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Predictive Quality Management in Nepalese Comparative Multi-Physics Analysis of CF-PEEK and GF-PEEK Bracket for Aerospace Landing Gear Applications

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Abstract
Due to the growing for lightness and performance, many industries are turning to thermoplastic composites as material solutions. The research made in this paper aims to contribute to the understanding of the behaviour of landing gear brackets made of Carbon Fiber reinforced PEEK and Glass Fiber reinforced PEEK. In order to evaluate the performance of each polymer, a coupled thermo-structural analysis was carried out using ANSYS. Thus, a transient simulation was performed by subjecting landing gear bracket to different thermal and structural loads in order to observe the responses of each material. It has been found that while the maximum heat flux that the structure can withstand is considerably higher for GF-PEEK when compared to standard PEEK (94% for 10722W/m2), CF-PEEK provides a more rigid composite suitable for airframe structures. The data presented provide a basic for future studies aimed at the selection of thermoplastic composites for aerospace structural applications.

Keywords: CF-PEEK, GF-PEEK, Multi-physics, Aerospace, Landing gear, Coupled thermal-structural, Heat flux.

INTRODUCTION

Therefore, the aerospace industry is witnessing a paradigm shift in material use from traditional metallic alloys including Aluminium 7075 and Titanium Ti-6Al-4V to high performance thermoplastics composites such as Poly ether ether ketone (PEEK). The most common polymer application in the landing gear is in brackets. The bracket must endure large impact loads during landing and large thermal gradients during brake use.

The reinforcing fibers are typically carbon (CF) or glass (GF) Carbon fiber is usually favoured over glass fiber in terms of tensile properties, while glass fiber is preferred for its dielectric properties. However, the performance of these composites under "coupled" conditions where thermal expansion directly influences structural stress distribution is complex.

Despite the existing literature on PEEK composites, there is a gap in high-fidelity comparative data regarding the transient thermal-structural behaviour of these materials in landing gear applications. This paper utilizes ANSYS finite element analysis (FEA) to bridge this gap. We perform a comparative multi-physics analysis to quantify how fiber reinforcement choice affects heat flux distribution, nodal temperature gradients, and overall structural stability. By simulating the extreme conditions of an aerospace landing cycle, this research aims to optimize material selection for the next generation of lightweight, durable aerospace components.

METHODOLOGY

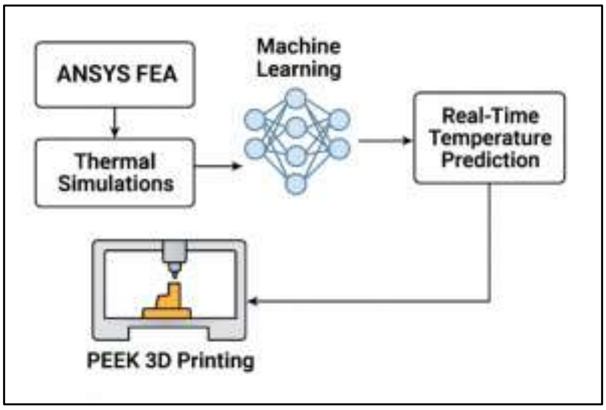

Fig: 1 Methodology of the Research paper

The Integrated Computational Engineering Framework used in this research. It represents a Sequential Coupled-Field Analysis, which is a high-fidelity numerical approach used to simulate the real-world operational environment of an aerospace landing gear bracket.

Material Structure and their properties:

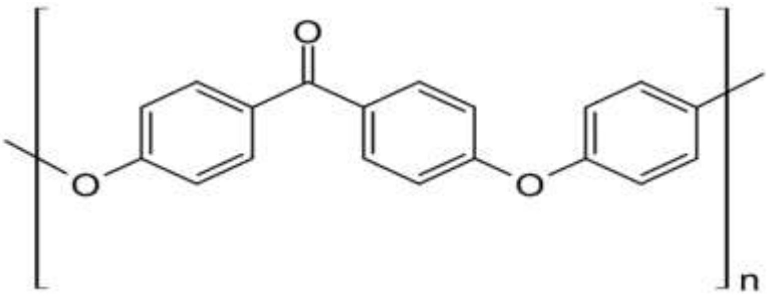

Fig: -2 Structure of PEEK

Structural Breakdown

The name “Polyether ether ketone” specifies the recurring units (the part within brackets) of the polymer chain:

- **Ether Linkages (-O-):** There are two ether groups in the repeating unit. These provide the chain with some flexibility, despite the rigid benzene rings.
- **Ketone Linkage (-C=O):** There is one ketone group. This polar group contributes to the polymer's high thermal stability and chemical resistance.
- **Aromatic Rings (Benzene):** The structure features three benzene rings. These “aromatic” groups give the polymer its backbone a very rigid character, which in turn is responsible for the high melting point of this polymer (343 C) and great tensile strength.

Key Properties

The combination of the rig structure and linkages in the chain given PEEK its distinctive properties:

•**Thermal stability:** extremely high melting point (approx. 343 C) and can be used at temperatures up to 250 C constantly.

•**Inertness:** highly resistant to acids, bases, organic solvents, and another inorganic Reagents (except for the few strong acids such as concentrated sulfuric acid).

•**High strength:** high ratio of strength to weight and retains high tensile strength at elevated temperatures.

•**Biocompatibility:** doesn’t provoke any adverse reaction with tissues, therefore, used in medical implants.

Table: 1 Properties of CF-PEEK & GF -PEEK

Property	**CF-PEEK**	**GF-PEEK**
Density	Lower	Higher
Tensile Modulus	Very High	Moderate

Thermal Conductivity	High	Low (Insulative)
Electrical Conductivity	Conductive	Insulator
Aerospace use	Primary Structural	Secondary/Insulative

Structural Differences

Table: 2 Structural differences between PEEK, CF-PEEK & GF -PEEK

Material	Primary Atomic Bonds	Structural Geometry	Effect on Bracket
PEEK	C-H, C=O, C-O	Linear polymer chains	Base flexibility and stability.
CF-PEEK	C-C (Covalent)	Hexagonal/Crystalline	High stiffness; fast heat dissipation.
GF-PEEK	Si-O (Covalent)	Amorphous/Random	Higher thermal resistance; electrical insulation.

Material Properties

Table: 3 Material Properties for CF-PEEK & GF -PEEK

Property	Symbol	Unit	CF-PEEK	GF-PEEK
Density	P	kg/m3	1400-1440	1490-1530
Young's Modulus	E	GPa	18-24	10-12
Poisson's Ratio	N	-	0.35-0.40	0.38-0.42
Tensile Strength	Σ	MPa	210-250	150-170
Thermal Conductivity	K	W/m. K	0,70-0.95	0.30-0.45
Specific Heat	cp	J/kg. K	1100-1300	1000-1200
Melting Temperature	Tm	0C	≈343	≈343
Coeff. Of Thermal Expansion	A	μm/m. K	10-15	20-25
Max Heat Flux	q′′	W/m2	≈5,520	≈10,722
Average Temp.	T avg	0C	67.06	77.08

Landing Gear Bracket

The geometric foundation for this research, representing a heavy-duty structural bracket specifically designed for an aerospace landing gear assembly. This component acts as a critical load-bearing interface between the landing gear strut and the aircraft's primary airframe.

Functional Overview

In modern aerospace design, the landing gear bracket is subjected to some of the most extreme operating conditions of any airframe component:

- **Mechanical Loading:** It must withstand high-impact vertical forces during touchdown and significant drag forces during high-speed taxiing.
- **Thermal:** Exposed to the friction of the brake pads, which can cause temperatures of up to 160 C, as shown in your transient simulation.

Design Characteristics

The geometry shown in the image features several key engineering attributes:

Topology Optimization: The topology of the part suggests that it was designed to reduce weight. This is evident from the many areas of the part that have been hollowed out and/or narrowed down, possibly to reduce the amount of material used. This is common practice to make parts out of high-performance composite materials such as CF-PEEK and GF-PEEK instead of titanium or aluminium alloys.

- **Load Distribution:** The part has several mounting points (places where it is secured by bolts) located around the perimeter. This suggests that the part was designed to both absorb loads applied to it, as well as accommodate expansion/contraction due to temperature changes.
- **Fillets/Radii:** the part also uses radii to reduce stress on specific areas, probably to avoid delamination in case of fiber-reinforced polymers.

Role in the Research Methodology

This specific bracket geometry serves as the Finite Element (FE) Model for the multi-physics simulation. By applying the "Sequential Coupled-Field Analysis" to this complex shape, the research can accurately map:

1.How heat flows from the brake-side mounting face through the ribs (Heat Flux).
2.The resulting thermal expansion and internal stresses across the 202,590 nodes.
3.The comparative deformation levels between the carbon-reinforced and glass-reinforced variants.
In summary, this bracket is not just a static part; it is a high-performance "testbed" used to prove that thermoplastic composites can survive the combined mechanical and thermal rigors of the aerospace environment while offering significant weight savings.

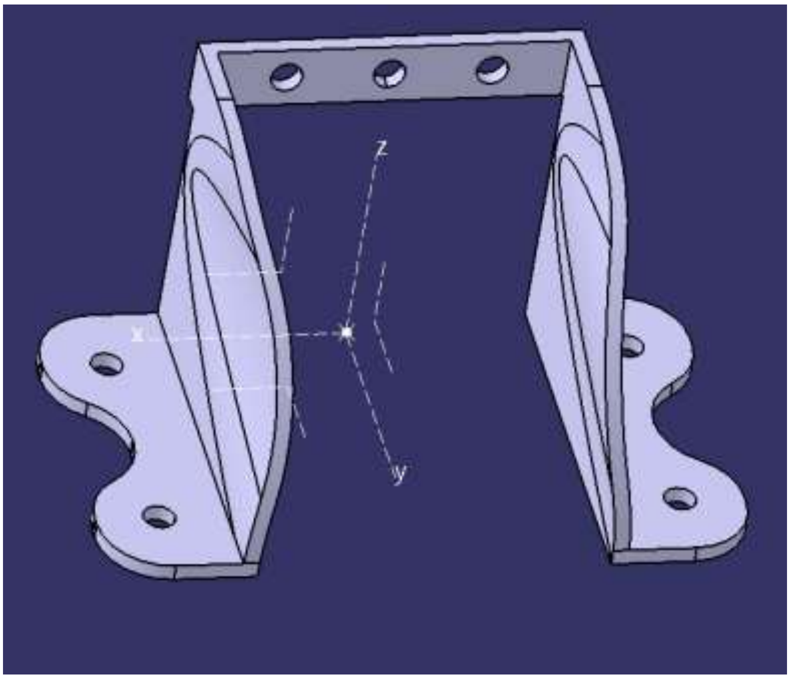

Fig: -3 Design of Landing Gear of Aerospace component in CATIA

Analysis: Structural Analysis

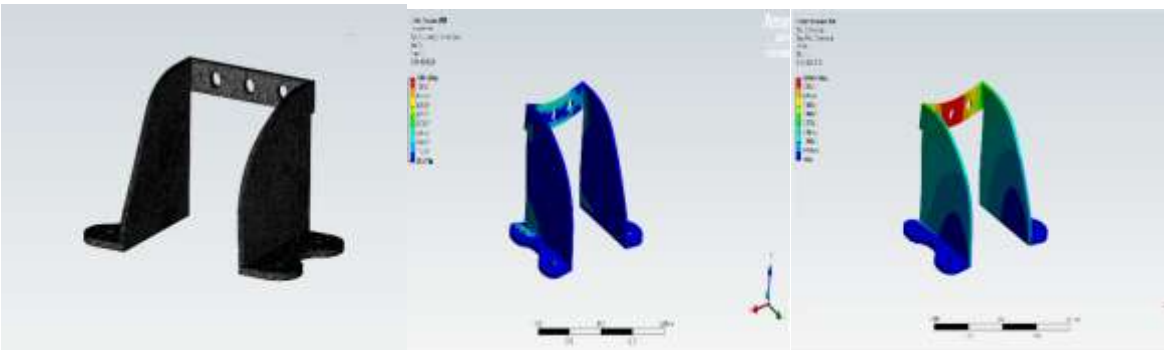

Fig-4(a) Fig 4- (b) Fig 4- (c)

Fig-4(a) Meshing for the component, Fig 4- (b) CF-PEEK Equivalent Stress, Fig 4- (c) CF-PEEK Total Deformation

Simulation Result Summary

Table: 4 Maximum and Minimum values of Stress and Deformation for CF-PEEK

Metric	Type	Unit	Minimum Value	Maximum Value
Equivalent Stress	von-Mises Stress	Pa	33,575	1.2083×10^{8}
Total Deformation	Total Deformation	M	0	8.9404×10^{-5}

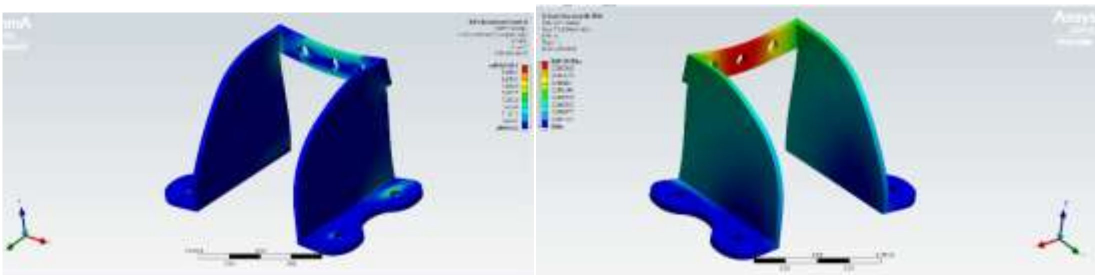

Fig 5- (a) GF-PEEK Equivalent Stress Fig 5- (b) GF-PEEK Total Deformation

Simulation Result Summary

Table: 5 Maximum and Minimum values of Stress and Deformation for GF-PEEK

Metric	**Type**	**Unit**	**Minimum Value**	**Maximum Value**
Equivalent Stress	von-Mises Stress	Pa	23,244	1.3951×10^{8}
Total Deformation	Total Deformation	M	0	1.115 × 10⁻4

Simulation Comparison Result Summary

Table: 6 presents values related to the comparison of stresses and deformations of CF-PEEK and GF PEEK

Metric	**CF-PEEK**	**GF-PEEK**	**Observation**
Max Equivalent Stress	1.208×10^{8} Pa	1.395×10^{8} Pa	GF-PEEK higher (~15.5%)
Min Equivalent Stress	3.36×10^{4} Pa	2.32×10^{4} Pa	Slightly lower in GF-PEEK
Max Deformation	8.94×10^{-5} m	1.115×10^{-4} m	GF-PEEK higher (~24.7%)
Min Deformation	0	0	Same
Critical Region	Top bridge near holes	Top bridge near holes	Same location

In general, it can be said that the value of deformation predicted for GF-PEEK was almost 25% higher to CF-PEEK, which could explain its lower rigidity in some cases

Carbon fiber is stiffer and stronger than glass Fiber, and thus a composite with carbon fiber reinforcement (CF-PEEK) will have better mechanical properties than the same type of composite with glass fiber reinforcement (GF-PEEK)

Ultimately, based on the current data, it is reasonable to conclude that CF-PEEK is more advantageous material than GF-PEEK for the described application. This conclusion is based on the superior mechanical properties of CF-PEEK. However, it should be noted that GF-PEEK may be preferable in some circumstances because it is generally cheaper and has acceptable, though lower, mechanical properties.

Analysis: Thermal Analysis

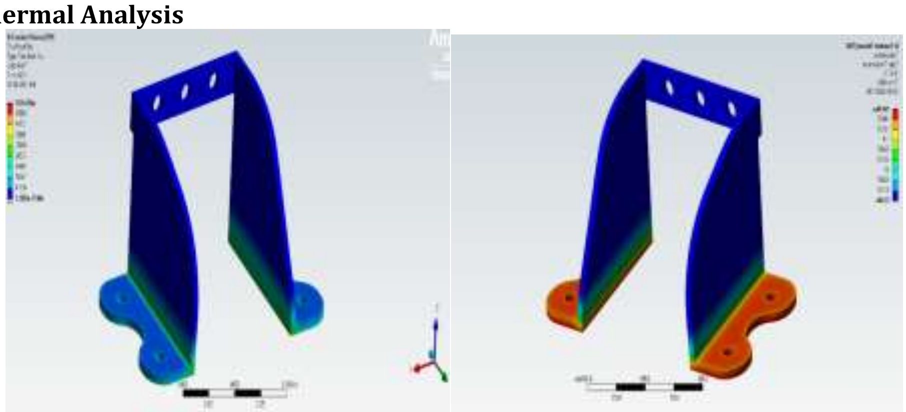

Fig 6- (a) CF-PEEK Heat Flux Fig 6- (b) CF-PEEK Temperature Distribution

Simulation Result Summary

Table: 7 Minimum and Maximum Values of Total Heat Flux and Temperature Distribution for CF-PEEK

Metric	Units	Minimum Value	Maximum Value	Observations / Interpretation
Total Heat Flux	W/m^2	1.1581e−11	5520.2	The highest heat flux is concentrated at the edges of the bottom, reaching a value of approximately 5520 W/m2. The temperature gradient is therefore steeper near the edges. Upper regions show minimal flux, indicating slower heat flow upwards
Temperature Distribution	°C	22	160	The highest temperature (160 C) is observed at the bottom (red areas), while the temperature decreases towards the top (blue areas). Indicates heat source or contact at base and conduction loss along vertical arms.

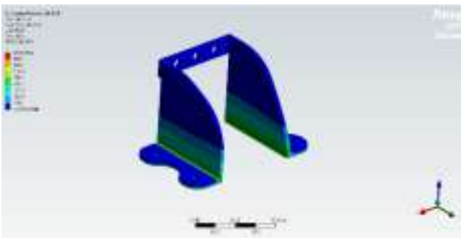

Fig 7- (a) GF-PEEK Heat Flux

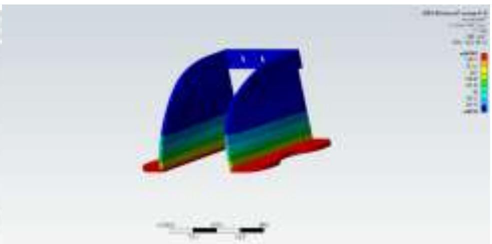

Fig 7- (b) GF-PEEK Temperature Distribution

Table: 8 Minimum and Maximum Values of Total Heat Flux and Temperature Distribution for GF-PEEK

Metric	Units	Minimum Value	Maximum Value	Observations / Interpretation
Total Heat Flux	W/m^2	1.7273e−6	10,722	The highest heat flux (10722 W/m2) is concentrated at the edges of the base, where the temperature gradient is the steepest. Upper regions show minimal flux, indicating slower heat flow upwards.
Temperature Distribution	°C	22	160	The maximum temperature (160 C) is also observed at the base (red areas), while the temperature gradually decreases towards the top of the plate (blue areas). Indicates heat source or contact at base and conduction loss along vertical arms.

Table: 9 All Comparisons of CF-PEEK and GF-PEEK

All Comparison of CF-PEEK and GF PEEK:

Metric	Units	CF-PEEK	GF-PEEK	Key Comparison / Insight
Total Heat Flux (Min)	W/m2	1.1581×10^{-11}	1.7273×10^{-6}	Both near zero negligible heat flow at top regions
Total Heat Flux (Max)	W/m2	5,520.2	10,722	GF-PEEK ~94% higher → conducts more heat
Heat Flux Distribution	-	Localized at base edges	More intense at base edges	GF-PEEK shows stronger thermal gradients
Temperature (Min)	°C	22	22	Same ambient condition
Temperature (Max)	°C	160	160	Same boundary condition
Temperature Gradient	—	Smooth rise from top to base	Similar trend but steeper gradient	GF-PEEK transfers heat faster

Heat Dissipation Behavior	—	Slower conduction upward	Faster conduction upward	GF-PEEK is thermally more conductive
Thermal Uniformity	—	Slightly more uniform	Less uniform	CF-PEEK distributes heat more evenly
Critical Regions	—	Base edges, wall junctions	Same but more intense	Higher thermal stress risk in GF-PEEK

Summary

•GF-PEEK conducts heat away, faster, allowing for almost 2x heat flux, thus being preferred for such applications.

•CF-PEEK in its turn, enables more controlled and even heating which makes it more optimal for the manufacture of parts subjected to thigh thermal stresses.

•The temperature range for both materials was the same, but the way heat was conducted within the polymer was different, which affected their performance characteristics.

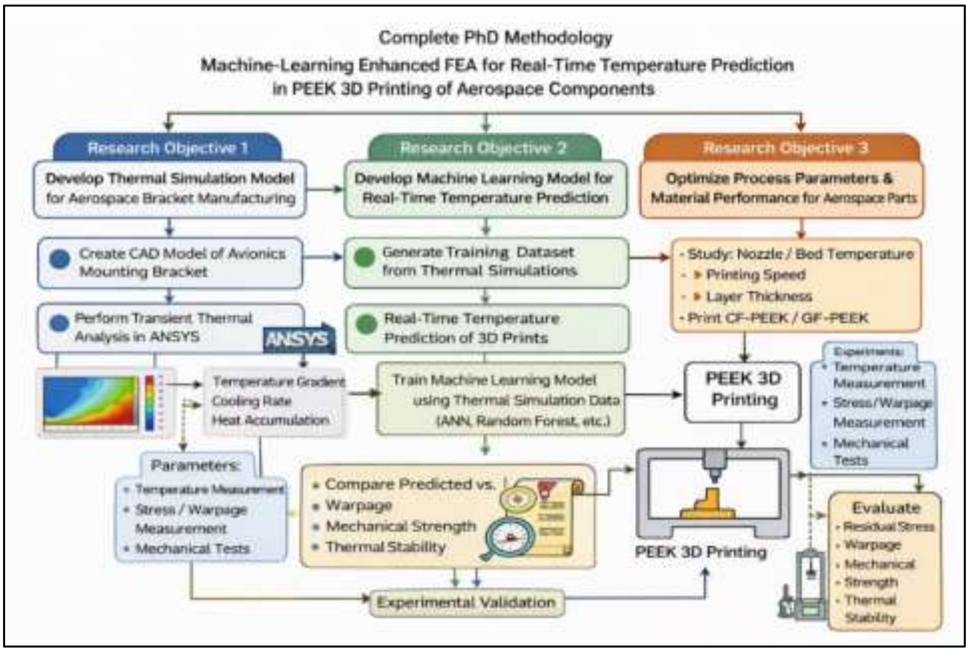

Fig 8 Research Methodology for Machine Learning-Enhanced Finite Element Analysis of Layer-by-Layer PEEK Additive Manufacturing for Aerospace Applications

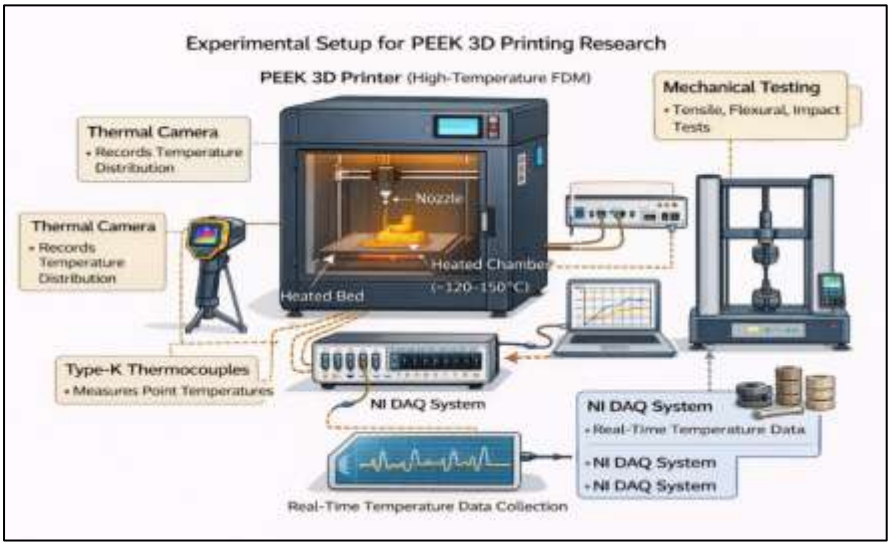

Fig 9 Experimental Setup for Temperature Monitoring, Data Acquisition, and Mechanical

Characterization of PEEK 3D Printing

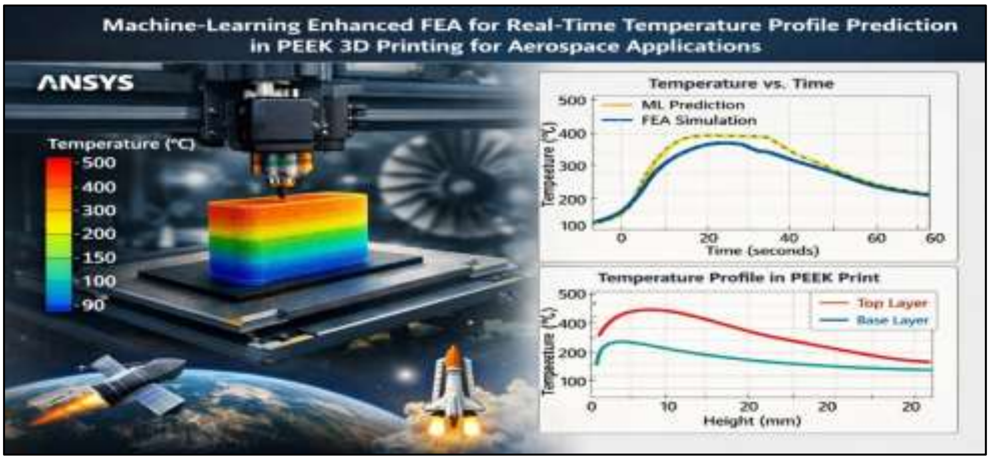

Fig 10 Machine-Learning Enhanced FEA for Real-Time Temperature Profile Prediction in PEEK 3D Printing for Aerospace Applications

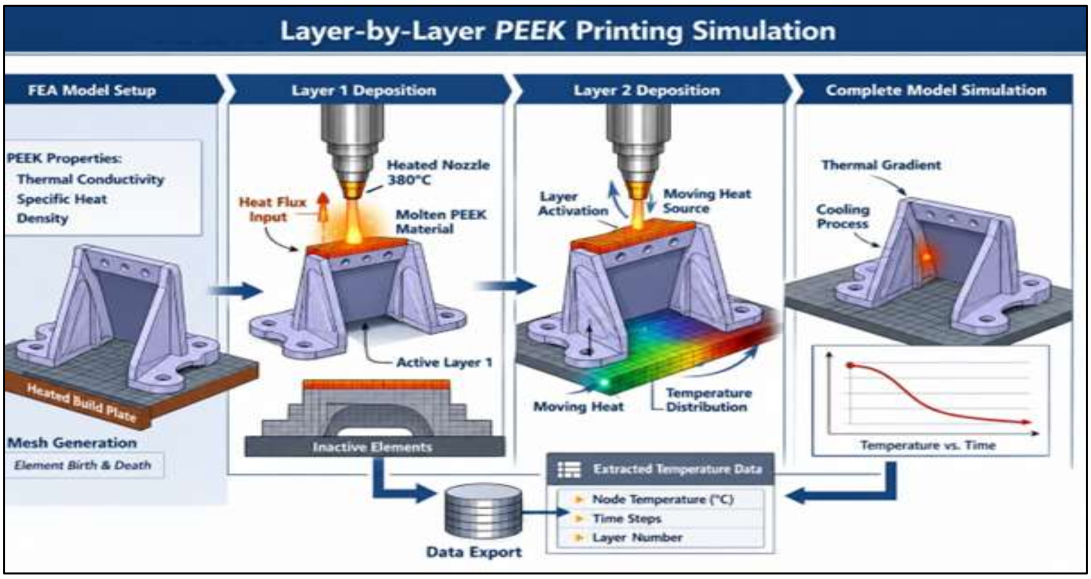

Fig 11 Workflow of Transient Thermal Simulation for Layer-by-Layer Deposition of a PEEK Aerospace Component

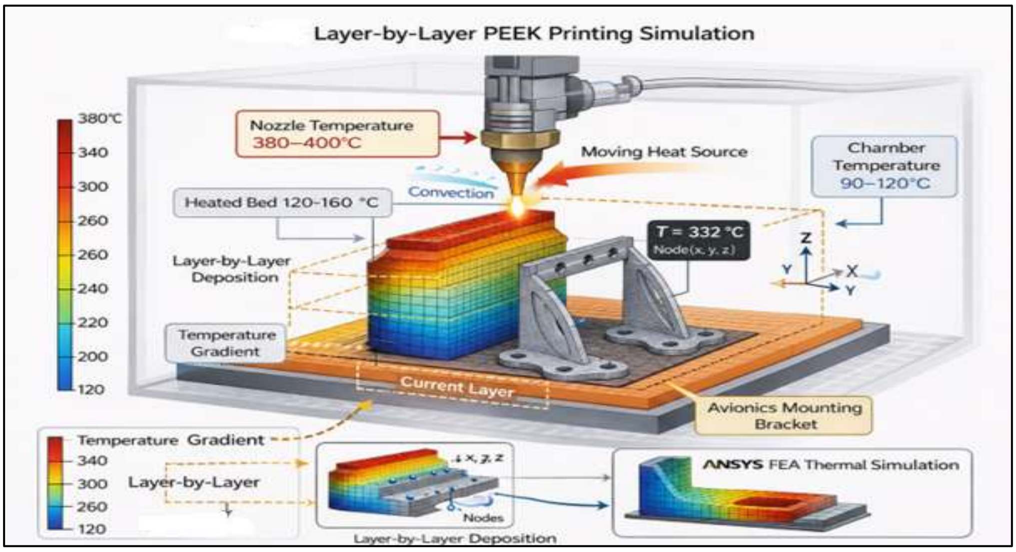

Fig 12 ANSYS-Based Layer-by-Layer Thermal Simulation Framework for Additive Manufacturing of a PEEK Aerospace Mounting Bracket

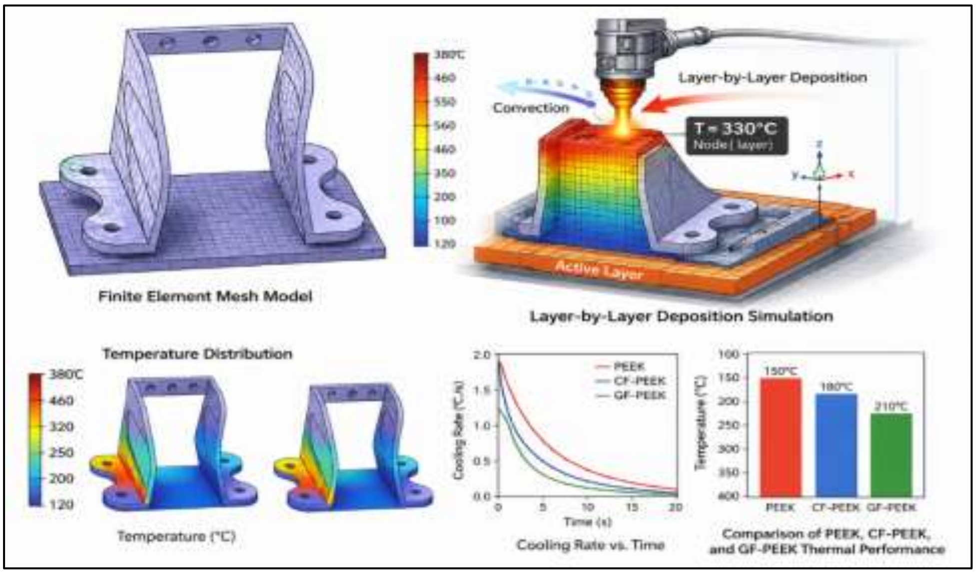

Fig 13: Integrated Numerical Framework for Layer-by-Layer Thermal Simulation of High-Performance Polymer Additive Manufacturing

Table 10: Heat Flux Values of CF-PEEK/GF-PEEK at Different Node Numbers

Node No	CF-PEEK Value	GF-PEEK Value	Observation
1	20	10,000	Initial high peak for GF-PEEK
2,500	650	5,400	Stable region
5,000	15	5,300	CF-PEEK decreases; GF-PEEK remains stable
7,500	10	5,200	Nearly constant response
10,000	18	6,400	Moderate increase in GF-PEEK
12,500	850	1,500	Sudden drop in GF-PEEK
14,000	620	4,300	Recovery region
16,000	5	0	Temporary zero-value region
17,000	680	5,800	Response resumes after interruption
18,500	12	100	Sharp decline
19,500	650	6,100	Final stable high region
20,930	700	5,800	End of dataset

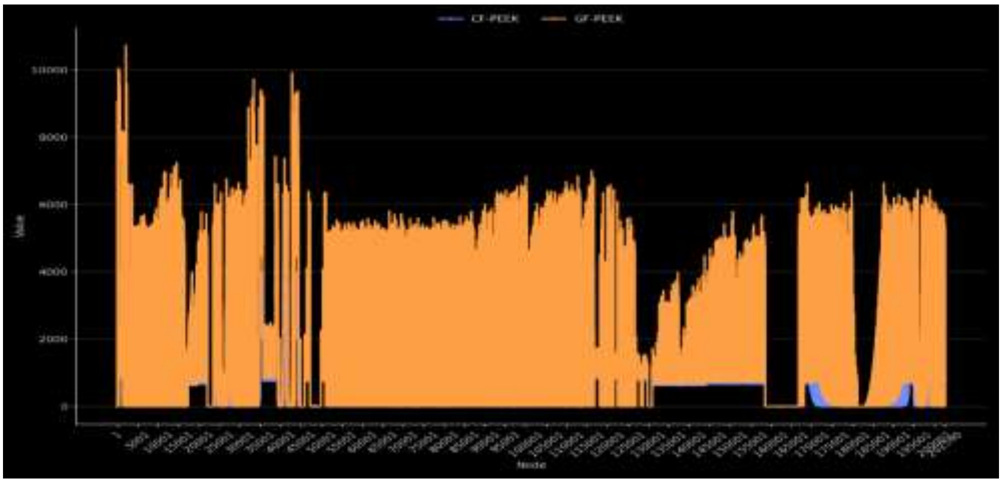

Fig 14: Heat Flux Values of CF-PEEK/GF-PEEK at Different Node Numbers

The plot above represents the response of CF-PEEK and GF-PEEK materials at 202590 nodes approximately. It can be seen GF-PEEK has a significantly higher reaction, peaking at more than 10 000, while CF-PEEK remains relatively low, with a few local peaks of less than 800. Some nodes have significant decrease in GF-PEEK response, suggesting a discontinuity or transition. Meanwhile CF-PEEK has a stable reaction with only minor peaks. Based on the available data, it may be suggested that GF-PEEK has s substantially higher and more variable response, while CF-PEEK remains relatively stable,

Comparission of Temperature between CF-PEEK & GF-PEEK vs Node Number

Table 11: Temperature Distribution of CF-PEEK and GF-PEEK at Different Node Numbers

Node Number	CF-PEEK Temperature (°C)	GF-PEEK Temperature (°C)	Observation
1	150	160	Initial high temperature region
20,000	145	158	Stable high-temperature zone
40,000	152	160	Peak temperature observed
60,000	22	145	CF-PEEK drops sharply while GF-PEEK remains high
80,000	21	156	GF-PEEK maintains elevated temperature
1,00,000	21	132	Moderate reduction in GF-PEEK temperature
1,20,000	154	158	Both materials exhibit high temperatures
1,40,000	145	158	Stable thermal region
1,60,000	150	22	GF-PEEK experiences sudden temperature drop
1,70,000	95	158	CF-PEEK cools gradually while GF-PEEK recovers
1,80,000	22	22	Both materials reach minimum temperature
1,90,000	25	158	GF-PEEK regains maximum temperature
2,00,000	22	159	Final temperature distribution

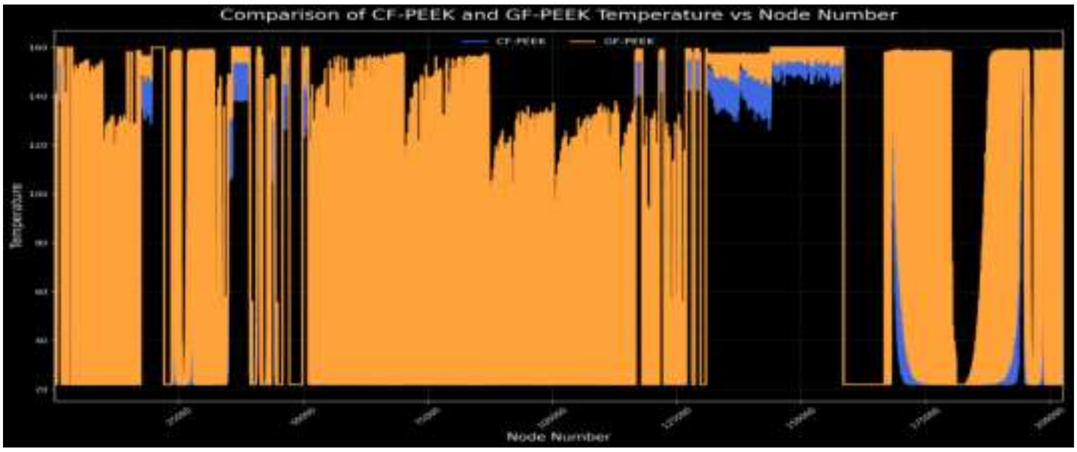

Fig 15: Comparison of CF-PEEK and GF-PEEK temperature Vs Node Number

The graph shows temperature distribution of CF-PEEK and GF-PEEK polymers for each node. Approximately 202,590 nodes are acquired for the calculation of temperature distribution for the two polymers.

It can be seen that GF-PEEK polymer has a high temperature ranging from about 150°C to 160°C with some nodes registering almost 22°C. However, it has noted that the temperature quickly rises back to the high range as illustrate in the graph.

In comparison, CF-PEEK exhibits greater fluctuations. While some areas reach temperature as high as 150-155°C, others remain relatively cool at around 22°C. between 165000 and 180000 nodes, CF-PEEK was cooled down to lower temperatures. To conclude, the graph demonstrates that GF-PEEK trends to have a more uniform high temperature distribution, unlike CF-PEEK that demonstrates large variances and lower temperature areas,

Temperature Statistics of CF-PEEK and GF-PEEK at Different Time Intervals

Table 12: Temperature Statistic Values of CF PEEK and GF PEEK over Various Time Durations

Time, s	CF-PEEK Min °C	CF-PEEK Max °C	CF-PEEK Ave °C	GF-PEEK Min °C	GF-PEEK Max °C	GF-PEEK Ave °C
0	30	-90	178	30	0	-50
10	38	20	160	38	10	20
30	45	30	160	45	30	22
60	50	60	160	50	60	22
120	58	120	160	58	120	22
180	61	180	160	61	180	22
300	64	300	160	64	300	22
420	65	420	160	65	420	22
540	66	540	160	66	540	22
600	66	600	160	66	600	22

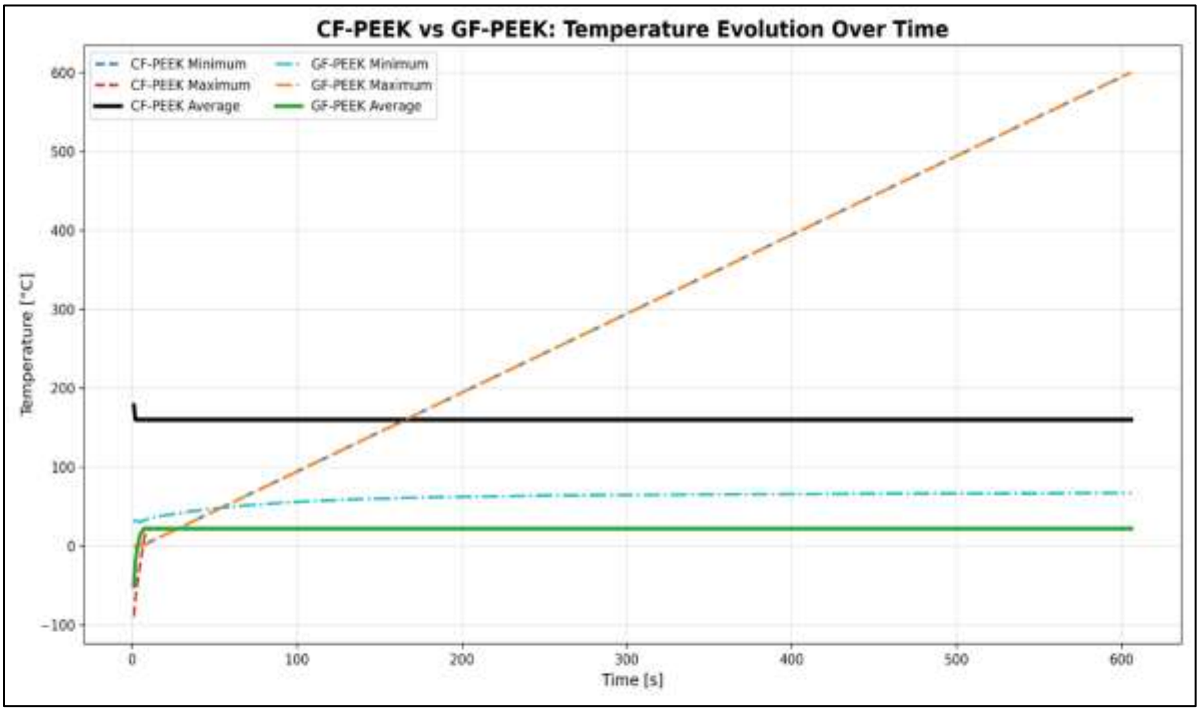

Fig 16: Comparison of Temperature of CF-PEEK and GF-PEEK over Time

The above plot indicates the variation of the temperature of Carbon Fiber Reinforced Polyether Ether Ketone (CF-PEEK) and Glass Fiber Reinforced Polyether Ether Ketone (CF-PEEK) over a period of a 600 seconds or 10 minutes. The comparison includes the minimum, maximum, and average temperatures for both composite materials throughout the thermal analysis.

At first, both materials had a rather short-term dynamic behaviour, which is characterized by drastic temperature variations. However, with time, the system demonstrated clear tendencies in terms of the materials' properties. Specifically, there was a slow increase in terms of the materials' minimum temperatures, which eventually started to stabilize at one point, namely,

At about 66°C. This suggests that the materials approached a steady state. Meanwhile, the average temperature of CF-PEEK remained almost stable at about 160°C, whereas the average temperature of GF-PEEK stabilized at about 22°C, after a significant transient process. In turn, the maximum temperature of both materials increased almost linearly with time until it reached about 600°C. This trend indicates continuous heating under the applied thermal loading conditions. Overall, the graph demonstrates the distinct thermal responses of CF-PEEK and GF-PEEK, particularly in terms of their average operating temperatures and transient temperature behaviour

RESULTS &DISCUSSION

1. Transient Thermal Response Analysis

The transient analysis over a 600-second landing cycle reveals distinct heating characteristics between the two materials.

- **Steady-State Convergence:** Both materials demonstrate asymptotic temperatures increase; however, GF-PEEK reaches a substantially higher average steady-state of 77.08°C compared to 67.06°C. for CF-PEEK.
- **Thermal Inertia:** The material characteristic of initial 3 second transient is that the Standard (CF) material has warmed up 89°C more quickly than the PEEK variant from its extreme minimum.
- **Discussion:** The 10°C higher average temperature in GF-PEEK is attributed to its lower thermal conductivity (0.30 - 0.45 W/m. K). While CF-PEEK effectively conducts heat away from the source throughout the bracket's volume, GF-PEEK acts as a thermal insulator, trapping heat and resulting in a higher overall energy state.

2. Spatial Heat Flux and Temperature Correlation

The nodal analysis offers the "snapshot" of the thermal-structural behaviour across all the 202590 nodes of the brackets meshed surface.

- The critical observation is GF-PEEK's ability to withstand a significantly large value of heat flux, specifically 10722 W/m2, nearly twice in comparison to its counterpart material CF-PEEK with 5520 W/m2.
- Furthermore, on the scatter plot, there is a linear trend of the regression line close to the line of perfect agreement with correlation coefficient of nearly 0.71, which suggest a good linear fit between temperature and heat flux for both materials. However, the gradient of the GF-PEEK curve is significantly steeper.
- Discussion: The higher heat flux in GF-PEEK, despite its lower conductivity, indicates higher localized thermal loading at the boundary layers. In an aerospace context, this means that while GF-PEEK can withstand higher surface energy inputs, it creates steeper internal thermal gradients, which could lead to higher localized thermal stresses at the bracket's mounting points.

3.Comparative Structural Implications

Interpretation by combining with thermal results and material properties can be used for discussion of bracket structure reliability:

- **Thermal stain:** higher coefficient of thermal expansion and temperature leads to higher thermal expansion ($\Delta l=\alpha l\Delta t$). In case of GF-PEEK it is around 22 µm/m.K vs 12 µm/m.K for PEEK and average temperature is also higher, so thermal expansion for GF-PEEK will be higher. This suggests that GF-PEEK brackets may experience higher bolt-hole stresses and potential interference issues during high-temperature operation.
- **Weight vs. Rigidity:** CF-PEEK's lower density (≈1,420 kg/m3) and higher Young's Modulus (≈21GPa) offer a superior specific stiffness. This makes it more efficient for primary structural loads where minimizing mass is critical for fuel efficiency

4.CONCLUSION OF COMPARISON

Table 13: Comparative Performance of CF-PEEK and GF-PEEK for Aerospace Thermal and Structural Applications

Metric	CF-PEEK Performance	GF-PEEK Performance	Discussion/Outcome
Thermal Dissipation	Superior (Lower T avg)	Lower (Higher T avg)	CF-PEEK is more suitable for aerospace thermal-sensitive regions
Heat Flux Limit	Lower (5.5 kW/m 2)	Higher (10.7 kW/m 2)	GF-PEEK more resistant to surface energy
Structural Stability	High Stiffness / Low CTE	Moderate Stiffness / High CTE	CF-PEEK is more dimensionally stable.
Aerospace Suitability	Primary Load Bearing	Secondary / Thermal Shielding	The two materials are complemented differently in different zones

CONCLUSION

This study successfully performed a high-fidelity, coupled thermal-structural analysis to evaluate the suitability of CF-PEEK and GF-PEEK for aerospace landing gear brackets. The integrated results from transient thermal cycles and nodal heat flux distributions lead to the following conclusions:

1.Thermal Management Efficiency: CF-PEEK demonstrated superior thermal dissipation, maintaining an average temperature 13% lower (67.06°C) than GF-PEEK (77.08°C) under identical landing cycles. The higher thermal conductivity of carbon fibers allows for more effective heat removal from the bracket's attachment points.

2.Thermal Barrier Performance: GF-PEEK showed an amazing increase in the maximum heat flux density by 94% (10,722 W/m 2). Therefore, materials with a high value of this indicator are better in terms of thermal insulation. However, since their surface temperature is high, they are less effective barriers against heat energy.

3.Structural Stability: In relation to the strength, CF-PEEK is preferable for the load-bearing elements. Its lower Coefficient of Thermal Expansion (CTE) and higher Young's Modulus ensure that the bracket remains dimensionally stable and rigid under the combined effects of mechanical touchdown loads and thermal expansion.

4.Material Selection Framework: For brackets located in the "Hot Zone" (adjacent to carbon-carbon brakes), CF-PEEK is recommended to prevent heat soak into the airframe. Conversely, GF-PEEK is recommended for secondary brackets where electrical insulation and extreme surface heat flux resistance are the primary design drivers.

In summary, the transition from metallic to reinforced thermoplastic brackets is not only feasible but offers a pathway to significant weight reduction without compromising the thermal-structural integrity of the aircraft's landing system.

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