click on 'Strain' and then select 'Equivalent (von-Mises)'.
- Again, Click on "Solution (A6)". Now, select "Solve".
- The results of an object are obtained.

Modal Analysis:

Select "Static Structural".

Engineering Data:

In this, "Engineering data" is in-built automatically.

Geometry:

- Select "Geometry". Then, click on "Import Geometry". Later, select "Browse".
- Select the igs file name of an object which has already drawn in CATIA V5 and saved in igs format. Then, Open the file.
- "Geometry" process is finished. Modal:
- Select "Modal (B5)". Give a right click and then click on "Solve".
- Now, click on "Solution (B6)". Select tabular data and then click on "create mode shape results".
- The results of an object are obtained in the form of deformation nodes:

(i) Total deformation 1.
(ii) Total deformation 2.
(iii) Total deformation 3.
(iv) Total deformation 4.
(v) Total deformation 5.
(vi) Total deformation 6.

4. INTRODUCTION TO CATIA V5R20

Install CATIA V5R20 on your system and then start it by double-clicking on the shortcut icon of **CATIA V5R20** on the desktop of your computer. You can also choose **Start > All Programs >CATIA > CATIA V5R20** from the taskbar to start the program design applications and is basically for Automotive

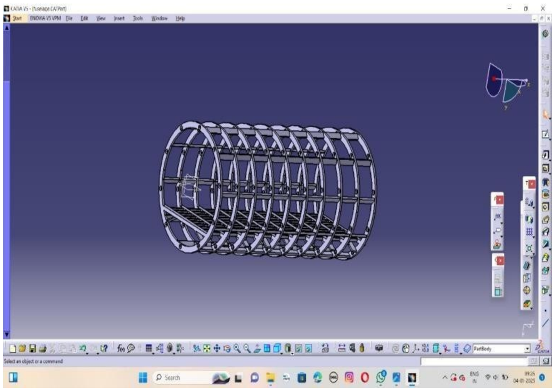

Fig: Overview of fuselage with lattice structure.

5. INTRODUCTION TO ANSYS

The Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When you first enter the program, you are at the Begin level.

At the Processor level, several processors are available. Each processor is a set of functions that perform a specific analysis task. For example, the general pre-processor (PREP7) is where you build the model, the solution processor (SOLUTION) is where you apply loads and obtain the solution, and the general postprocessor (POST1) is where you evaluate the

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results of a solution. An additional postprocessor, POST26, enables you to evaluate solution results at specific points in the model as a function of time.

STATIC STRUCTURAL ANALYSIS:

ALUMINIUM ALLOY 7075 – T6.

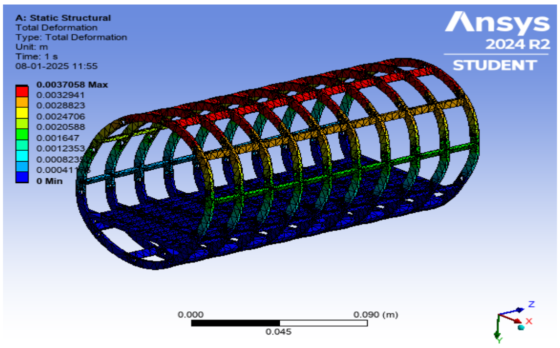

Fig: Total deformation (0m to $3.7058e^{-003}$m)

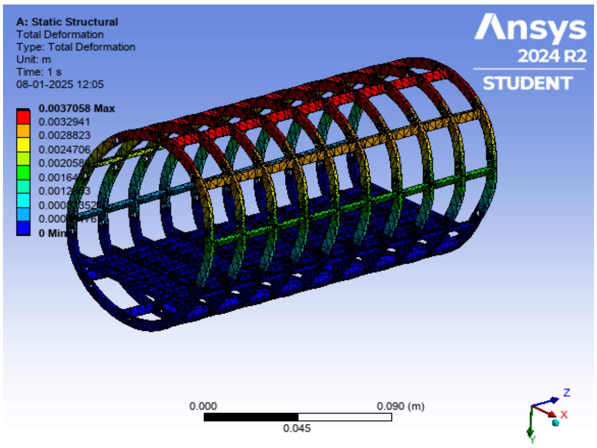

Fig: Total deformation (0 to $3.7058e^{-003}$ m)

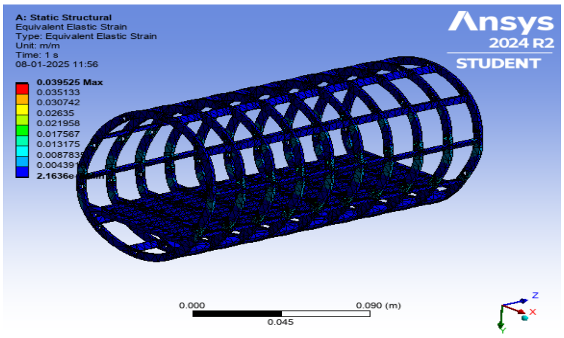

Fig: Equivalent Strain ($2.1636e^{-007}$ m/m to $3.9525e^{-002}$ m/m)

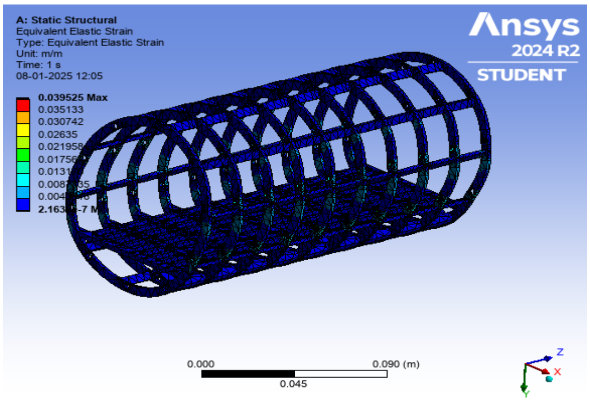

Fig: Equivalent Strain ($2.1636e^{-007}$m/m to $3.9525e^{-002}$ m/m)

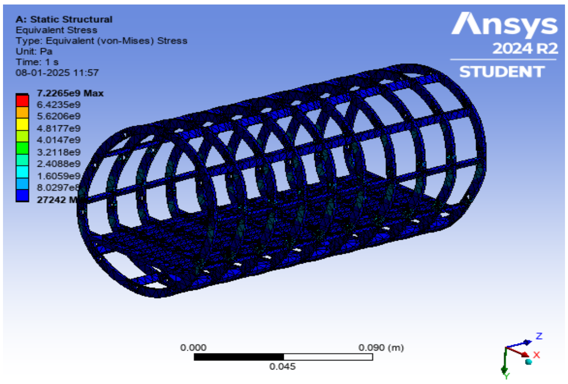

Fig: Equivalent Stress (27242 Pa to $7.2265e^{+009}$ Pa)

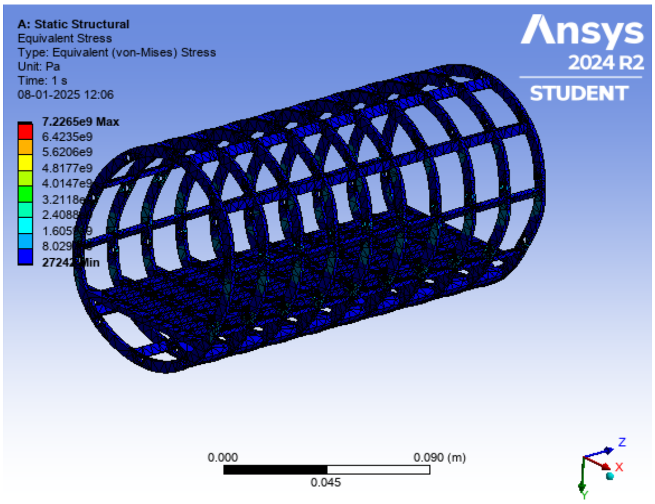

Fig: Equivalent Stress (27242 Pa to $7.2265e^{+009}$ Pa)

ALUMINIUM ALLOY LM25

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ALUMINIUM ALLOY 7068

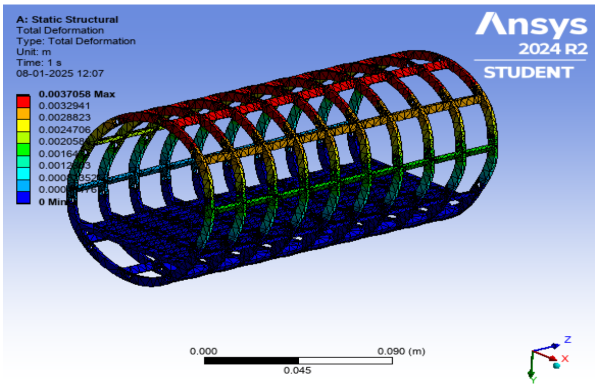


Fig: Total deformation (0 to 3.7058e^{-003} m)

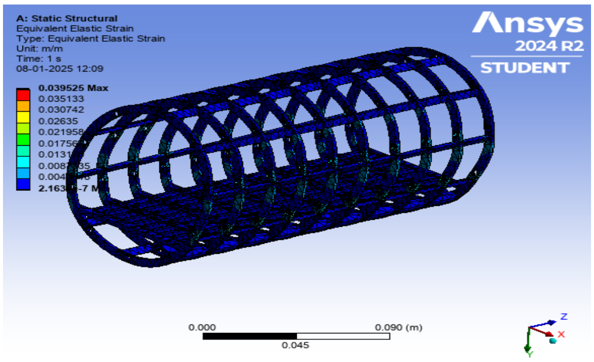


Fig: Equivalent Strain (2.1636e^{-007} m/m to 3.9525e^{-002} m/m)

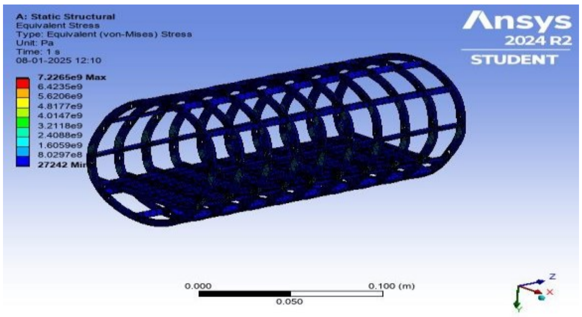
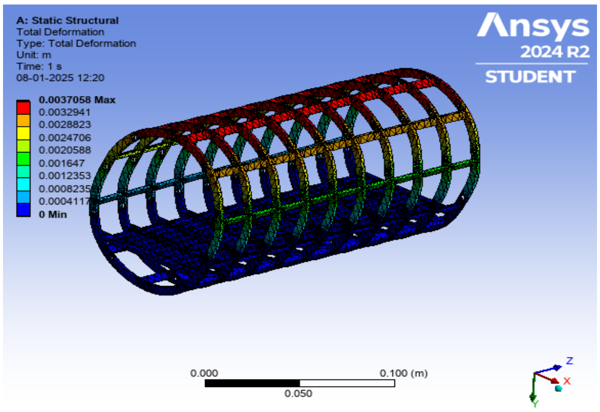


Fig: Equivalent Stress (27242 Pa to 7.2265e^{+009} Pa)

ALUMINIUM ALLOYS



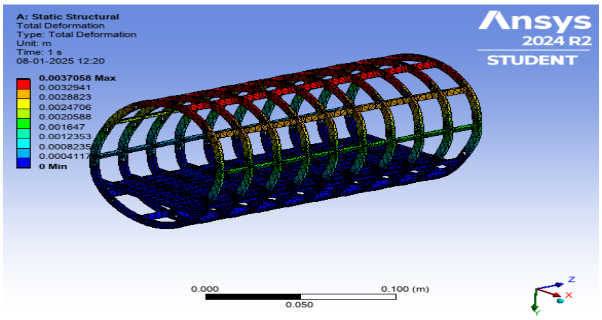


Fig: Total Deformation (0 to 1.0379e^{-002} m)

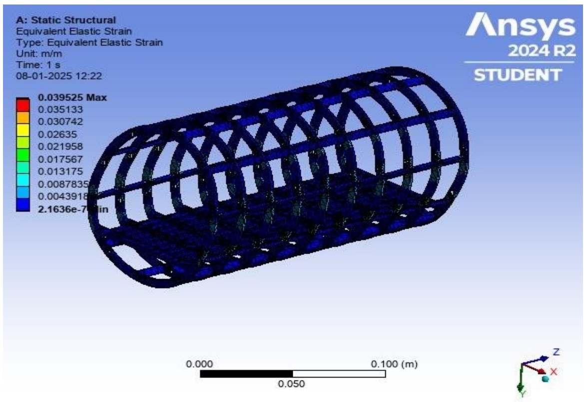


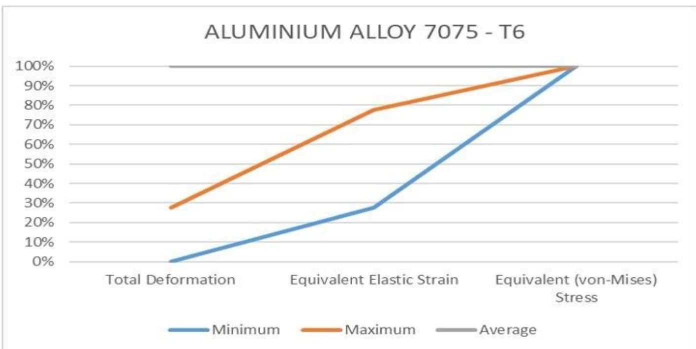
Fig: Equivalent Strain (5.8075e^{-007} m/m to 0.11101 m/m)

RESULTS

STATIC STRUCTURAL ANALYSIS:

ALUMINIUM ALLOY 7075 – T6.

Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
Results			
Minimum	0. m	2.1636e^{-007}m/m	27242 Pa
Maximum	3.7058e^{-003} m	3.9525e^{-002} m/m	7.2265e^{+009} Pa
Average	9.6914e^{-004} m	1.7452e^{-003} m/m	2.5753e^{+008} Pa



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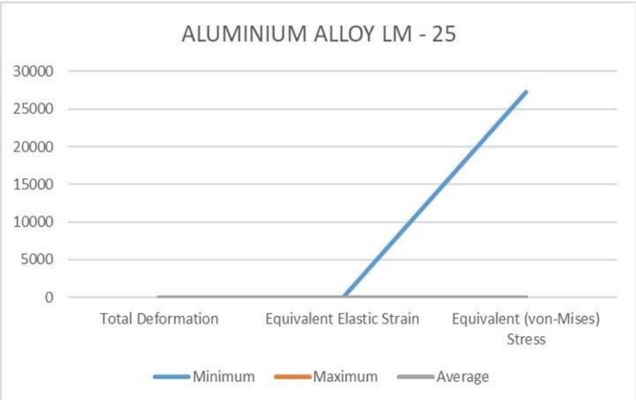
ALUMINIUM ALLOY LM25

Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
Results			
Minimum	0. m	5.8075e^{-007} m/m	26035 Pa
Maximum	1.0379e^{-002} m	0.11101 m/m	7.2071e^{+009} Pa
Average	2.7135e^{-003} m	4.9059e^{-003} m/m	2.5738e^{+008} Pa



ALUMINIUM ALLOY 7068

Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
Results			
Minimum	0. m	2.1636e^{-007} m/m	27242 Pa
Maximum	3.7058e^{-003} m	3.9525e^{-002} m/m	7.2265e^{+009} Pa
Average	9.6914e^{-004} m	1.7452e^{-003} m/m	2.5753e^{+008} Pa

MODAL ANALYSIS:

ALUMINIUM ALLOY 7075 – T6.

Object Name	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4	Total Deformation 5	Total Deformation 6
Definition						
Type	Total Deformation					
Mode	1.	2.	3.	4.	5.	6.
Results						
Minimum	0.51117 m	1.0746e-002 m	0.7387 m	0.33593 m	0.39763 m	1.049 m
Maximum	3.6637 m	4.5132 m	4.3297 m	4.0781 m	4.3488 m	3.298 m
Average	2.1671 m	2.0832 m	2.1009 m	2.042 m	2.0581 m	2.2236 m
Information						
Frequency	0. Hz			7.1302e-003 Hz	1.3353e-002 Hz	1.8459e-002 Hz

ALUMINIUM ALLOY LM25

Object Name	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4	Total Deformation 5	Total Deformation 6
Definition						
Type	Total Deformation					
Mode	1.	2.	3.	4.	5.	6.
Results						
Minimum	0.45395 m	5.2814e-002 m	0.78043 m	0.36549 m	0.39086 m	1.0447 m
Maximum	3.7546 m	4.5883 m	4.3854 m	4.2055 m	4.3963 m	3.3256 m
Average	2.1802 m	2.1078 m	2.134 m	2.0575 m	2.0746 m	2.2474 m
Information						
Frequency	0. Hz			6.779e-003 Hz	1.3405e-002 Hz	1.8763e-002 Hz

ALUMINIUM ALLOY 7068

Object Name	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4	Total Deformation 5	Total Deformation 6
Definition						
Type	Total Deformation					
Mode	1.	2.	3.	4.	5.	6.
Results						
Minimum	0.45395 m	5.2814e-002 m	0.78043 m	0.36549 m	0.39086 m	1.0447 m
Maximum	3.7546 m	4.5883 m	4.3854 m	4.2055 m	4.3963 m	3.3256 m
Average	2.1802 m	2.1078 m	2.134 m	2.0575 m	2.0746 m	2.2474 m
Information						
Frequency	0. Hz			6.779e-003 Hz	1.3405e-002 Hz	1.8763e-002 Hz

CONCLUSION

The structural analysis of fuselage with lattice structure of light jet aircraft has been presented. The result shows that the fuselage lattice structure is rigid and safe according to the failure theory analysis, which means the working stress is far below the yield strength of the materials. The result at this stage is satisfied higher than the stiffened shell structure but it needs more attention to the critical area of the structure since the fuselage is not as one body but consist of assembly parts constructed it. The critical area carried under study also includes the kinds of joins which assembled the whole parts. In turn, the design needs validation by experimental test and analysis with static and dynamic loads in order to get the good and safety result before producing the aircraft. In conclusion, the structural behaviour of has been simulated through four different cases of fuselage with lattice structure, which contain aluminium alloy 7075 – t6 in first case and aluminium alloy lm25 in second case aluminium alloy 7068 third case aluminium alloys fourth case. the second case, third case , fourth case of the fuselage with lattice structure shows lower deformation compared to the first case in both fixed structural investigation and modal investigation. Besides, the validation of results from the past studies using ansys is considered as a success and dependable as the percentage error is allowable. Finally, through the static structural model investigation, the deformation of the lifting surface structure has also been observed and is figured out. as future enhancement, different materials can be tested with different boundary conditions to find more suitable materials with good .fuselage made from composite materials performs better than conventional materials in all tests and the weight of fuselage is also been reduced by 10.7%.

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