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Design and Thermal Analysis of Annular Combustion Chamber of A Low Bypass Turbofan Engine in A Jet Trainer Aircraft

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Abstract— **The annular combustion chamber is a critical component in a low bypass turbofan engine, primarily used in jet trainer aircraft for its efficient performance and compact design. This study focuses on the design and thermal analysis of an annular combustion chamber to ensure optimal fuel-air mixture combustion, reduced emissions, and enhanced thermal efficiency. The design methodology includes detailed considerations of airflow patterns, temperature distribution, pressure loss, and material selection, ensuring durability and high-temperature resistance. Computational Fluid Dynamics (CFD) simulations are employed to analyze the thermal and flow characteristics, while Finite Element Analysis (FEA) is used for structural integrity evaluation under thermal loads. Results from the analysis highlight the performance of the combustion chamber in achieving uniform temperature distribution, minimizing hotspots, and maintaining structural stability.**

***Keywords*— Turbofan, Engine, Jet, Trainer, Aircraft.**

I. INTRODUCTION

Jet trainer aircraft serve as essential platforms for training pilots to operate advanced jet engines, necessitating high-performance propulsion systems that ensure reliability, efficiency, and safety. Among the critical components of a turbofan engine, the combustion chamber plays a pivotal role in converting chemical energy from fuel into thermal energy, subsequently driving the turbines to produce thrust [1]. The design of an annular combustion chamber, widely utilized in low bypass turbofan engines, demands meticulous attention to aerodynamic performance, thermal efficiency, and structural durability.

The annular combustion chamber, characterized by its compact and lightweight design, enables uniform airflow distribution and efficient combustion, making it suitable for the confined spaces of aircraft engines [2]. However, designing such chambers presents several challenges, including achieving optimal fuel-air mixing, minimizing pressure losses, reducing pollutant emissions, and maintaining material integrity under high thermal and mechanical loads. These challenges become even more critical in jet trainer aircraft, where the engine must perform reliably across varying flight conditions, from low-speed maneuvers to high-speed operations.

This study addresses the design and thermal analysis of an annular combustion chamber for a low bypass turbofan engine, emphasizing its application in jet trainer aircraft. The primary objective is to ensure an optimal balance between performance, durability, and environmental compliance [3]. A systematic approach is adopted, beginning with the theoretical design of the combustion chamber, considering key parameters such as combustion efficiency, air-fuel ratio, flame stability, and pressure drop. Computational methods, including CFD and FEA, are employed to analyze the chamber's thermal and structural behavior, providing insights into temperature distribution, stress concentrations, and deformation patterns under operational conditions [4].

The thermal analysis is particularly critical in understanding the temperature gradients across the combustion chamber, which influence the material selection and cooling mechanisms. High-temperature materials, such as nickel-based superalloys, are evaluated for their suitability in

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withstanding thermal stresses and oxidation. Additionally, advanced cooling techniques, including film cooling and effusion cooling, are incorporated into the design to enhance thermal performance and extend the component's lifespan [5].

The significance of this study lies in its contribution to improving the performance and reliability of turbofan engines in jet trainer aircraft. By addressing the complex interplay of design, thermal management, and structural integrity, this research provides a framework for developing combustion chambers that meet the stringent requirements of modern aviation [6]. Furthermore, the findings from this analysis have broader implications for the advancement of turbofan engine technology, offering insights that can be applied to other aerospace applications [7].

The subsequent sections of this paper delve into the detailed design methodology, computational analysis, and results, followed by a discussion on the implications of the findings and potential areas for future research. By integrating advanced simulation techniques with practical design considerations, this study aims to set a benchmark for the development of efficient and reliable combustion systems in modern jet engines.

II. METHODOLOGY

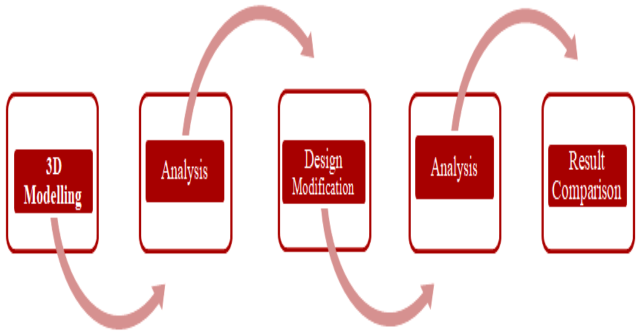

Figure 1: Flow chart

3D Modeling:

- **Purpose:** This is where the design process takes shape. A 3D model is created using software like CAD (Computer-Aided Design) or 3D modeling tools. This allows for a realistic visualization of the product or system, including its size, shape, and how its components interact.

- **Importance:**
    - **Tangible Representation:** A 3D model provides a concrete object to interact with, making it easier to understand the design's form and function.
    - **Early Issue Detection:** Potential problems and design flaws can be identified and addressed early on in the process, saving time and resources later.
    - **Communication Tool:** The model serves as a communication tool for designers, engineers, and stakeholders, facilitating better collaboration and understanding.

2. Analysis:

- **Purpose:** This stage is crucial for evaluating the design's usability and identifying areas for improvement. Various methods are employed to gather feedback:
    - **User Testing:** Observing users interacting with prototypes or simulations of the product helps understand how they use it, where they encounter difficulties, and what their overall experience is.
    - **Expert Reviews:** Usability experts analyze the design based on established principles of user experience (UX) and human-computer interaction (HCI).
    - **Heuristic Evaluation:** Experts assess the design against a set of usability principles (heuristics) to identify potential problems.
    - **Simulations:** Simulations can be used to model real-world scenarios and predict how the product will perform under different conditions.

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3. Design Modification:

- **Purpose:** Based on the insights gathered during the analysis phase, the design is modified to address the identified issues and improve its usability.
- **Types of Modifications:**
  - **Functional Changes:** Modifying how the product works, adding features, or improving existing ones.
  - **Aesthetics Changes:** Altering the visual appearance, color scheme, or overall aesthetics to enhance appeal and user experience.
  - **Ergonomic Changes:** Adjusting the size, shape, and layout of the product to improve comfort and ease of use.
  - **Accessibility Changes:** Making the product usable by people with disabilities, such as providing alternative input methods or visual aids.

4. Result Comparison:

- **Purpose:** After each round of modifications, the new design is compared to the previous version to assess the impact of the changes. This helps in understanding whether the modifications have resulted in improvements in terms of:
  - **Usability:** How easy it is for users to learn and use the product.
  - **User Satisfaction:** How happy and satisfied users are with the product.
  - **Efficiency:** How quickly and effectively users can achieve their goals using the product.
  - **Error Rate:** How often users make mistakes while using the product.

5. Iteration:

- **Purpose:** The UCD process is iterative, meaning the steps are repeated multiple times. Each iteration involves refining the design based on the feedback and analysis from the previous iteration.
- **Benefits of Iteration:**
  - **Continuous Improvement:** Iterative refinement leads to a gradual improvement in the design, addressing issues and enhancing usability step by step.
  - **Flexibility:** The iterative approach allows for flexibility and adaptation to changing user needs and requirements.
  - **User-Centered Focus:** By continuously incorporating user feedback, the design remains focused on the needs and preferences of the target audience.

III. SIMULATION AND RESULTS

The simulation is performed using ANSYS software.

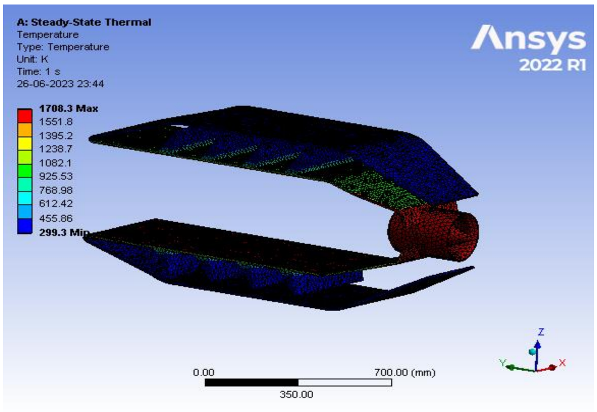

Figure 2: Thermal analysis- Temperature

Thermal analysis is a technique used to study materials by observing their properties as a function of temperature. It helps in understanding how materials behave under different thermal conditions, such as heating or cooling. This information is crucial for various applications, including materials selection, process optimization, and quality control.

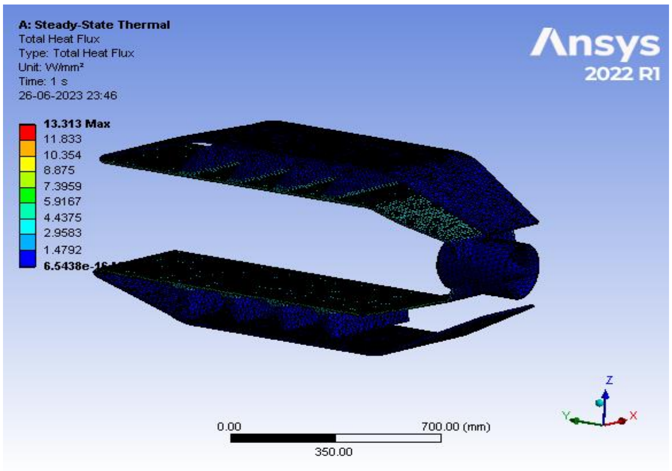

Figure 3: Total Heat flux

Total heat flux represents the total amount of heat energy transferred per unit area per unit time. It encompasses all modes of heat transfer, including conduction, convection, and radiation. Understanding total heat flux is critical in various engineering applications, such as thermal management in electronics, building energy efficiency, and the design of heat exchangers.

Table 1: Result Comparison

	Material used in Design	Total Heat Flux (Maximum)		
		Base Model	Modified Model	Units
01	Structural Steel	11.63	13.313	W/mm^2

	Material used in Design	Total Heat Flux (Minimum)		
		Base Model	Modified Model	Units
01	Structural Steel	$4.8426\ e^{-16}$	$6.5438\ e^{-16}$	W/mm^2

IV. CONCLUSION

The design and thermal analysis of the annular combustion chamber for a low bypass turbofan engine in a jet trainer aircraft demonstrates the critical role of optimizing the combustion process and heat management. Through detailed simulations and material selection, it is possible to enhance the engine's efficiency and performance while maintaining operational safety. The analysis highlights the need for a balanced design that ensures uniform temperature distribution, efficient fuel combustion, and adequate cooling mechanisms to withstand high thermal stresses. This approach not only improves engine longevity and reliability but also contributes to meeting the stringent performance standards of modern jet trainer aircraft.

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