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Review 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 of low bypass turbofan engines, particularly in jet trainer aircraft, where efficiency, reliability, and durability are paramount. This review provides an in-depth analysis of the design, performance, and operational characteristics of annular combustion chambers. Key focus areas include the combustion process, fuel-air mixing, flame stability, and emission control strategies. The study emphasizes the influence of advanced materials and cooling technologies on enhancing thermal efficiency and extending component life. Additionally, the review explores the challenges associated with designing annular combustion chambers for trainer aircraft, such as meeting stringent emission regulations while maintaining optimal performance.**

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

I. INTRODUCTION

The annular combustion chamber is a fundamental component in modern turbofan engines, playing a vital role in ensuring efficient combustion and delivering the necessary thrust for aircraft operations. In jet trainer aircraft, where operational efficiency and pilot training reliability are critical, the performance of the combustion chamber directly impacts engine performance, emissions, and overall mission effectiveness [1]. The design of an annular combustion chamber must account for multiple factors, including aerodynamic efficiency, thermal management, and the ability to withstand extreme operating conditions [2].

Jet trainer aircraft often operate in a diverse range of environments and flight conditions, requiring their engines to deliver consistent performance under varying loads and atmospheric conditions. The low bypass turbofan engine, typically used in such aircraft, combines the advantages of high thrust-to-weight ratio and operational flexibility. The annular combustion chamber, as a key component of these engines, ensures the efficient conversion of chemical energy into thermal energy while maintaining flame stability and reducing emissions [3].

The challenges in designing annular combustion chambers are multifaceted. Achieving uniform fuel-air mixing, maintaining stable combustion, and minimizing emissions are key design objectives [4]. Moreover, the use of advanced cooling techniques, such as film cooling and transpiration cooling, is crucial for protecting the chamber walls from high temperatures and enhancing durability. The choice of materials also plays a significant role in ensuring the structural integrity of the combustion chamber under extreme thermal and mechanical loads [5].

This review examines the state-of-the-art advancements in annular combustion chamber technology for low bypass turbofan engines, focusing on their application in jet trainer aircraft [6]. It highlights the critical design considerations, including combustion efficiency, emission control, and thermal management. Furthermore, the review delves into the impact of advanced manufacturing techniques, such as additive manufacturing, and computational tools, such as computational fluid dynamics (CFD), on optimizing chamber performance [7].

The introduction of stricter environmental regulations and the growing emphasis on sustainable aviation have driven significant innovations in combustion chamber design. Researchers and engineers are exploring new strategies to enhance efficiency and reduce emissions, such as the use of lean-burn combustion systems and alternative fuels [8]. Additionally, advanced diagnostics and testing methods are being employed to gain deeper insights into combustion dynamics and refine design methodologies.

II. LITERATURE REVIEW

C. Priyant et al.,[1] The design of an annular combustion chamber in a gas turbine engine is the backbone of this paper. It is specifically designed for a low bypass turbofan engine in a jet trainer aircraft. The combustion chamber is positioned in between the compressor and turbine. It has to be designed based on the constant pressure, enthalpy addition process. The present methodology deals with the computation of the initial design parameters from benchmarking of real-time industry standards and arriving at optimized values. It is then studied for feasibility and finalized.

T. Jiang et al.,[2] presents the modeling and control optimization of the shaft driven lift fan (SDLF) engagement. The SDLF propulsion system is a key component for short takeoff and vertical landing (STOVL) aircraft. Through lift fan engagement, the propulsion system can obtain high levels of thrust augmentation required for STOVL. Coordination of control of the lift fan, the cruise engine, and the clutch during SDLF engagement is essential for STOVL aircraft control. The dynamic performance model of the SDLF propulsion system is built to design the control law during the SDLF engagement. The dynamic model of the clutch is obtained by analyzing the working principle of the clutch. According to the different working states of the clutch, the balance equations of the propulsion system, namely its dynamic performance model, are set up. A pointwise optimization method is proposed to optimize the control law during the SDLF engagement.

F. Wang et al.,[3] Remaining useful life (RUL) prediction is one of the most crucial components in prognostics and health management (PHM) of aero-engines. This paper proposes an RUL prediction method of aero-engines considering the randomness of failure threshold. Firstly, a random-coefficient regression (RCR) model is used to model the degradation process of aero-engines. Then, the RUL distribution based on fixed failure threshold is derived. The prior parameters of the degradation model are calculated by a two-step maximum likelihood estimation (MLE) method and the random coefficient is updated in real time under the Bayesian framework.

L. Qin et al.,[4] With the continuous development of aviation equipment, the safety, reliability and maintainability of aircraft are facing higher requirements. A wall climbing robot with ducted fan is designed for aircraft appearance inspection. The robot can quickly reach the target detection area by flying, and then perform wall-climbing detection. To improve the effective thrust, the key thrust device of the robot is calculated and the structural design is optimized. The physical prototype is built and the effectiveness of the design scheme is verified by experiment results.

Z. Xie et al.,[5] The strong blade vibration in the airplane engine causes high alternating stress, which leads to low fatigue life and flight risk. The investigation of its vibration characteristics and reduction approach is crucial in the aircraft engine design and operation. This paper proposed a MFC bonded smart fan model based on the large deformation of plate theory. The feasibility of MFC patch is verified through the comparison between the numerical results with the literature ones.

X. Wu et al.,[6] For piezoelectric ceramic actuators working under continuous high-frequency drive signals, there are two issues that have to be considered. The first is the input drive circuit, which must meet the dynamic output power and output accuracy at the same time. The other is the output displacement of the amplifying mechanism. In this paper, a dual closed-loop piezoelectric ceramic high-frequency drive control circuit with overload protection is designed by combining the amplifier circuit with the push-pull output. By establishing displacement-charge model, on the basis of the original displacement feedback control, a series capacitor with leakage compensation method is used to realize the charge feedback control, and the output can be controlled at the same time to ensure the output accuracy, and the dynamic output power is considered.

G. Martynenko et al.,[7] considers an approach to numerical simulation of bird strike on the fan blades of an aircraft dual-flow turbojet engine. The purpose of such simulation modelling is determining the most critical cases of bird impact

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from the strength viewpoint of the blade apparatus. These cases are determined by the Airworthiness Standards for aircraft engines, which must be met for all of their designed components. However, only some of them are the most critical and subject to in-depth verification. To identify such cases, finite-element modelling using explicit dynamics methods is applied. The choice of the most critical case from the strength viewpoint of the blades is made between two variants simulating a flock of medium-size birds or a single big bird with given sets of parameters (mass, sizes, speed, angle) with the rotating fan wheel.

R. C. Bolam et al.,[8] The aim of this paper is to provide a method of estimating torque versus speed characteristics of single and dual-stage electrically powered Rim Driven Fans which are intended for aircraft propulsion. The methodology is based on the well-known Euler equation which considers the change in angular momentum of the air as it passes through the fan rotors. A derivation of the useful and versatile Specific Work parameter (Y) is provided along with its important relationship with the fan Work Co-efficient (ψ) and an explanation of the relevance of the Fan Flow Co-efficient ($\emptyset$) in determining the flow of air through the RDF device.

Y. Shen et al.,[9] During the production and development of a certain type of aircraft, frequent sampling of the pipeline connecting the engine and the body occurred, which not only had a great impact on the production schedule, but also produced huge waste. In this paper, the measurement technology of laser tracker is researched, and digital measurement technology is applied for the first time in the assembly process of aeroengine. By using the laser tracker to measure the shape parameters of aeroengine in advance, the space coordinate system of the aeroengine is established, and the pipeline interface space is fitted. Coordinates and correction of pipeline manufacturing process parameters have greatly reduced the sampling of pipes in the assembly process of aero-engines. It is verified through actual production and manufacturing.

R. C. Bolam et al.,[10] presents starting point from which to get a feel for the rough-order-magnitude of an RDFs performance and to elucidate a conventional calculative methodology suitable for a quick and easy reality-check before undertaking more accurate numerical analysis techniques. Initially, the properties of an existing aerospace fan design, namely that of the IAE V2500-A5 turbo-fan engine, is used to validate this approach and then the same methodology is used to estimate a first-guess performance prediction for a range of single-stage RDFs of varying sizes from 100mm to 500mm diameter, operating over a range of speeds from zero to 25 kRPM. Finally, a comparison between a single-stage and a dual-stage (contra-rotating) 200mm diameter RDF for a UAV application is conducted. The performance limits of the RDFs considered in this analysis have been established to ensure that the fan blades are always operating within the subsonic flow regime.

III. CHALLENGES

The development and operation of annular combustion chambers for low bypass turbofan engines in jet trainer aircraft present numerous technical and operational challenges. These challenges span multiple domains, including thermal management, emissions control, material selection, and the integration of advanced design methodologies. Below is an in-depth discussion of the key challenges faced in this context:

1. Thermal Management and Cooling

- **High Thermal Loads**: Annular combustion chambers operate at extremely high temperatures, often exceeding 2,000 K, to achieve efficient combustion. This creates significant thermal stress on the chamber walls and surrounding components.
- **Cooling Mechanisms**: Advanced cooling techniques, such as film cooling, transpiration cooling, and regenerative cooling, are required to protect the chamber walls. However, designing efficient cooling systems without compromising combustion efficiency remains a significant challenge.
- **Heat Distribution**: Ensuring uniform heat distribution across the chamber to prevent localized hotspots is critical to avoid material degradation and failure.

2. Combustion Efficiency

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- **Fuel-Air Mixing**: Achieving uniform and efficient mixing of fuel and air is essential for stable combustion. Uneven mixing can lead to incomplete combustion, reduced efficiency, and increased emissions.
- **Flame Stability**: Maintaining a stable flame across a wide range of operating conditions is challenging, especially during rapid throttle changes or low-power settings in trainer aircraft.
- **Ignition Reliability**: Reliable ignition in extreme environments, including high altitudes and cold conditions, is a persistent challenge.

3. Emission Control

- **Stringent Regulations**: Modern aviation faces increasingly stringent regulations on nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (UHC). Designing combustion chambers that meet these requirements while maintaining high performance is difficult.
- **Lean-Burn Systems**: Although lean-burn combustion reduces NOx emissions, it increases the risk of flame instability and blowout, particularly at low power settings.
- **Soot Formation**: Controlling soot and particulate matter emissions is challenging, especially when operating on conventional jet fuels.

4. Material Selection

- **High-Temperature Materials**: Combustion chambers require materials that can withstand extreme temperatures and mechanical stresses. Developing materials with high thermal resistance, low weight, and adequate fatigue strength remains a major challenge.
- **Cost and Availability**: Advanced materials, such as ceramic matrix composites (CMCs) and superalloys, are expensive and may require specialized manufacturing techniques.
- **Oxidation and Corrosion**: Prolonged exposure to high temperatures and reactive gases leads to oxidation and corrosion, reducing component lifespan.

5. Design Optimization

- **Aerodynamic Design**: Optimizing the aerodynamics within the combustion chamber to ensure efficient airflow, reduced pressure losses, and minimal turbulence is a complex task.
- **Compactness**: Jet trainer aircraft demand compact and lightweight engine designs. Balancing compactness with performance and durability is a persistent design trade-off.
- **Computational Modeling**: While computational fluid dynamics (CFD) tools provide valuable insights, accurately simulating the highly complex combustion process remains computationally intensive and time-consuming.

6. Operational Challenges

- **Dynamic Operating Conditions**: Trainer aircraft often experience rapid throttle transitions and varying flight conditions, which demand a combustion chamber capable of adapting to changing airflow and fuel flow rates.
- **Engine Durability**: Frequent training operations result in high engine usage, necessitating components with extended service life and low maintenance requirements.

IV. CONCLUSION

The annular combustion chamber of a low bypass turbofan engine plays a pivotal role in ensuring the performance, efficiency, and environmental compliance of jet trainer aircraft. Despite significant advancements, challenges persist in thermal management, emission control, material durability, and adapting to alternative fuels. Innovations in cooling techniques, computational modeling, advanced materials, and sustainable fuel integration offer promising pathways for overcoming these challenges. By addressing these complexities through multidisciplinary approaches, future designs can achieve improved reliability, enhanced efficiency, and reduced environmental impact, contributing to the advancement of aviation technology and the development of next-generation trainer aircraft.

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