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Combustion efficiency analysis and key emission parameters of a turboprop engine at various loads

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ABSTRACT

In this study, combustion efficiency of a military type turboprop engine is determined at various loads with the aid of emission data. Also, emission data collected from the engine run at various loads by experimental methods is used to introduce emission parameters such as the emission index, the power emission index and the energy emission index. The calculation method of the power emission index and the energy emission index for a turboprop engine is incorporated in literature by this study. Additionally, the relationship between determined parameters is proven in this study. As a result of the study, the combustion efficiency of the engine is found to be variable between 97.8% and 99.9%, as expected from a modern aircraft engine.

1. Introduction

Gas turbine engines are the main power units of air vehicles and operated in power plants. The main purpose of aircraft gas turbine engines that are used to run both commercial and military aircrafts, unmanned aerial vehicles (UAVs) in the aviation industry known as air breathing engines, generate thrust to provide movement of aircraft. A simple gas turbine is composed of an air inlet, air compressor, combustion chamber, turbine and exhaust nozzle. Air taken into an air inlet is pressurized in the air compressor and warmed up. Afterwards, fuel is burned with the benefit of the pressurized air in the combustion chamber. Thus, high energy shows up. Exhaust gases carrying out high energy leave the combustion chamber and generate the required compressor power by turning turbine blades. Then hot gases run out through the exhaust nozzle to meet the thrust demand of the aircraft [1–3].

The emergence of gas turbine engines was in accordance with Newton's Third Law, which was presented in the years 1600–1700. In addition, the first studies on modern aircraft gas turbine engines were performed in the 1900s during the Second World War. From that day to the present time significant development was achieved [1–4]. At the present time, much research continues on to improve the performance of aircraft gas turbine engines. Amid this research, studies on design improvement to enhance component performance take an important place right along with alternative fuel usage studies [5–9]. Therefore, many texts can be found about studies on performance analysis of different aircraft gas turbine engines on the basis of thermodynamic principles and different component performance analysis. Engine analysis with the aid of energy and exergy methods prove system efficiency, improvement potential, environmental impacts and sustainability indicators [10–18]. Also, numerical analysis and experimental studies examine other performance parameters of the engine and its components [19–23].

In the manner of all power generation cycles, providing more energy to the gas turbine engine enhances generated power. As mentioned before, energy purveyance to the gas turbine engine occurs in the combustion chamber [24,25]. In this case, many studies on performance evaluation of combustion chambers can be found. It is clear that the main goal of the studies is improving combustion efficiency of combustor designs. Temperature pattern and pressure loss are essential criteria, as well as combustion efficiency. As a result of the texts that

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can be found in the literature; major parameters such as adiabatic flame temperature, equivalence ratio, emission distribution varieties with different fuels and heat loss are proven [25–37]. This article aims to determine the combustion efficiency for a turboprop aero engine in the LTO (landing and take-off) flight cycle with the aid of exhaust emission data. Whilst examining combustion parameters and fuel characteristics, the neglect of combustion efficiency in other studies is clear [25–37]. However, combustion efficiency is significant for understanding the quality of the combustion process and the utilization ratio of the fuel heat value [36]. In this study, unlike others, emission data collected from a turboprop engine by experimental methods is preferred to theoretical calculation methods for determination of combustion efficiency.

2. System description and experimental procedure

2.1. System description

Thrust generated with a propulsion system is required for an aerial vehicle to move. Many types of aircraft, especially commercial aircrafts with short range and military aircrafts, use a turboprop engine for this purpose. Turboprop engines consist of a gas turbine core engine and propeller. The core engine is similar to the turbojet engine with a few differences. The core engine, which expands all the hot exhaust through the nozzle, is used to turn the turbine, not to produce thrust. Velocity of the exhaust gases released from the nozzle of the turboprops is low and produces less thrust. This type of turboprop engine is called the single-shaft turboprop. Another type of the turboprop engines includes an additional turbine stage which is connected to a drive shaft. The drive shaft transmits power to the gear box connected to the propeller that generates the thrust. This second type of turboprop engine is called the free-turbine turboprop engine [1–4,18,38–40].

The T56-A-15 engine, investigated in this study, is a type of single-shaft turboprop engine. The propeller shaft of the engine is offset above the core engine that is comprised of fourteen stage axial-flow compressors, six can through-flow combustors congregated in a single annular chamber and four stage turbines, as illustrated in Fig. 1. The T56-A-15 turboprop engine is still in use as the power unit of the C-130 Hercules tactical transport aircrafts in the Turkish Air Forces [41–43].

2.2. Exhaust emission measurement

In this study, experimental data is obtained from the EPA Report [41]. The experimental data used was collected at the Detroit Diesel Allison Plant as stated in the report. Measured quantities are listed below as stated in the text:

- Unburned hydrocarbons,
- Carbon monoxide and carbon dioxide,
- Nitric oxide and nitrogen oxide,
- Smoke,
- Aldehydes

The flame ionization detector, infrared analyser and electron chemiluminescent analyser are used to specify the composition of sample exhaust gas during the measurement. In the course of measurement, a sampling probe with twenty-eight holes is used to soak up exhaust gas. Also, the staff benefited from seven legs for attaching the probe to the engine tailpipe. As defined in the report, heated lines are used to transfer sample exhaust gas from the engine to analysers. Further explanation about the measurement system can be found in the report text. Data collected from the T56-A-15 engine is summarized in Table 1 as a result of the experimental study.

During this experimental study, engine power estimation is assumed, and the RPM equivalences of the flight phases are given in Table 2. As given in Table 2, the test is performed on the basis of the ICAO LTO emission measurement methodology.

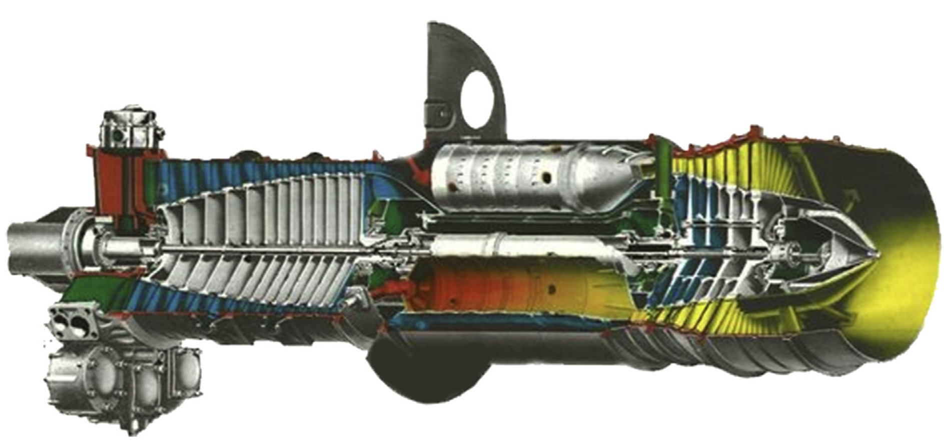

Fig. 1. Illustration of the T56-A-15 turboprop engine.