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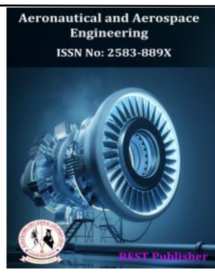

Thermo Structural Design of Airframes

Mallela Abhiram, S. Narender, *J. Arivudainambi

Adhiyamaan College of Engineering, Hosur, Tamil Nadu, India.

*Corresponding Author Email: abhiram.aero.16@gmail.com

Abstract: *Ceramic randoms are critical components in aerospace applications, providing electromagnetic transparency while withstanding high thermal and mechanical loads. This study examines the structural integrity and thermal response of a ceramic redone bonded to a metallic bulkhead using high-temperature adhesive. The key challenge addressed is the mismatch in thermal expansion coefficients and stress concentrations at the adhesive interface under combined thermal and mechanical loading. Using Creo Parametric and Creo Simulate, a 3D model of the assembly was developed to perform both structural and thermal analyses. Simulations included axial and normal loading conditions representative of flight environments, along with steady-state thermal conditions up to 1000°C. Results showed that thermal gradients induced differential expansion between ceramic and metal, leading to significant interfacial stresses, especially at the bond edges. Structural analysis indicated that normal loads introduced higher localized shear stresses compared to axial loads, potentially leading to adhesive failure if not properly accounted for. The adhesive layer's performance was sensitive to thickness and uniformity, affecting overall stress distribution. In conclusion, the combination of ceramic, metal, and high-temperature adhesive performs adequately under defined conditions, but careful attention to bonding techniques and material compatibility is essential. Creo proved effective for integrated thermal structural analysis and serves as a reliable tool for design optimization in high temperature aerospace structures.*

Keywords: *Thermo-structural design, Airframes, Finite Element Analysis (FEA), Thermal stress, High-temperature materials, Aerospace structures, Thermal loading, Structural integrity.*

1. INTRODUCTION

The word radome is a portmanteau of radar and dome. The function of the radome is to protect the antenna from adverse environments while having an insignificant effect on the electrical performance of the enclosed antenna or antennas. Among various radome materials, ceramics have emerged as a preferred choice due to their exceptional thermal stability, mechanical strength, and low dielectric loss—especially under highspeed and high-temperature conditions encountered in aerospace and defense applications. This technical paper focuses on the comprehensive design and analysis of a ceramic radome using PTC Creo, a parametric 3D CAD modeling software widely adopted in advanced engineering design. The objective is to develop a structurally sound and electromagnetically transparent radome geometry that can withstand aerodynamic loads without compromising signal integrity. The paper details the modeling workflow, material selection criteria, and finite element analysis (FEA) conducted to evaluate structural performance under operational stress conditions. Through the integration of Creo's parametric design tools and simulation capabilities, this study provides insights into design optimization strategies that balance electromagnetic performance with mechanical reliability. The results serve as a foundation for future experimental validation and iterative development in the field of advanced radome engineering.

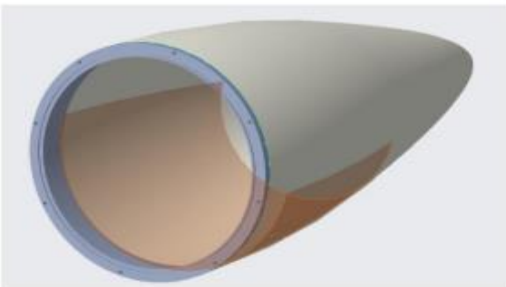

FIGURE 1.

2. LITERATURE REVIEW

2.1 Taylor et al. (2021) provide a comprehensive examination of the thermo-structural design considerations for ceramic radomes used in high-performance missile systems. The study focuses on the unique challenges posed by the high thermal and aerodynamic stresses encountered during hypersonic flight. Taylor et al. emphasize the critical role of material selection in ensuring the radome’s ability to 3 withstand extreme temperatures and mechanical forces while maintaining radar functionality. The authors suggest that radomes must be designed not only to resist thermal shock and mechanical stress but also to offer minimal interference with radar waves. They highlight the need for advanced computational methods, such as finite element analysis (FEA), to optimize the structural and thermal performance of ceramic radomes, ensuring they meet the demanding requirements of modern missile systems. (1) McLean and Rahman (2019) discuss the advantages of using ceramic matrix composites (CMCs) in missile systems, with a specific focus on their application in radomes. CMCs combine the high-temperature resistance of ceramics with the enhanced toughness and damage tolerance of composite materials. This combination provides a promising solution to the inherent brittleness of traditional ceramics, making them more suitable for high-performance missile applications. The authors argue that CMCs improve the radome's impact resistance and durability under thermal cycling, offering significant improvements over traditional monolithic ceramics. They explore the potential of these materials to enhance the overall performance of missile radomes, particularly in applications requiring high resistance to extreme temperatures, aerodynamic stresses, and impact damage. (2) Kumar and Sato (2020) provide a detailed review of high-temperature ceramic materials for missile radomes, emphasizing the essential properties required for effective performance under hypersonic flight conditions. Their research highlights materials such as alumina (Al_2O_3) and silicon carbide (SiC), which are known for their high thermal stability, strength at elevated temperatures, and low electrical conductivity, making them ideal for radar applications. The authors also 4 explore the design considerations associated with these materials, stressing the importance of balancing thermal resistance with mechanical properties to prevent failure under extreme aerodynamic and thermal loads. Furthermore, Kumar and Sato discuss the potential for advanced ceramic materials, such as ceramic matrix composites and nanostructured ceramics, to improve the radome's performance, particularly in terms of damage tolerance and resistance to thermal shock, thereby enhancing the overall durability and effectiveness of missile systems. (3).

3. METHODOLOGY

Design Software: PTC Creo Parametric used for 3D modeling and simulation.

3.1 Geometry:

3.1.1 Ogive-shaped radome designed for aerodynamic efficiency.
3.1.2 Parametric features: wall thickness, height, base diameter.
3.1.3 Created using sketch, extrusion, and shell tools for a uniform hollow structure.

3.2 Material Selection:

3.2.1 Chosen material: Silicon Nitride (Si3N4) ceramic.

3.3 Properties:

3.3.1 Young’s Modulus 3.3.2 Poisson’s Ratio
3.3.3 Density

3.3.4 Tensile Strength

3.4 Meshing and Boundary Conditions:

3.4.1 Tetrahedral mesh applied with refinement at high-stress zones.
3.4.2 Boundary condition: fixed base (airframe mounting simulation).
3.4.3 Load applied: aerodynamic pressure on outer surface.

3.5 Structural Analysis:

3.5.1 Performed static structural (FEA) in Creo Simulate.

3.6 Outputs analyzed:

3.6.1 von Mises stress
3.6.2 Total deformation
3.6.3 Safety factor

3.7 Design Optimization:

3.7.1 Iterative adjustments of thickness and curvature for stress distribution improvement.
3.8 Objective: ensure structural integrity while minimizing weight.

4. RESULTS & DISCUSSION

Finite Element Analysis (FEA) of the ceramic radome bonded to a metallic bulkhead using a high-temperature structural adhesive reveals that the structural integrity of the assembly is 5 maintained under the applied loading conditions. The simulation indicates negligible beam-related stresses, suggesting the absence of dominant bending, torsional, or axial effects in the design. Displacement results demonstrate that the primary deformation occurs along a single axis, yet remains within acceptable operational limits, with minimal translation in other directions and no observable rotational deformation. The von Mises stress distribution highlights that the peak stress remains below the yield strength of both the ceramic and metallic components, ensuring safe stress margins. Principal stress evaluation identifies compressive stress dominance, characteristic of thermally loaded ceramic structures. Shear stress components also remain controlled, reinforcing the effectiveness of the adhesive layer in distributing interfacial loads. Strain energy values further confirm that the structure efficiently absorbs and redistributes the applied mechanical and thermal loads without risk of adhesive failure or delamination.

5. STRUCTURAL ANALYSIS

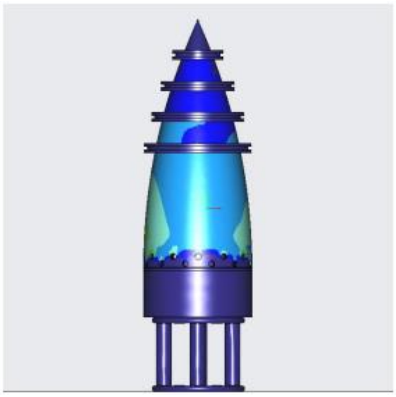

FIGURE 2. Stress-Von Mises

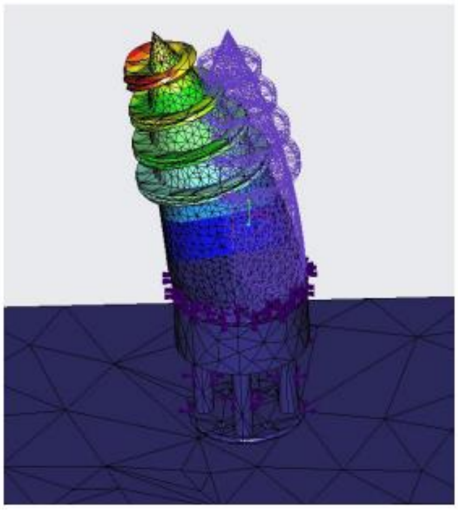

FIGURE 3. Deflection

Thermal Analysis

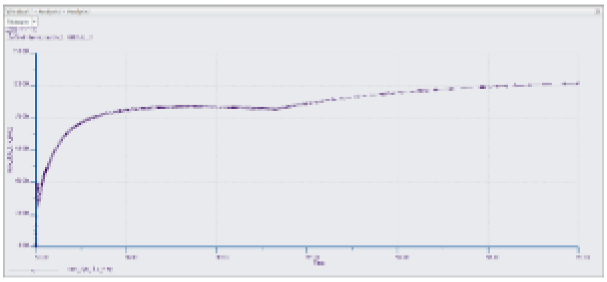

FIGURE 4. Max-Dyn-flux

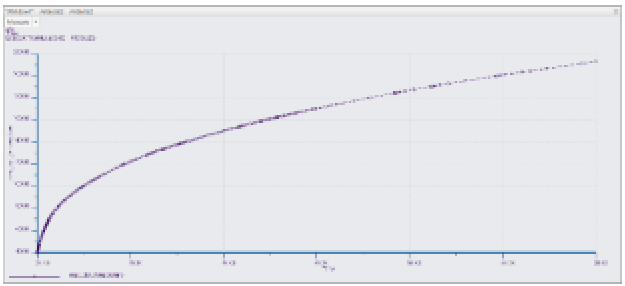

FIGURE 5. Max-Dyn-Temperature

FIGURE 6. Min-Dyn-Temperature

6. CONCLUSION

The analysis confirms that the ceramic radome bonded to a metallic bulkhead with high-temperature adhesive performs reliably under expected loading conditions. The structure shows minimal deformation, no critical stress concentrations, and stable stress distribution across materials and interfaces. These results support the adhesive bonding approach as a viable and robust solution for high-temperature aerospace applications.

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