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A review on the structures and characteristics of micro-turbojet engines

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Abstract

Nowadays, micro-turbojet engines are widely used in various fields, from recreational devices to drones and missiles in the military industry. Given their remarkable performance, numerous companies have entered this area and produced a variety of products. This widespread use and diverse range of products have led to an increased importance of review studies in this subject. In this research, an extensive study has been conducted on micro-turbojet engines with a thrust force below 1000 Newtons. These engines have a diameter less than 300 mm, compressor pressure ratio less than 5 and fuel consumption lower than 2500 gr/min. Statistical analysis of the engines within this thrust range has yielded valuable information regarding the structural and performance specifications of this category of engines, which is presented in the form of tables and graphs. In this study, the main components of these engines, including the compressor, combustion chamber, turbine, and auxiliary systems, as well as their interconnections, are described. Although the overall structure of these engines is similar to large-scale aircraft engines, there are significant differences in design philosophy, types of main components, and details. At the end of the paper, specifications of over one hundred micro-turbojet engines available worldwide including thrust range, dimensions, engine rotor speed, air flow rate, fuel consumption, and turbine temperature are presented.

Keywords: Micro-turbojet engines, aerial vehicle, thrust, performance characteristics.

1. Introduction

Small turbojet engines (micro-turbojet) are a category of turbojet engines that are widely used in recreational, military, and civilian fields. This wide application has led to the production of many products in this area. Micro-turbojet engines have lower overall efficiency and service life than larger models and instead have a simpler design and manufacturing process. Although the general structure of these engines is similar to large turbojet engines, there are many differences in details from large engines, and this has made it important to conduct research focused on this category of engines.

In 2015, Oppong et al. [1] conducted a study on the performance of micro-turbojet engines. In this study, the operating cycle of these engines was first explained, then the performance modeling and its challenges were investigated. Moreover, the studies conducted in this field, including performance of different engine components, as well as the overall performance of the engine were introduced. In 2016, Dutczak [2] studied small gas turbine engines (with power range of less than 10 kW for power-generator engines and less than 250 Newtons for propulsion engines) in terms of structure and specifications. In this research, the characteristics of some small gas turbine engines, including four engines to produce thrust and two engines to produce power were presented. In 2019, Costa et al. [3] investigated turbojet and turbofan engines with a thrust range between 2,600 and 6,000 newtons to find the most important characteristics affecting these types of engines. They found that engines in this range of thrust have pressure ratios between 3 and 9 for turbojet engines and up to 14 for turbofan engines. The turbine inlet temperature in these engines is between 800 and 1010 degrees Celsius. Their rotational speed is between 29,000 and 42,000 rpm. The diameter and length of these engines are between 300 and 450 and 750 and 1500 mm, respectively. The mass flow rate of the air entering these engines is between 4 and 8.5 kg/s and their weight is from 55 to 115 kg. The general purpose of this type of research is to introduce the general structure of the engine and compare the characteristics and performance of different engines.

The design and performance simulation of micro-turbojet engine components have also been investigated in several researches. The design methods used are often combined with 3D simulation of mass flow using the computational fluid dynamic method and experimental data. The main components of micro-turbojet engines, similar to turbojet engines, include the compressor, combustion chamber, and turbine, which have been extensively studied so far. From this category, we can refer to the researches done in the area of compressor design and simulation [4-14], combustion chamber [15-18] and turbine design [19-21].

According to the studies published until now, no comprehensive research has been conducted in which sufficient information is provided regarding the characteristics and structure of micro-turbojet engines. Such research is very efficient both in selection of a micro-turbojet engine and in the design process. In the current research, a comprehensive introduction of micro-turbojet engines with a thrust level of less than 1000 newtons is provided. At the beginning of this paper, the general structure and performance of these engines are reviewed, then their main and auxiliary components are described. At the end of paper, the specifications of a large number of micro turbojet engines are presented.

2. General Structure and Characteristics of Micro-Turbojet Engines

Micro-turbojet engines consist of three main parts: compressor, combustion chamber, and turbine. These components and the cross section of three micro-turbojet engines have been shown in Figure 1.

In this section, the overall performance of micro-turbojet engines is examined based on a statistical study of the performance of more than 100 engines. The specifications of these engines are presented separately in the final section of the paper. Important structural and performance characteristics include engine dimensional specifications, compressor pressure ratio, maximum propulsion power, exhaust gas temperature, fuel consumption, etc., which are usually announced by manufacturing companies. The range of changes of some of the most important structural and operational features of these engines is given in Table 1.

Table 1. Range of changes of structural and operational specifications of micro-turbojet engines

Specification (unit)	Range
Diameter (mm)	55-235
Length (mm)	112-568
Pressure Ratio	1.5-4.7
Max. Thrust (N)	16-979
Exhaust Gas Temperature (c)	650-875
Fuel Consumption (gr/min)	52-2262

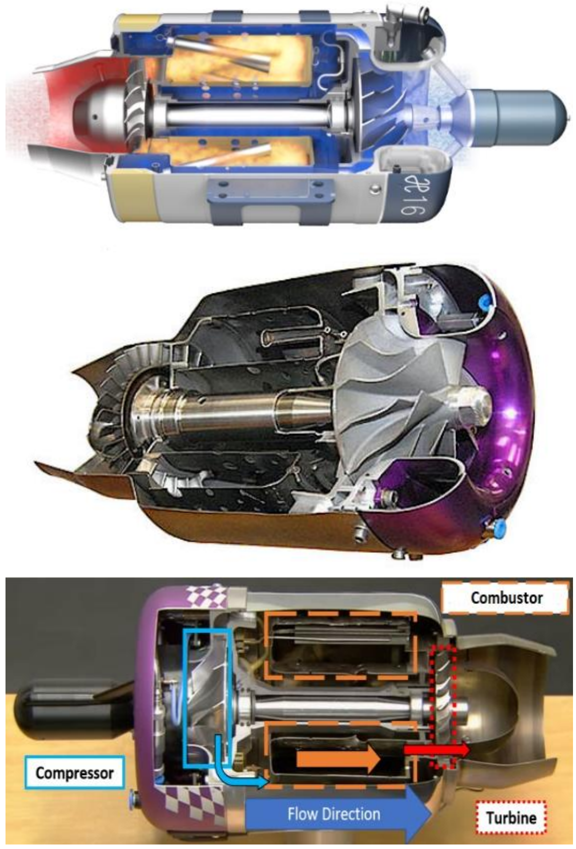


Figure 1. Cross section of three micro-turbojet engines [22-24]

To further investigate the performance characteristics of micro-turbojet engines, the trend of changes in some of the main characteristics of these engines is presented in Figure 2. These results are extracted based on statistical information. Figure 2(a) shows the maximum changes in the mass flow rate of the air entering the engine according to its diameter. Considering the direct relationship between the mass flow rate and the engine inlet area, the upward trend in this graph is quite reasonable. In Figure 2(b) and Figure 2(c), the maximum thrust and rotational speed are shown according to the engine diameter. Normally, with the increase in the diameter of the engine, the thrust increases, and its rotational speed decreases. In Figure 2, parts (d) and (e), the diagram of the maximum thrust is shown in terms of fuel consumption and specific fuel consumption, respectively. According to these figures, although the fuel consumption increases with the increase of thrust, the specific fuel consumption generally decreases.

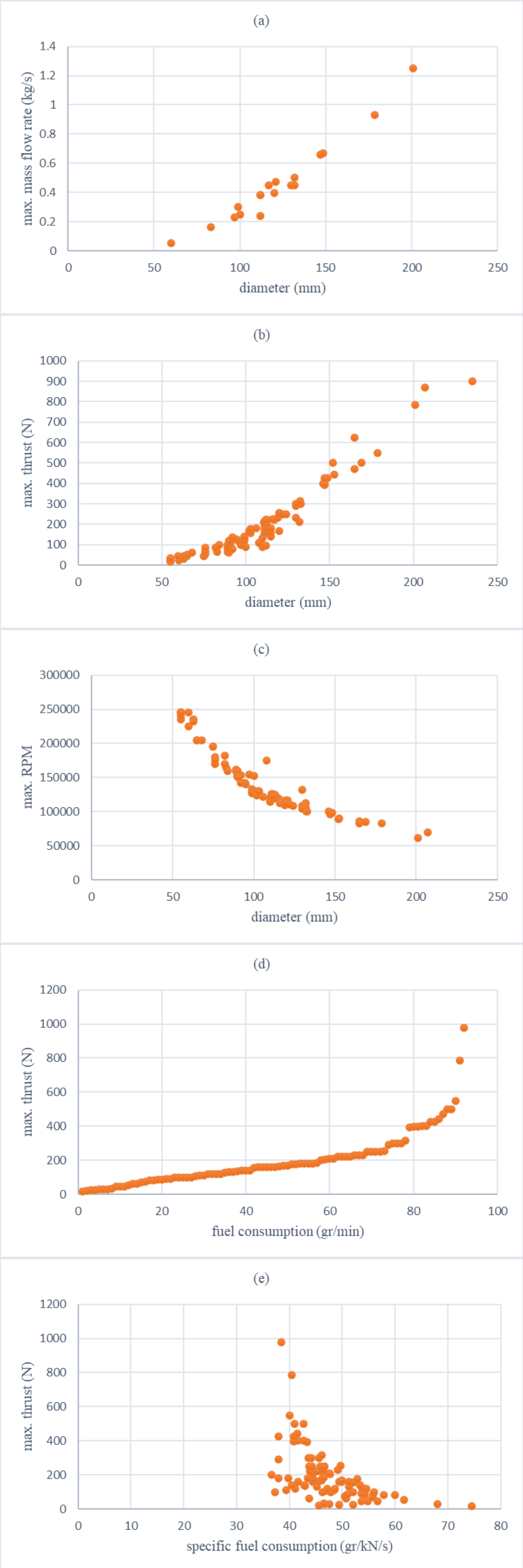


Figure 2. Trend of maximum mass flow rate, thrust and RPM of micro-turbojet engines

3. Main Components of Micro-Turbojet Engines

The main components of a turbojet engine are compressor, combustion chamber, and turbine. These components correspond to different processes of the Brayton cycle. Also, the nozzle has the role of converting the generated power of the cycle into kinetic energy and producing propulsion power. The mentioned parts are used in all turbojet engines, regardless of their size. However, micro-turbojets cannot be considered as miniaturized examples of large aero-engines. Although the laws governing on the performance of engines are the same, the design of a micro-turbojet has different requirements than large engines. The simplicity and lack of complexity in the structure of microturbine jet engines are considered the primary priority for manufacturers and users. For this reason, many auxiliary systems of large engines such as anti-surge systems, the control system of stator vanes or tip clearance, the cooling system of turbine blades, and the control system of nozzle exit cross-section are not found in micro engines. This simplicity of the design is not without cost and leads to a decrease in the efficiency and service life of the engine. Apart from this, micro-turbojets are also very different from large engines in terms of the design of the main components. The arrangement of the main parts of most micro-turbojets consists of a radial compressor stage, an evaporation tube combustion chamber, an axial turbine stage, and a converging nozzle. An example of an engine with this arrangement can be seen in Figure 3.

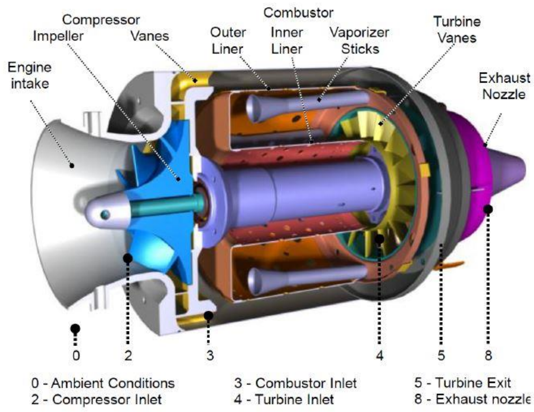
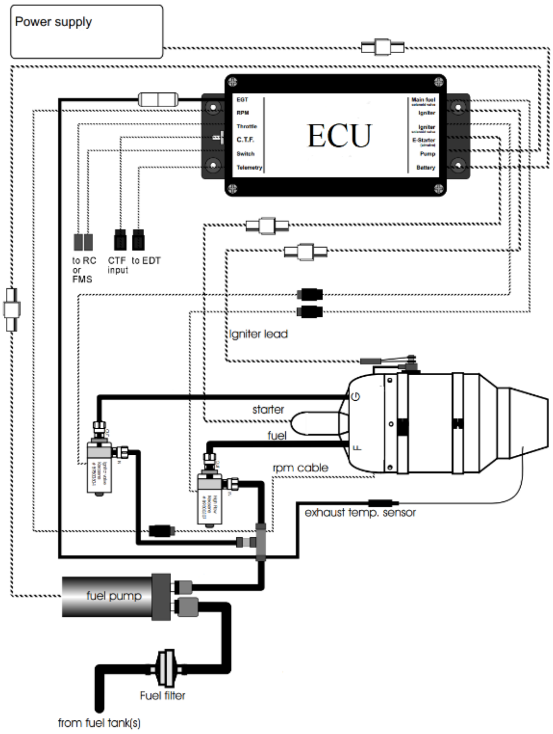


Figure 3. Internal view and various components of a micro-turbojet engine [25]

4. Auxiliary Components of Micro-Turbojet Engines

The auxiliary components of a micro-turbojet engine often include a fuel pump, solenoid valve (two), starting system, electrical control unit, sensor (rotational speed and temperature of exhaust gases), and power supply. Figure 4 (a) shows a micro-turbojet engine with its auxiliary systems, and Figure 4 (b) shows how different components are connected schematically. The start system of micro-turbojet engines is available in two types: air start and electric start. In the air start mode, blowing air into the engine creates the initial rotational speed required for the engine in the starting phase, and in the electric mode, an electric motor is used as a starter and this motor provides the initial rotational speed for the engine. Today, most micro-turbojet engines use an electric starter. Micro-turbojet engines are available in two types of propane start and kerosene start in terms of fuel consumption in the start-up phase. The engine shown in Figure 4 has an electric starter and uses kerosene during the start-up phase.

(a)



(b)

Figure 4. A Micro-turbojet engine with its auxiliary systems [26]

5. Conclusions

In this research, micro-turbojet engines with propulsion power of less than 1000 newtons were studied and analyzed. This category of turbojet engines, despite their differences with large turbojet engines, have similarities with each other and are similar in terms of overall structure and operation. In this paper, while examining this issue, some of the most important dimensional and operational characteristics of this category of engines and their changes were examined. Similar to large engines, this category of engines also consists of three main components: compressor, combustion chamber, and turbine, and each component was described in detail in this paper. Also, the auxiliary systems used in micro-turbojet engines and how they are related to the main parts were explained.

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