UTM Faculty of Mechanical Engineering UNIVERSITI TEKNOLOGI MALAYSIA THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 15, 2025, 1-4

A FUNDAMENTAL REVIEW OF IMPROVEMENTS IN AIRCRAFT GAS TURBINE ENGINE

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ABSTRACT

The performance of aircraft gras turbine engine is critical to aviation sector. This directly impact the fuel efficiency, thrust output and environmental sustainability. This paper reports recent advancements and applied technologies aimed at increasing the performance of the gas turbine engine critical components. Through a review of literatures, the study identifies recent technological improvements and engineering innovations that have contributed greatly to the aircraft gas turbine engine performance.

KEYWORD

Gas turbine engine performance

INTRODUCTION

Aircraft engines mainly use two type of power generator source. The piston engine that caters small to medium sized aircraft, and the gas turbine engine that have been used widely in commercial and military aircrafts. The basic operation of these engines consists of multiple components that work together to convert fuel into thrust. Gas turbine engines can be categorized into four types, turbojet, turbofan, turboprop and turboshaft engine. Continuous quest for improved performance is driven by the need for higher engine efficiency, reduced emissions, lower fuel consumption, and increase thrust to weight ratio. This study will involve the critical components in turbojet and turbofan engine: intake section, compressor, combustion chamber, turbine stage and exhaust nozzle. Figure 1 shows the improvement of three GE turbofan engines; GE CF6-6 introduced into commercial widebody aircraft in 1971, GE90-115B powering the previous Boeing 777 model in 1990, and GE Aerospace latest engine, GE9X which powers the new family of Boeng 777x since 2020. The increase in thrust output of these engines were made possible with the advancement in aerodynamic design, material properties, combustion processes, and cooling techniques (Giampaolo, 2006).

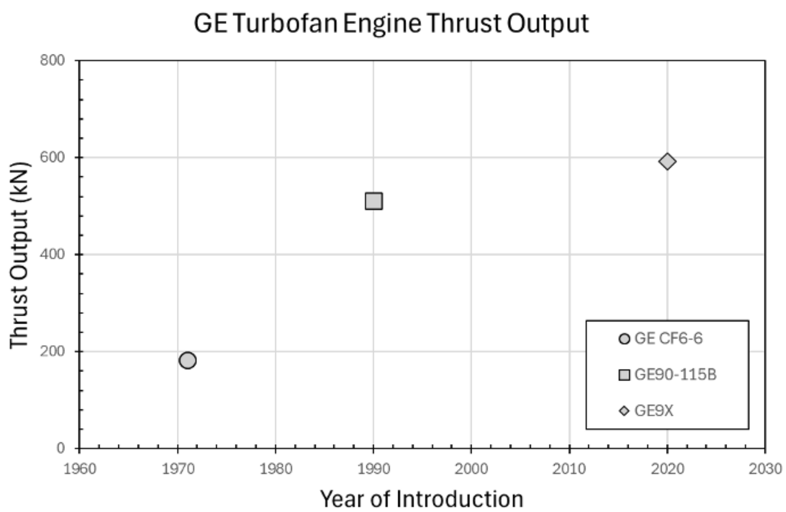

Figure 1: Improvement of GE gas turbine engines power output
(Source: GE Aerospace)

INTAKE SECTION

The intake section is designed to efficiently capture and direct air into the engine. The design ensures smooth air directed to the compressor face with minimum energy loss. The intake air should also be free of turbulence to achieve maximum operating efficiency. A bellmouth design are usually employed due to their high pressure recovery and minimal flow distortion. Subsonic intake design is usually used in commercial aircraft, while military aircraft could have subsonic and supersonic intake design depending on their flight operations. Intake designs typically have curved inlet shapes that reduced flow separation and provide steady airflow to the compressor under varying angles of attack and flight speeds. There is a growing environmental concern regarding the noise produced by the intake design. Qiu and Ying (2015) proposed an intake design for general aero-engine to reduce the noise produced.

COMPRESSOR

The compressor section compresses the air from the intake section. This is very essential for an efficient combustion. Modern gas turbine engines use multiple stage axial compressor to progressively increase the air pressure to desired levels. In economical point of view, multiple stage compressor also allows easy of maintenance, services and parts longevity. Blisks, or integrated bladed disks, is one of the technologies that help reduced weight and increase compressor efficiency (Ravi Kumar, 2013 and Dilba, 2019). However, because it is manufactured as a single unit, the main downside is the cost of maintenance and repairability. Many manufacturers have gone back to the individual blade and slot design to increase the repairability and serviceability of the compressor blades. The focus is now towards finding new composite materials to reduce the weight, increase airflow performance, and wear tolerance. Figure 2 shows the increase in compression ratio in the compressor section for different types of engines. As the compressor technology improves, engineers and manufacturers could increase the compression processes higher to allow more compressed air available for the combustion process. Modern gas turbine engines may allow up to 60:1 compression ratio.

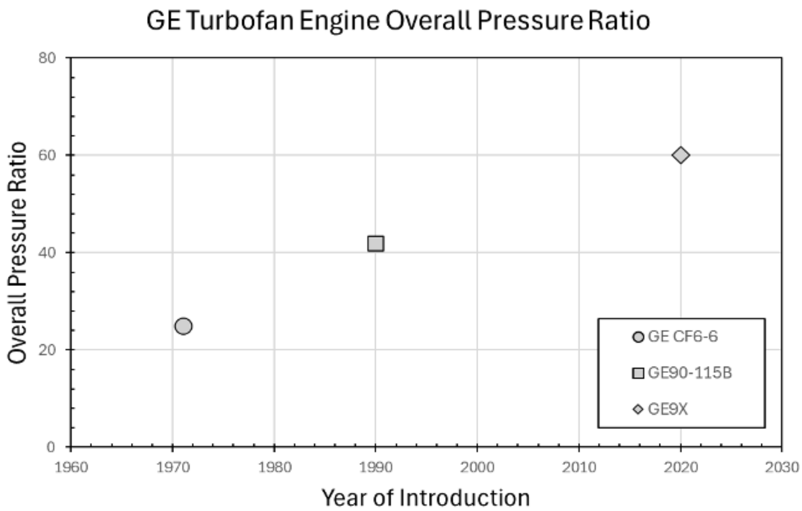

Figure 2: Improvements of engine overall pressure ratio
(Source: GE Aerospace)

COMBUSTION CHAMBER

Combustion chamber is where the compressed air will be mixed with fuel in a specific ratio to produce the required power output. Combustion chambers must ensure complete combustion while minimizing emissions. There are mainly three types of combustion chamber designs: can, annular and can-annular. Annular combustion chamber design is widely used in modern gas turbine engines due to their compact design and uniform temperature distribution. To cope with the high combustion temperature demand, the combustion chamber parts are also coated with thermal barrier coating to decrease its thermal loads (Schilke, 2004). Technologies such as lean-burn combustors and staged combustion help to reduce the NOx emissions and improve combustion efficiency. Alternative fuels such as biofuels and Sustainable Aviation Fuel were also introduced to reduce carbon emissions.

TURBINE STAGE

The turbine stage extracts energy from the hot combustion products to drive the compressor and other necessary aircraft components. To endure the high thermal loads, engineers employ cooling techniques to allow the turbine components to work above its own material's melting point (Han and Wright). Internal cooling involves air passing through internal passages and impinges the inner parts of the turbine blade. Meanwhile, external cooling involves ejection of cooling air from the turbine blade to provide protective layer of cool air covering the turbine blade surface. The turbine blades experience the same load as the compressor blades, but in addition of high thermal stresses. Therefore, the turbine blades were manufactured using high temperature Nickle based superalloys and coated with thermal barrier coatings to enhance the heat resistance and extend their lifespan. Figure 3 shows the increasing trend in turbine inlet temperature. The increase in turbine inlet temperature also indicates that higher combustion temperature output is possible.

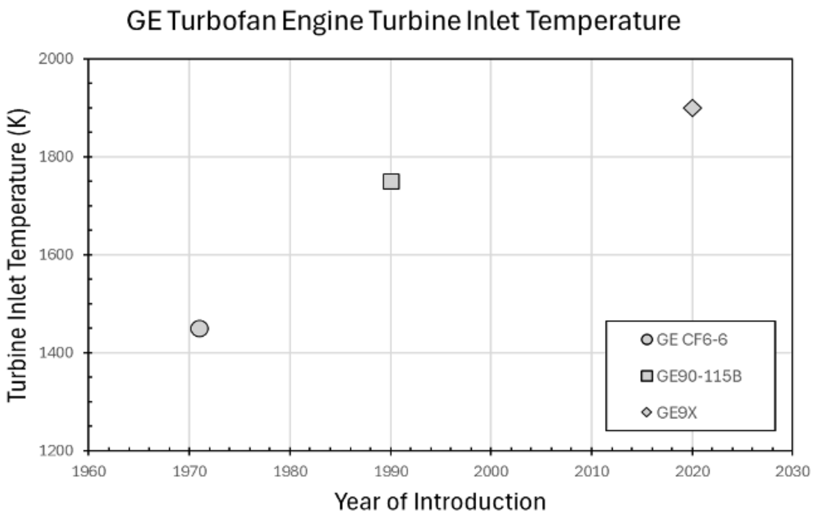

Figure 3: Increase in turbine inlet temperature
(Source: GE Aerospace)

EXHAUST NOZZLE

The exhaust nozzle is responsible for converting thermal energy into kinetic energy to produce thrust. For a turbojet engine, the exhaust nozzle produces 100% of the thrust output. A turbofan on the other hand, can be further categorized into two types, a high bypass ratio (70:30) for commercial applications, and low bypass ratio (30:70) for military usage. Depending on the flight operation, different exhaust nozzle design may be applied. A convergent design typically used for subsonic flight regime, while a convergent-divergent nozzle design will be used for supersonic flight regime. Variable area nozzles and thrust vectoring technologies also enhances nozzle performance by optimizing exhaust flow under varying flight conditions (Afridi et al., 2023). In military application, an afterburner may also be fitted to further enhance thrust generation.

CONCLUSION

In conclusion, improving the performance of aircraft gas turbine engine requires a holistic approach that addresses each component of the engine. Advances in aerodynamic design, material properties, combustion processes, and cooling techniques have collectively enhanced the overall engine efficiency and environmental considerations. Continued research, development and innovation in these specific areas will be a crucial part in meeting the future aviation demands.

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