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Design Analysis and Fabrication of the Aircraft Landing Gear

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Abstract: Designing a landing gear of an aircraft for sustaining structural integrity and performance is the key concept in aircraft engineering which helps in guaranteeing safe take-offs and landings. The components like shock absorbers, lug joints, and torque links considerably effect durability of landing gear. Materials like titanium alloys, high speed steel, aluminium alloys, AISI steel and carbon fiber-reinforced polymer are the frequently used materials with their own strengths and limitations. Although titanium alloys offer superior strength-to-weight ratios, they are more expensive than aluminum alloys, which are more cost-effective but could not be as strong when subjected to extreme stress. CFRP materials improve mechanical qualities while lowering weight. The requirement for exact design and careful analysis is highlighted by the fact that landing gear failures are frequently caused by material fatigue, excessive loads, or incorrect assembly. The use of the Finite Element Method (FEM) improves reliability, ensuring greater safety and efficiency in modern aircraft. This research focuses on developing and assessing the structural integrity of aircraft landing gear, followed by building and testing a prototype to evaluate its performance.

Keywords*: Shock Absorbers, Lug Joints, Torque Links, FEM, Structural Integrity, Aircraft Safety, Weight Reduction.*

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I. INTRODUCTION

A brief study of aircraft landing gear as shown in fig.1. The main purpose of using landing gear in aircraft is for take-off and landing the aircraft on runway. The common materials include Titanium alloys, Carbon fiber-reinforced polymers (CFRP), high-strength stainless steel, Aluminium 7075, and Alloy Steel 4340. These materials offer strength and durability under stress.

- STRUCTURAL SUPPORT: The landing gear provides the primary structural support to the aircraft while it is on the ground. It absorbs the impact forces during landing and supports the aircraft's weight during taxiing, take-off, and landing.
- SHOCK ABSORPTION: The landing gear includes shock absorbers, typically oleo-pneumatic struts, which compress to absorb the impact energy during landing. These struts contain a combination of hydraulic fluid and compressed gas, which cushion the landing impact and prevent damage to the aircraft structure.
- RETRACTION AND EXTENSION: Most modern aircraft have retractable landing gear to reduce aerodynamic drag during flight. Hydraulic or electric actuators extend the landing gear before landing and retract it after takeoff. The retraction and extension mechanisms are controlled by the pilot through the aircraft's control systems.
- BRAKING SYSTEM: The landing gear is equipped with a braking system, typically found on the main wheels. This system helps to slow down and stop the aircraft during landing roll-out and during ground operations. Modern braking systems often include anti-skid features to prevent wheel lock-up and maintain control during braking.
- STEERING MECHANISM: Nose landing gear usually includes a steering mechanism that allows the pilot to control the direction of the aircraft while taxiing on the ground. This is typically achieved through hydraulic actuators linked to the aircraft's steering controls.
- TIRE AND WHEEL ASSEMBLY: The tires and wheels of the landing gear are designed to withstand the high loads and stresses encountered during take-off and landing. They provide the necessary friction for braking and the structural integrity to support the aircraft.

II. LITERATURE REVIEW

Several research works are being conducted to optimize the materials and thereby improve the structural stability of landing gear. The studies on the S1223 aerofoil and carrier arresting processes improved durability, manufacturability,

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and safety. Aerofoil changes enhanced lift and structure, while a coupling model captured gear interactions for efficiency [1,3]. The studies showed that the NL2 fairing reduced noise by 2–6 dBA, while the combined LNTs reduced it by 4–7 dBA. Propeller failures were caused by notches from foreign object damage (FOD) and fatigue due to mechanical factors, but no corrosion was found [4,20]. Optimization studies on EMAS using a Boeing 737 highlighted the need for load measurements on landing gears. Research also found low-density concrete with high crushing strength reduces arresting distance, enhancing airport safety [7,8]. Optimization studies on landing gear materials showed Ti-6Al-4V's impact on natural frequency, while titanium alloy 10V-2Fe-3Al offered high safety and minimal stress. Fatigue analysis revealed corrosion and fretting failures in the Piaggio Avant P180 wheel flange, emphasizing improved inspections. Topology optimization of the AHRLAC nose wheel fork in Ti6Al4V(ELI) enhanced strength-to-weight ratio and fatigue performance. [9,19,22,5]. Failure analysis on landing gear components revealed fatigue cracks in the piston rod end due to high stress concentrations. The nose landing gear axle and support strut failed from overload conditions, with the strut's failure linked to improper pin installation [23,24,25]. Showed Carbon-Hercules AS4 composites improve landing gear performance, Ti 10-2-3 via LPBF has lower fatigue strength due to defects, and wheel dynamometers enhance safety by measuring forces during manoeuvres. [26,28,30]. Optimization Studies found SAE 1035 Steel outperforms Aluminium 7075, Titanium 6Al-4V, and Alloy Steel 4340, while high-strength stainless steel shows lower stress and deformation, enhancing landing gear integrity [32,33].

Fig 1: Aircraft Landing Gear

This showed torque link design reduced weight by 23.75%, composites improved energy absorption, and titanium alloy offered the best stress and safety performance for landing gear [34,35,36]. Studies on landing gear design achieved 67% weight savings using a performance-focused approach and ESLM for optimization. For 2024 aluminium alloy propellers, FOD-induced fatigue highlighted the need for strict maintenance protocols [38,40]. Optimization studies showed HMMS with distributed sensors improves landing gear health monitoring, fiber optics enhance reliability in weight-on-wheel systems, and pre-rotation strategies reduce tyre wear. Glass fiber prepregs optimize landing gear weight while maintaining strength [10,11,31,2]. On MR dampers showed peak efficiency at a 30mm drop height, accurate dynamic behavior modeling, and effective neural network control for varied landing scenarios. Improved pressure loss modeling reduced RMS error, enhancing shock absorber performance [6,12,16,18]. Studies on DSS landing gear revealed node deviation delays locking, while structural clearance has minimal impact. Nose gear material optimization reduced cylinder mass by 22.32% while ensuring safety. Multibody modeling showed attachment deformability is key for accurate landing dynamics [13,14,15]. The numerical methods accurately simulate landing gear dynamics, FEM predicts HPT blade creep under stress, and precise dimensions with kinematic analysis ensure main landing gear safety [17,27,21]. Finite element analysis of nose landing gear highlighted stress and displacement behavior, aligning with FAA safety guidelines. Studies on composites and design parameters improved landing gear performance, while fatigue analysis of light aircraft gear emphasized the impact of load profiles on durability [29,37,39].

III. METHODOLOGY

The Fig.2.Showcases the assembled aircraft landing gear, designed and modelled using SolidWorks for analysis purposes. This assembly includes essential components such as the wheel hub, disc plate, shafts, linkages, and end caps, forming a cohesive system that supports the aircraft during landing, take-off, and ground operations. The design emphasizes precision engineering to ensure functionality, durability, and reliability.

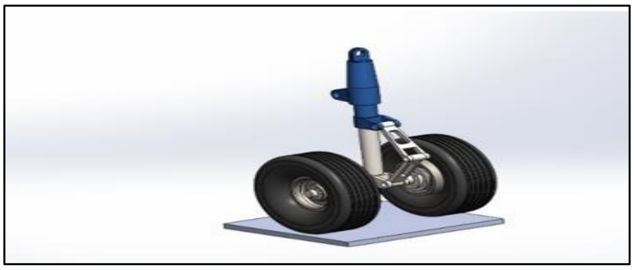

Fig 2: Assembled Aircraft Landing Gear

IV. ANALYSIS

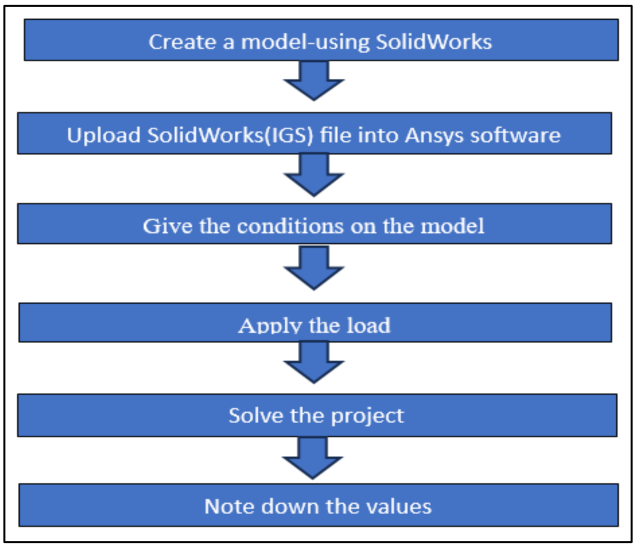

Fig 3: Step by Step Process

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V. RESULTS

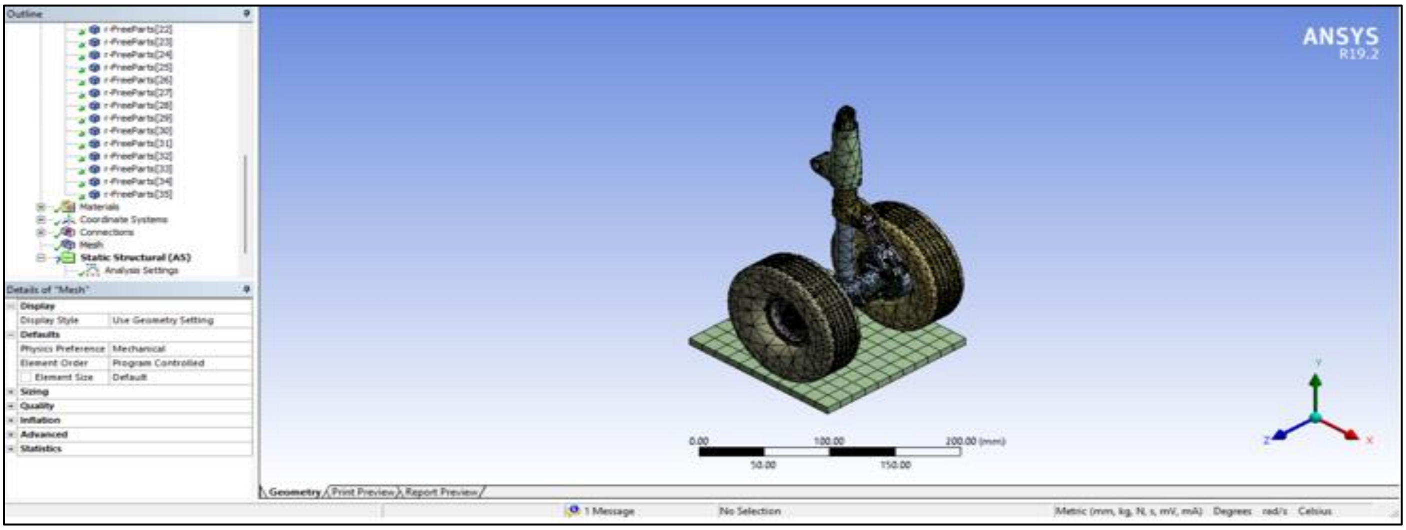

Fig 4: Aircraft Landing Gear on Mesh

A fine mesh was used in high-stress areas, with a coarser mesh elsewhere. The mesh had 250,000 elements and 300,000 nodes, with a 10 mm element size and refinements for accuracy. Quality parameters were maintained for reliable results.

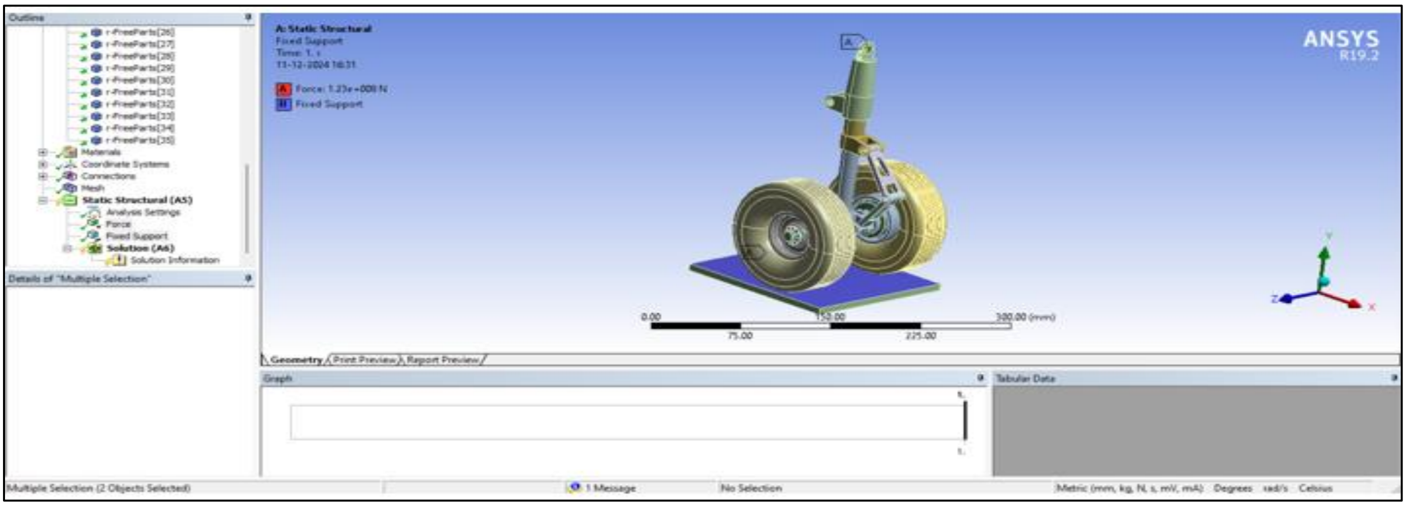

Fig 5: Applying Force and Fixing the Plane

As shown in Fig. 5, the landing gear base is fixed to simulate its attachment to the aircraft, ensuring proper force transmission. A 123,000,500 N force is applied to the top of the leg to simulate landing load.

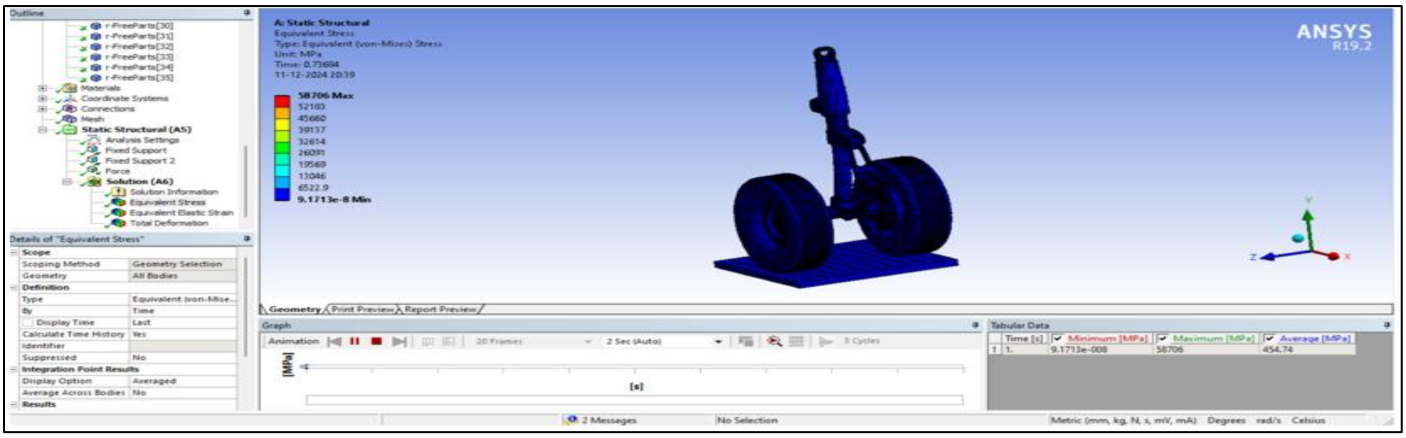

Fig 6: Stress used Material: Tl Alloy

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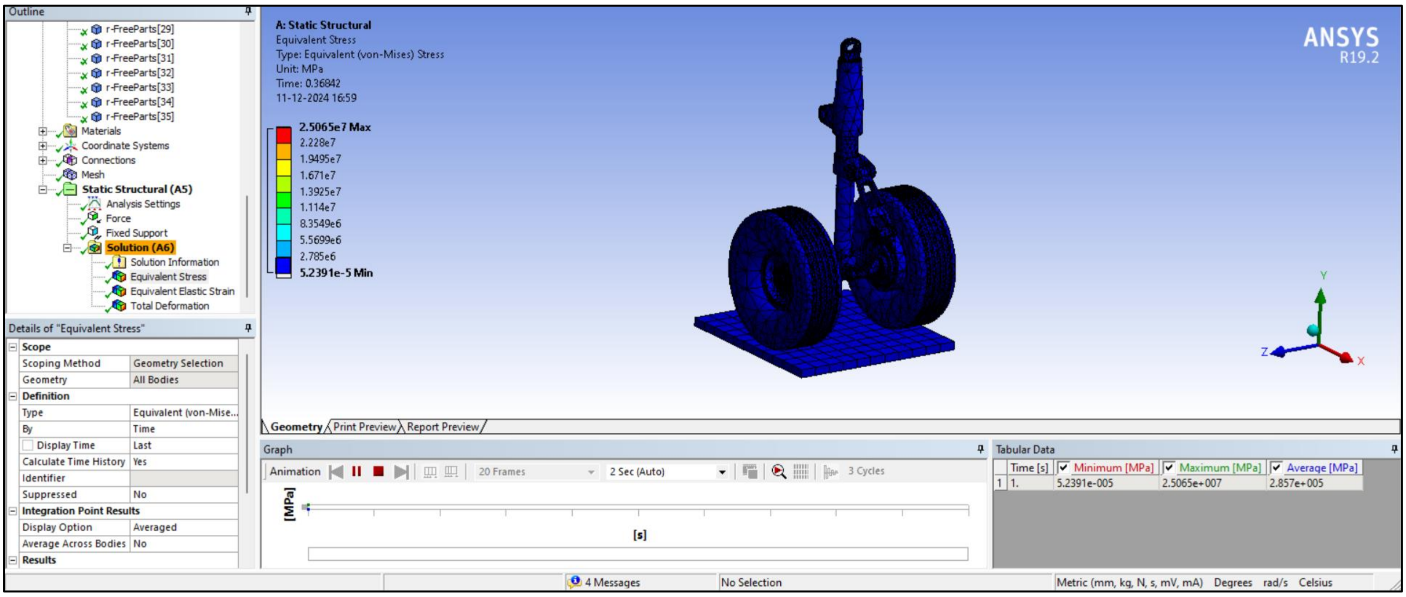

Fig 7: Stress used Material: CFRP

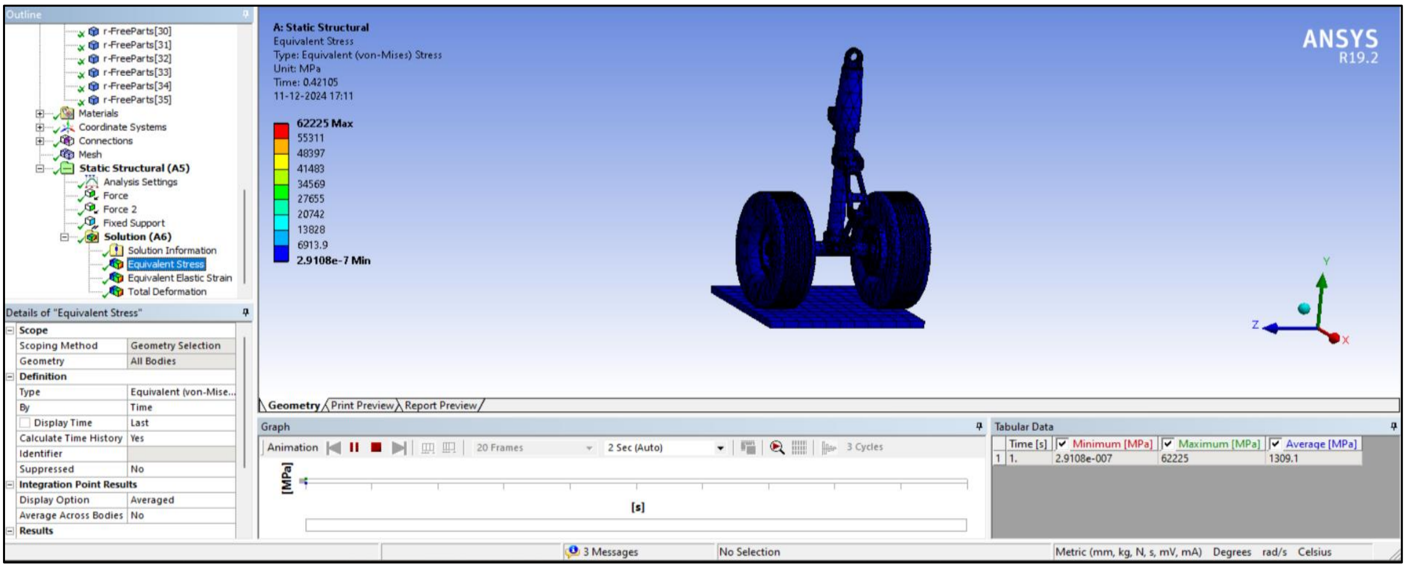

Fig 8: Stress used Material: AISI 4130

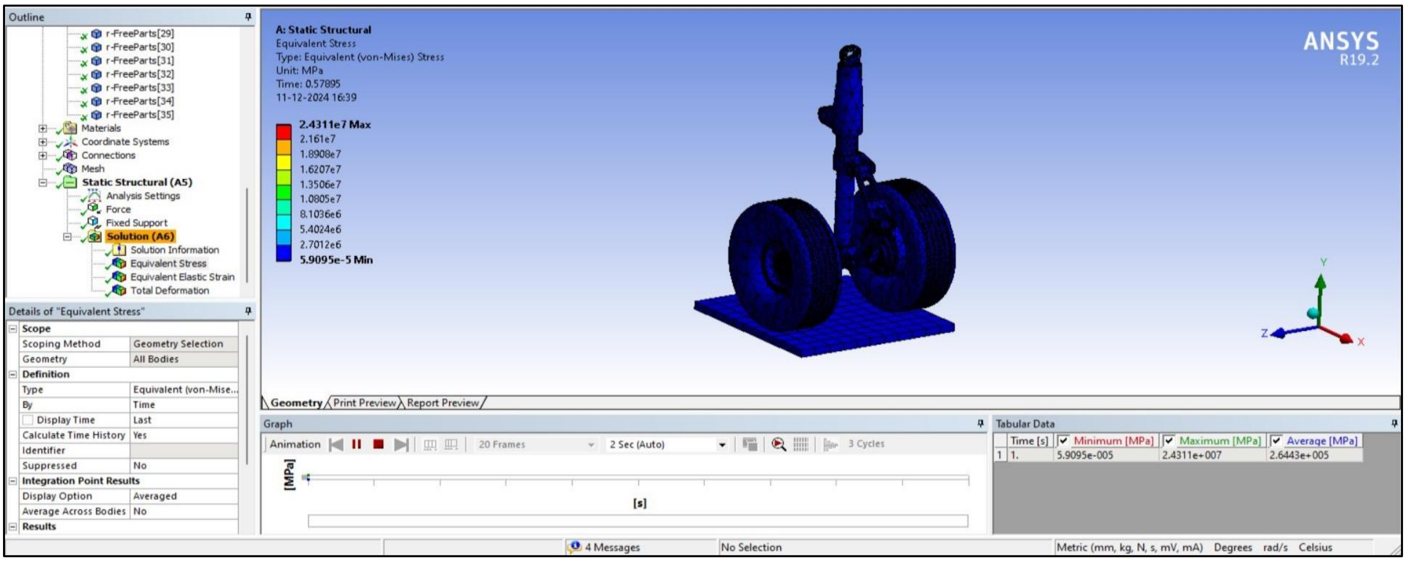

Fig 9: Stress used Material: HSS

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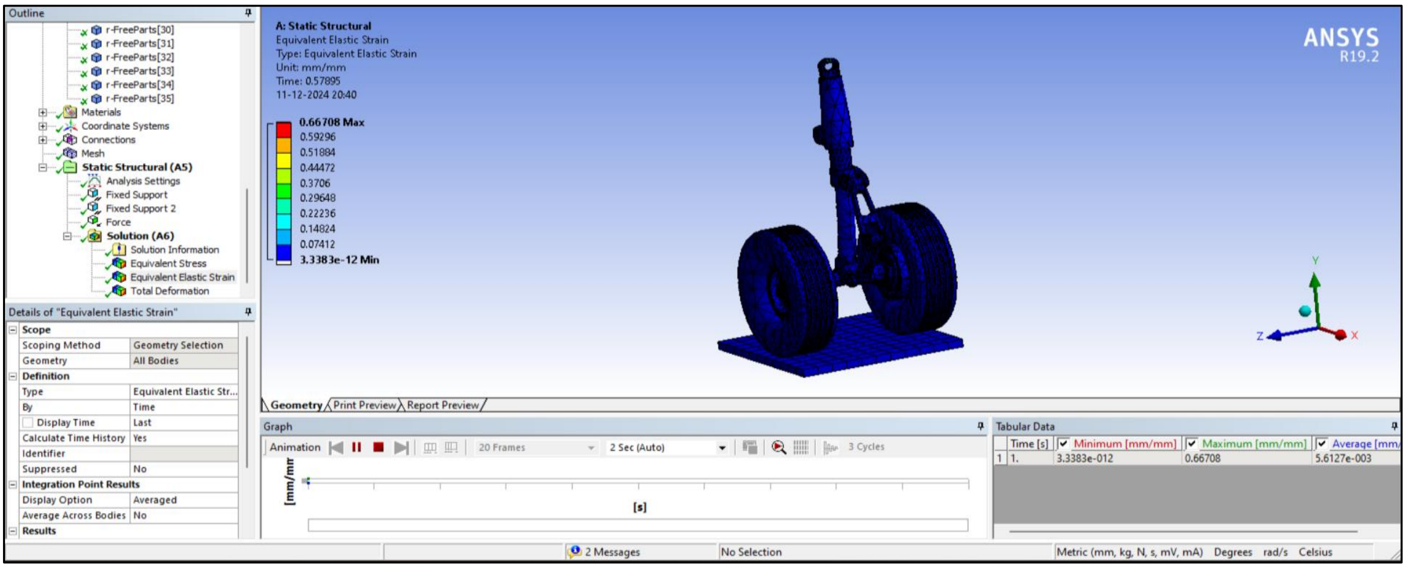

Fig 10: Strain used Material: TI Alloy

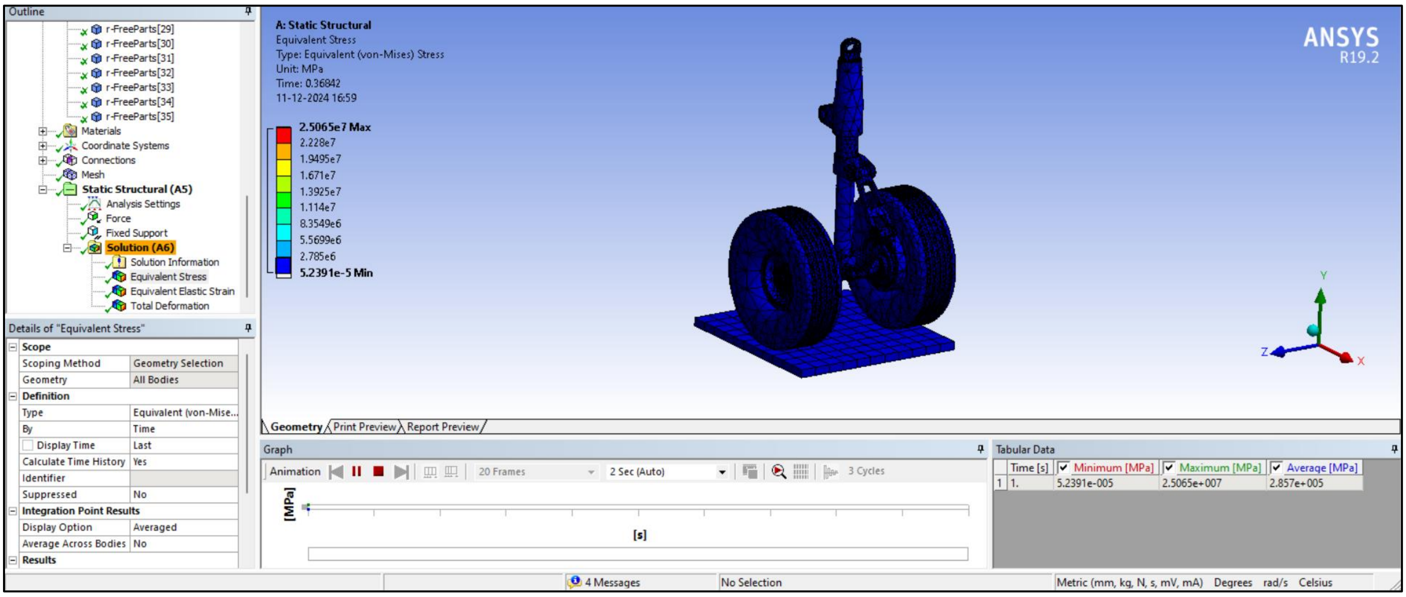

Fig 11: Strain used Material: CFRP

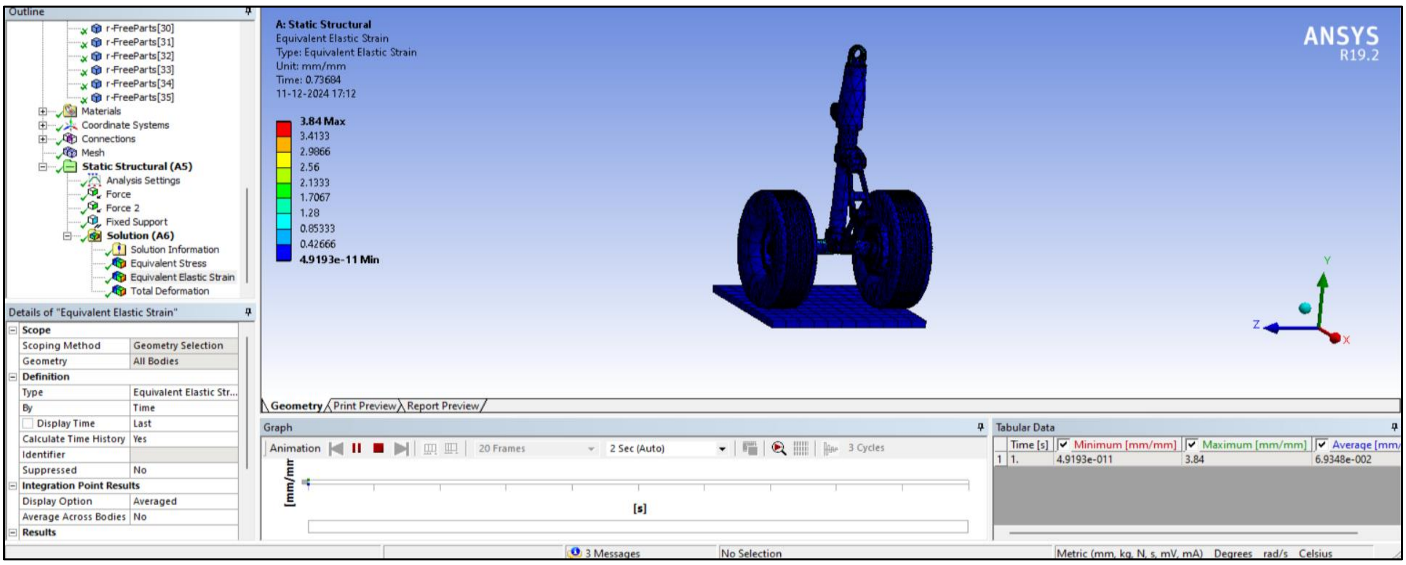

Fig 12: Strain used Material: AISI 4130

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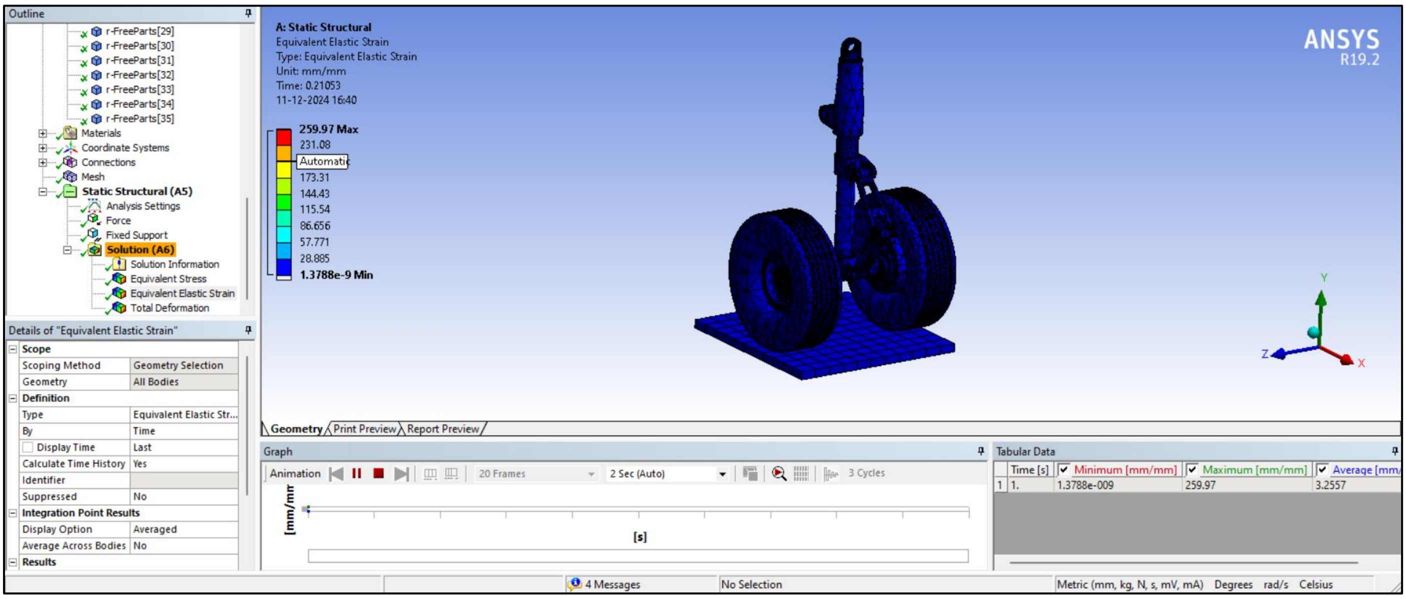

Fig 13: Strain used Material: HSS

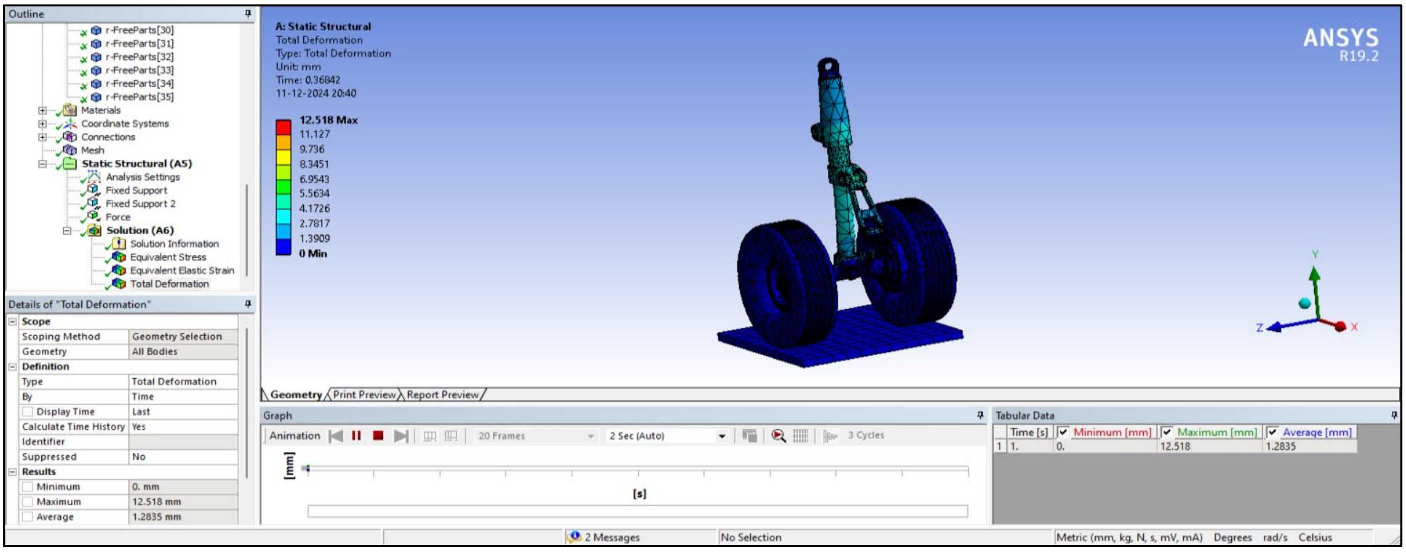

Fig 14: Total Deformation used Material: TI Alloy

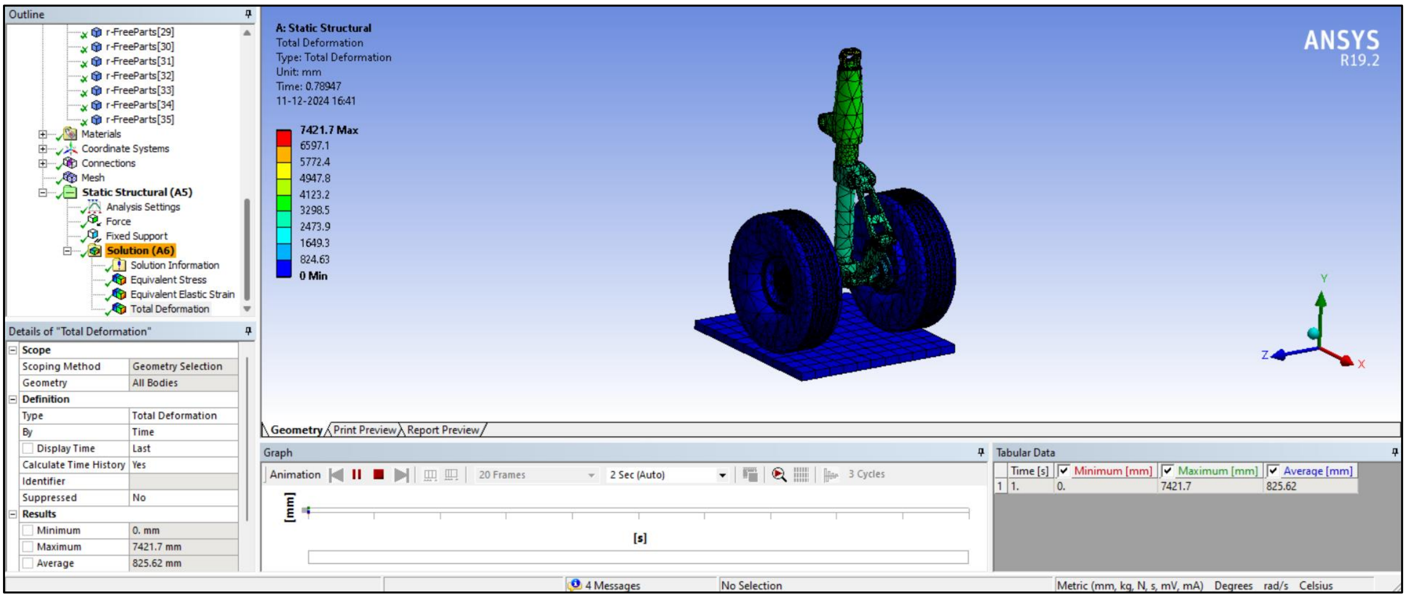

Fig 15: Total Deformation used Material: CFRP

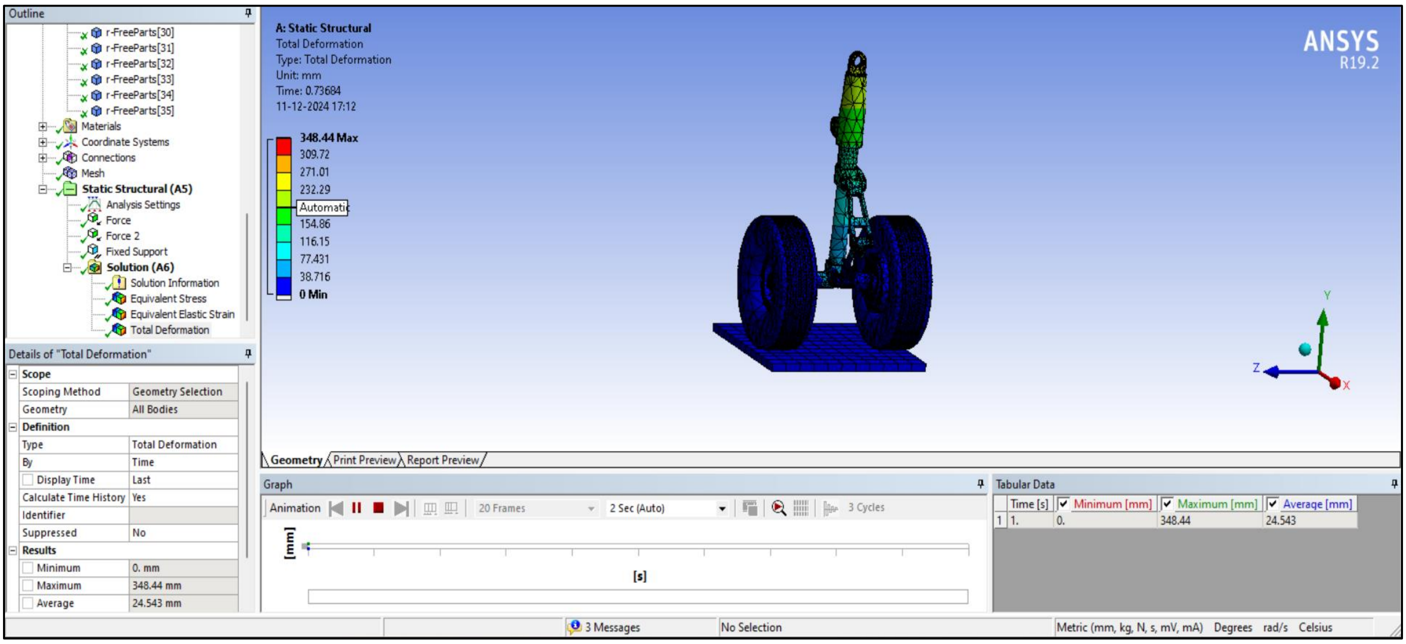

Fig 16: Total Deformation used Material: AISI 4130

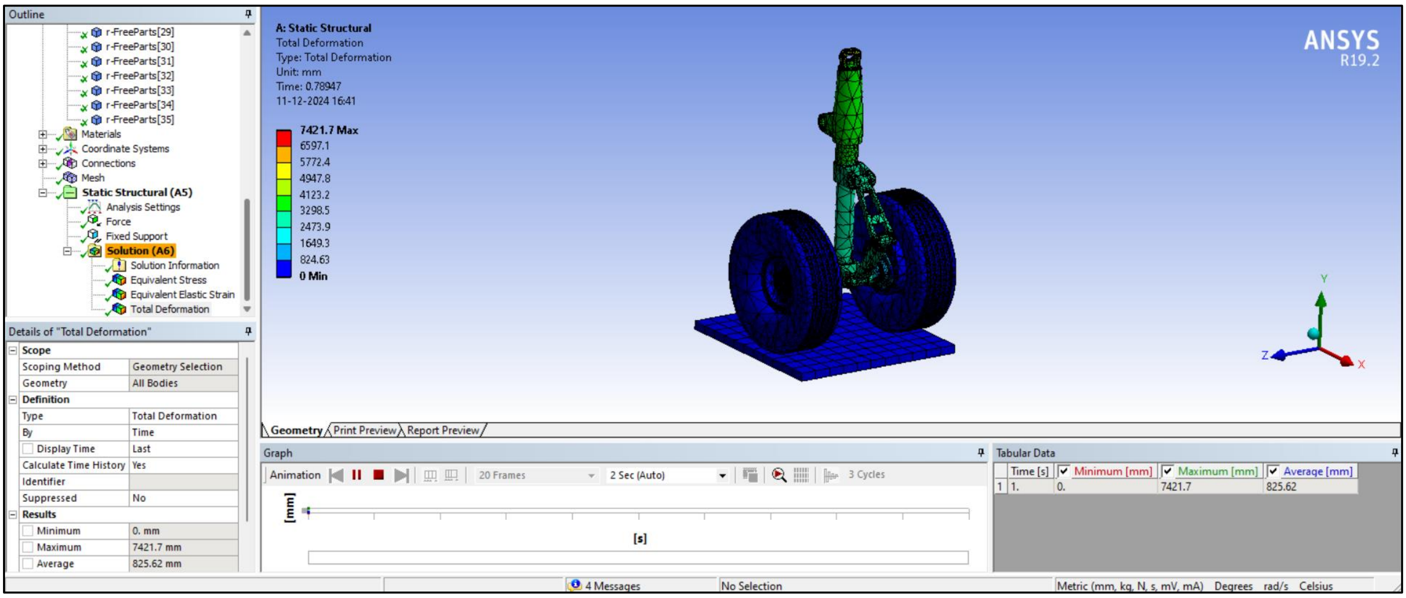

Fig 17: Total Deformation used Material HSS

Table 1: Force Acting on the Landing Gear During Aircraft Landing

PROPERTIES	MATERIALS			
	CFRP	TI	HSS	AISI4130
Max Stress	2.5303×107Mpa	2.4311×107MPa	3.4209×107Mpa	2.6402×107Mpa
Min stress	3.7667×10−5MPa	2.6143×10−5MPa	4.162×10−5Mpa	4.8078×10−5Mpa
Max Strain	270.1	259.97	330.68	428.46
Min Strain	9.7019×10−10	9.3009×10−10	6.2277×10−9	8.552×10−9
Max Deformation	3864.2mm	7421.7mm	5698.3mm	5609.8mm
Min Deformation	0	0	0	0

Based on the analysis of the above table the CFRP material exhibits values that are closest to those of titanium (Ti), indicating comparable structural performance in the evaluated parameters.

A. Testing

The aircraft landing gear was fabricated using CFRP material and then subjected to testing to evaluate its performance and structural integrity.

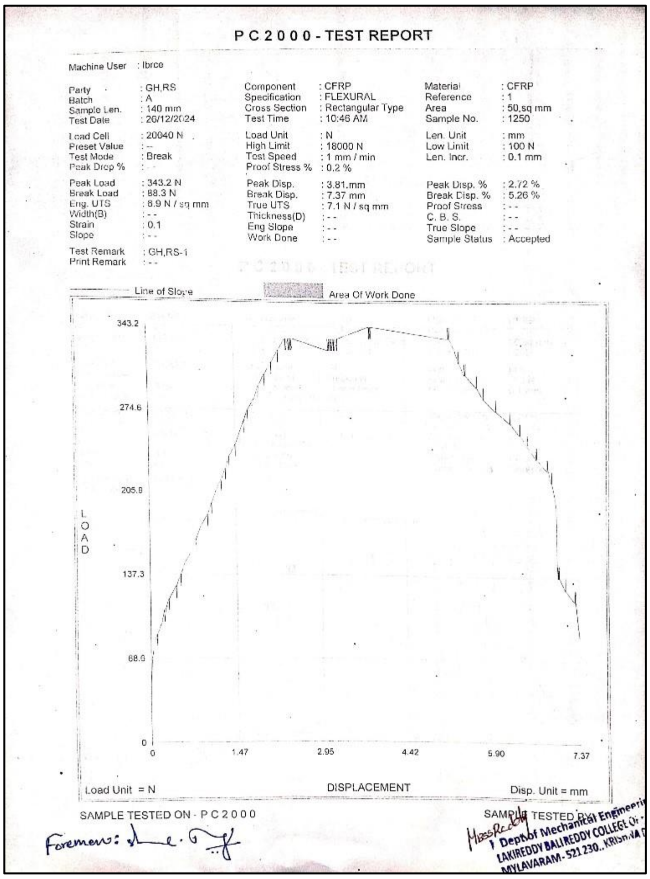

Fig 18: Bending Test Result-1

Fig 19: Bending Specimen-1

As shown in Fig. 18, specimen one recorded a peak load of 343.2 N and a break load of 88.3 N, with a break displacement of 7.37 mm. These values highlight the material's mechanical properties, including bending strength. Fig. 19. below illustrates the tested specimen.

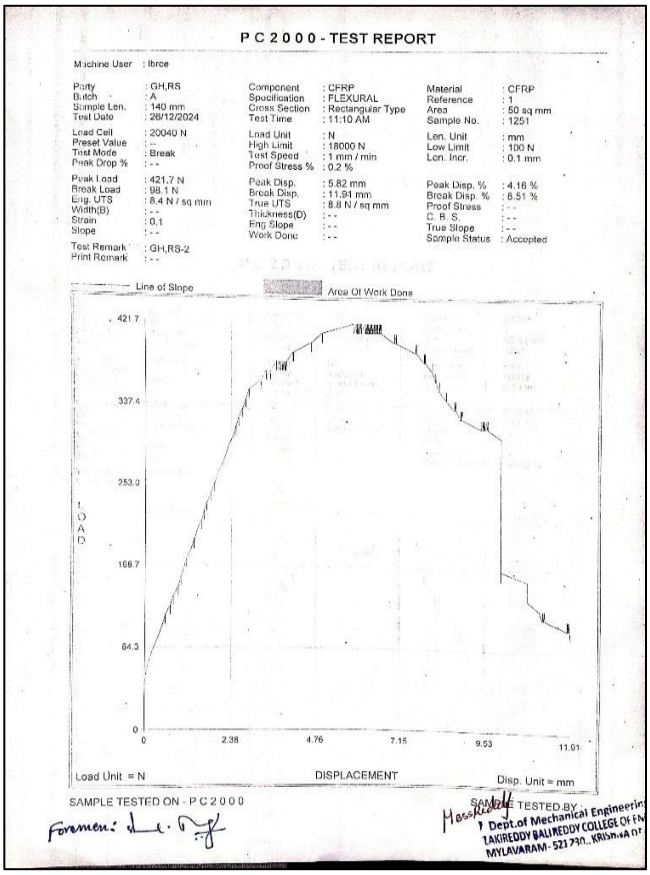

Fig 20: Bending Test Result-2

As shown in Fig. 20, specimen two recorded a peak load of 421.7 N and a break load of 98.1 N, with a break displacement of 11.91 mm. These values highlight the material's bending strength and deformation under stress. Fig. 21, below illustrates the tested specimen.

Fig 21: Bending Specimen-2

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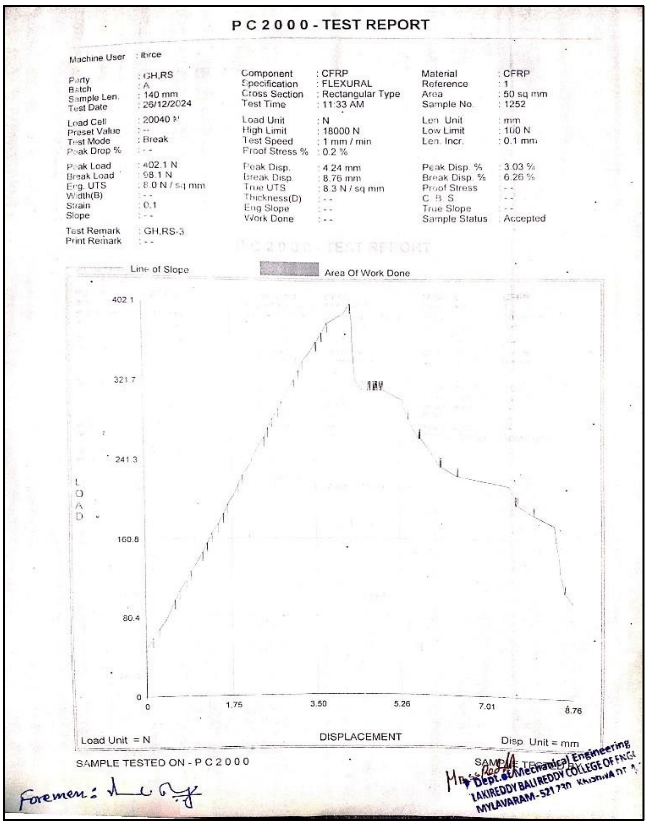

P C 2 0 0 0 - TEST REPORT

Machine User : Ibrce

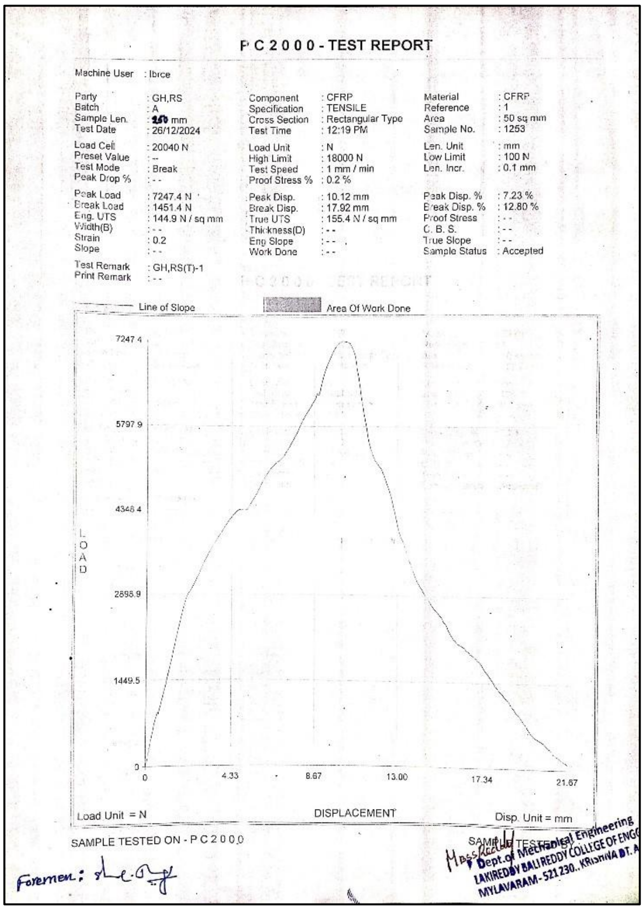
Party	: GH,RS	Component	: CFRP	Material	: CFRP
Batch	: A	Specification	: FLEXURAL	Reference	: 1
Sample Len.	: 140 mm	Cross Section	: Rectangular Type	Area	: 50 sq mm
Test Date	: 26/12/2024	Test Time	: 11:33 AM	Sample No.	: 1252
Load Cell	: 20040 N	Load Unit	: N	Len. Unit	: mm
Preset Value	: --	High Limit	: 18000 N	Low Limit	: 100 N
Test Mode	: Break	Test Speed	: 1 mm / min	Len. Incr.	: 0.1 mm
Peak Drop %	: - -	Proof Stress %	: 0.2 %		
Peak Load	: 402.1 N	Peak Disp.	: 4.24 mm	Peak Disp. %	: 3.03 %
Break Load	: 98.1 N	Break Disp.	: 8.76 mm	Break Disp. %	: 6.26 %
Eng. UTS	: 8.0 N / sq mm	True UTS	: 8.3 N / sq mm	Proof Stress	: - -
Width(B)	: - -	Thickness(D)	: - -	C. B. S.	: - -
Strain	: 0.1	Eng Slope	: - -	True Slope	: - -
Slope	: - -	Work Done	: - -	Sample Status	: Accepted

Test Remark : GH,RS-3
Print Remark : - -

Fig 22: Bending Test Result-3

As shown in Fig. 22, specimen three recorded a peak load of 402.1 N and a break load of 98.1 N, with a break displacement of 8.76 mm. These results highlight the material's bending strength and deformation behavior under stress. Fig. 23 below illustrates the tested specimen.

Fig 23: Bending Specimen-3


P C 2 0 0 0 - TEST REPORT

Machine User : Ibrce

Party	: GH,RS	Component	: CFRP	Material	: CFRP
Batch	: A	Specification	: TENSILE	Reference	: 1
Sample Len.	: 250 mm	Cross Section	: Rectangular Type	Area	: 50 sq mm
Test Date	: 26/12/2024	Test Time	: 12:19 PM	Sample No.	: 1253
Load Cell	: 20040 N	Load Unit	: N	Len. Unit	: mm
Preset Value	: --	High Limit	: 18000 N	Low Limit	: 100 N
Test Mode	: Break	Test Speed	: 1 mm / min	Len. Incr.	: 0.1 mm
Peak Drop %	: - -	Proof Stress %	: 0.2 %		
Peak Load	: 7247.4 N	Peak Disp.	: 10.12 mm	Peak Disp. %	: 7.23 %
Break Load	: 1451.4 N	Break Disp.	: 17.92 mm	Break Disp. %	: 12.80 %
Eng. UTS	: 144.9 N / sq mm	True UTS	: 155.4 N / sq mm	Proof Stress	: - -
Width(B)	: - -	Thickness(D)	: - -	C. B. S.	: - -
Strain	: 0.2	Eng Slope	: - -	True Slope	: - -
Slope	: - -	Work Done	: - -	Sample Status	: Accepted

Test Remark : GH,RS(T)-1
Print Remark : - -

Fig 24: Tensile Test Result-1

As shown in Fig 24, specimen one recorded a peak load of 7247.4 N and a break load of 1451.4 N, with a break displacement of 17.92 mm during the tensile test. These results highlight the material's tensile strength and deformation under stress. Fig. 25, below illustrates the tested specimen.

Fig 25: Tensile Specimen-1

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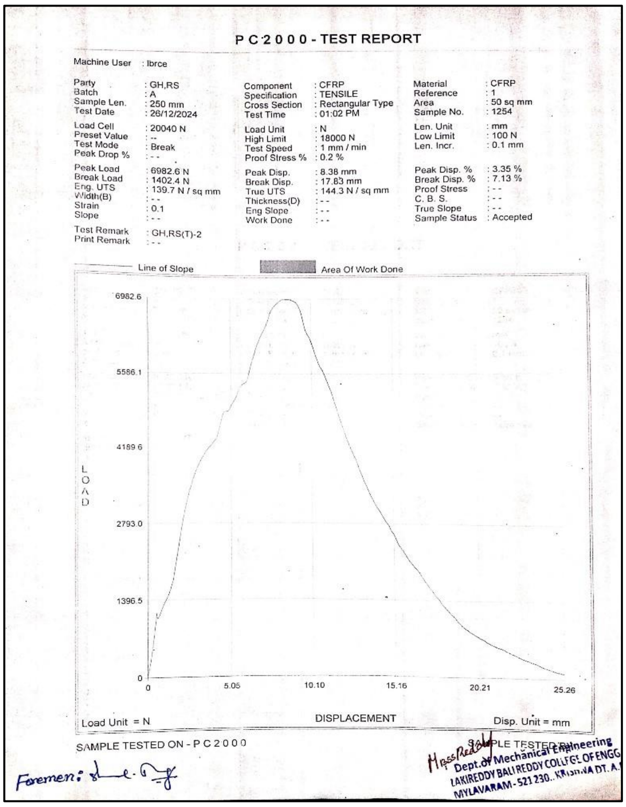

Fig 26: Tensile Test Result-2

As shown in Fig. 26, specimen two recorded a peak load of 6982.6 N and a break load of 1402.4 N, with a break displacement of 17.83 mm during the tensile test. These results highlight the material's tensile strength and deformation behavior. Fig. 27, below illustrates the tested specimen.

Fig 27: Tensile Specimen-2

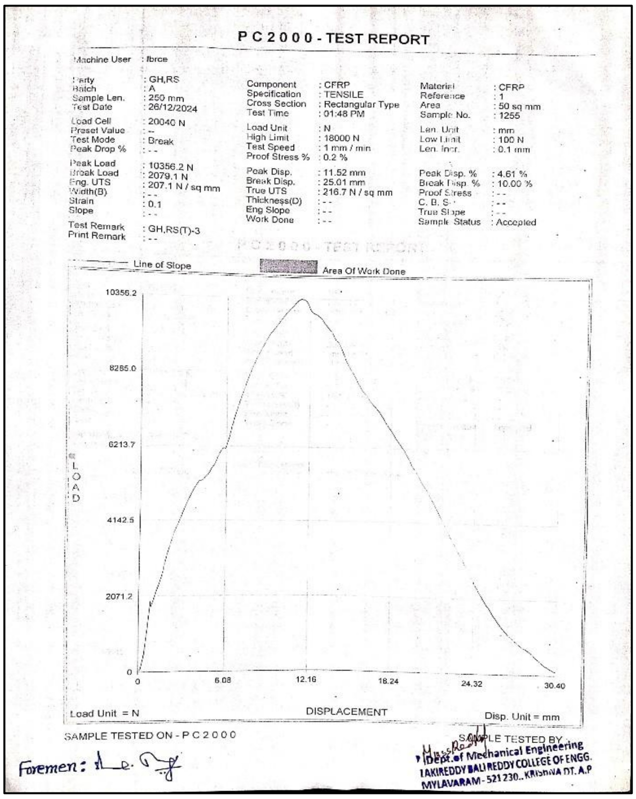

Fig 28: Tensile Test Result-3

As shown in Fig. 28, specimen three recorded a peak load of 10,356.2 N and a break load of 2,079.1 N, with a break displacement of 25.01 mm during the tensile test. These results demonstrate the material's high tensile strength and deformation capacity. Fig. 29, below illustrates the tested specimen.

Fig 29: Tensile Specimen-3

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➢ *Hardness Test*

For Specimen-1	For Specimen-2
d=2.8mm	d=3.1mm

$$BHN = \frac{2P}{\pi D\left(D-\sqrt{\left(D^2-d^2\right)}\right)}$$

$$\text{BHN}=\frac{2\times250}{\pi\times5(5-\sqrt{5^2}-\sqrt{(2.8)^2})} \qquad \text{BHN}=\frac{2\times250}{\pi\times5(5-\sqrt{5^2}-\sqrt{(3.1)^2})}$$

BHN = 37.12 BHN=29.59

Fig 30: Hardness Specimen-1

Fig 31: Hardness Specimen-2

As shown in Figs. 30 and 31, the Brinell Hardness Number (BHN) was 37.12 for specimen one and 29.56 for specimen two, indicating their resistance to deformation and ability to withstand localized forces without significant wear or damage.

➢ *Impact Test*

$$\boldsymbol{I} = \frac{\boldsymbol{E}}{\boldsymbol{A}}$$

$$I = \frac{230}{2750}$$

I =0.08364J/mm^2

Fig 32: Impact Specimen

As shown in Fig. 32, the impact test measured toughness under dynamic loading, with an energy absorption of 0.08364 J/mm², indicating resistance to sudden impacts and fractures.

VI. FINITE ELEMENT ANALYSIS

FEA was performed on the landing gear with a fixed base to simulate its attachment to the aircraft, ensuring accurate force transmission. Loads of 10,356.2 N, 7,247.4 N, 6,982.6 N, 421.7 N, 402.1 N, and 343.2 N were applied to the top of the leg to analysed the forces experienced during landing.

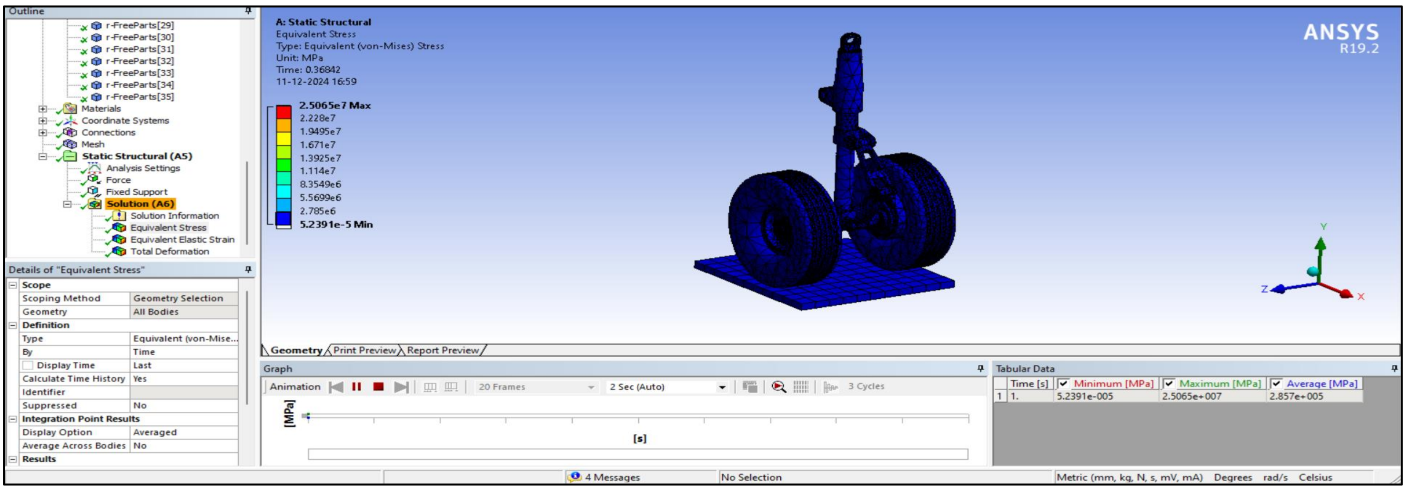

Fig 33: Maximum Stress

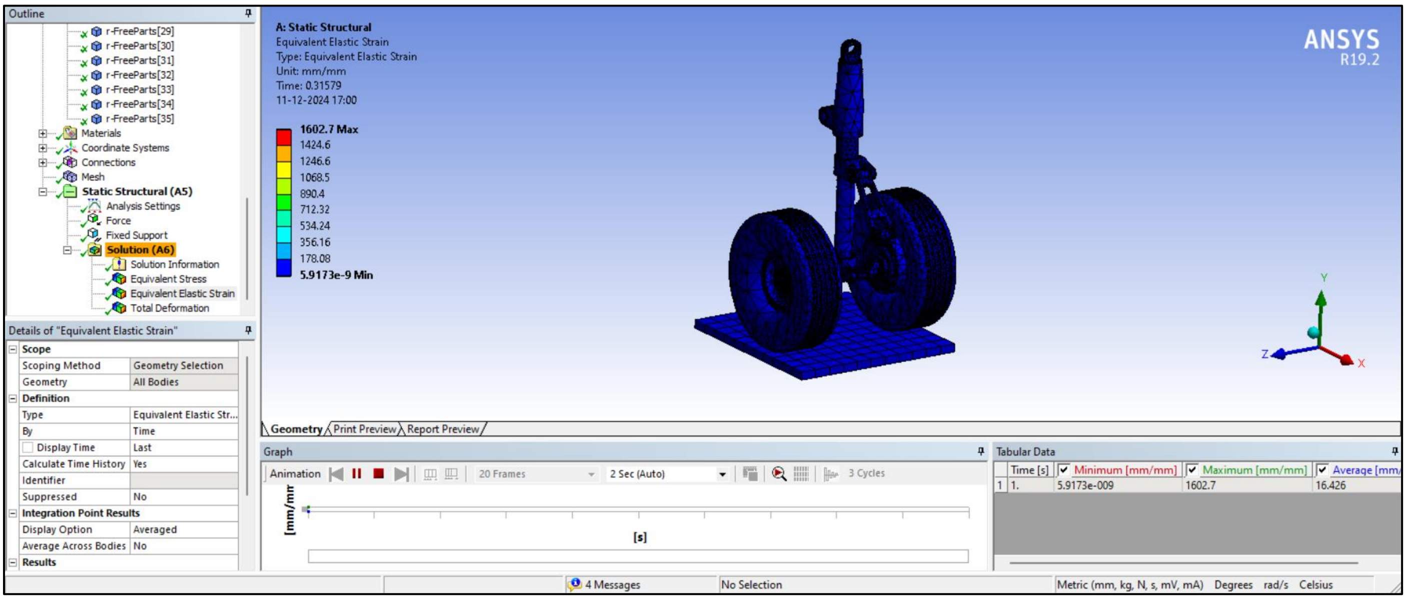

Fig 34: Maximum Strain

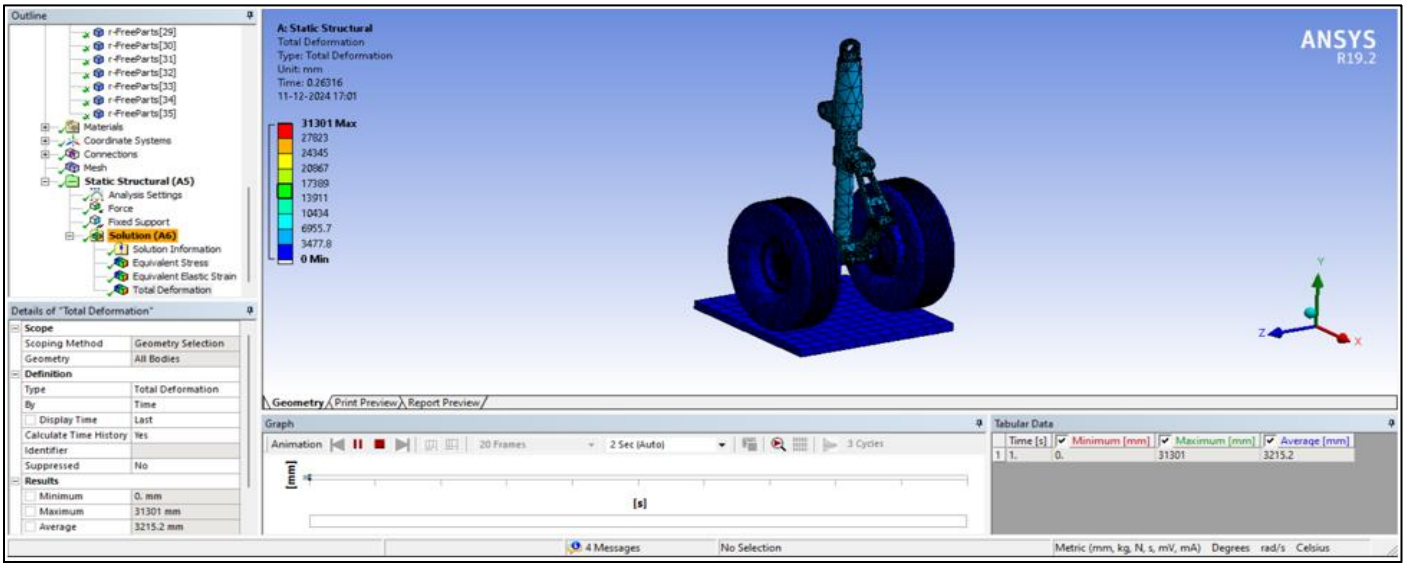

Fig 35: Total Deformation

Table 2: Comparison Between Fea and Tested Values

PROPERTIES	ANALYSIS VALUES	TESTED VALUES
Ultimate Strength	1.93Mpa	1.65Mpa
Strain	0.55642	0.1028
Breaking Strength	0.5782Mpa	0.3666Mpa
Stress	30050mpa	29060Mpa
Deformation	20.65mm	25.7mm

VII. CONCLUSION

The analysis and testing of the fabricated aircraft landing gear model provided valuable insights into its mechanical performance and structural reliability. The comparison between the ANSYS simulation results and the experimental data showed a close correlation, validating the design and fabrication processes. The mechanical tests, including tensile, bending, and hardness evaluations, demonstrated the material's strength and durability, meeting the required standards. The impact test further confirmed the model's toughness and ability to withstand sudden loads. Overall, the fabricated model successfully achieved the desired performance parameters, confirming its reliability for practical applications. The alignment between the analytical and experimental results highlights the effectiveness of the design approach and reinforces confidence in the material's suitability for such critical applications. These findings contribute significantly to the understanding of the structural behavior of landing gear components under real-world conditions.

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