Technical Sciences, 2024, 27, 105–112

Yearbook peer-reviewed scientific journal
ISSN 1505-4675
e-ISSN 2083-4527
TECHNICAL SCIENCES
Homepage: https://czasopisma.uwm.edu.pl/index.php/ts/

DOI: https://doi.org/10.31648/ts.10159

STAND CHARACTERISTICS OF THE GTM 400 MOD TURBOJET ENGINE

Łukasz Brodzik

ORCID: 0000-0002-6161-8459
Instytute of Thermal Energy
Poznań University of Technology in Poznań

Received 25 April 2024, accepted 3 June 2024, available online 3 June 2024.

Key words: turbojet engine, specific thrust, specific fuel consumption.

Abstract

Miniaturization of turbine jet engines not only enables testing of fuel mixtures but also opens up new possibilities for their use in smaller aircraft. In this work, measurements were carried out in the GTM 400 MOD engine in order to create the stand characteristics of unit thrust and specific fuel consumption. For both parameters, polynomials were determined describing their changes in the range of rotational speeds used. These calculations constitute the first stage of research on a hybrid turbojet engine powered by aviation kerosene and hydrogen. The reason for the research is to check the possibility of using hydrogen in turbomachinery engines. Hydrogen is one of the fuel additives approved for use by the European Union, which forces the aviation industry to reduce exhaust emissions into the atmosphere. Hydrogen can not only enrich aviation kerosene but also become an alternative fuel.

Introduction

During the operation of a turbojet engine, harmful chemicals are emitted into the atmosphere. There are nitrogen oxide, soot, unburned hydrocarbons, carbon monoxide, and carbon dioxide (KOTLARZ et al. 2006, KOTLARZ 2004,

Correspondence: Łukasz Brodzik, Zakład Inżynierii Lotniczej, Instytut Energetyki Cieplnej, Wydział Inżynierii Środowiska i Energetyki, Politechnika Poznańska, ul. Piotrowo 5, 61-138 Poznań, e-mail: lukasz.brodzik@put.poznan.pl

LEFEBRE 1998). The concentration of carbon monoxide and unburned hydrocarbons is highest at low engine operating ranges and disappears as a function of the increase in engine thrust. The opposite phenomenon applies to nitrogen oxides and smoke, the presence of which in exhaust gases at low rotational speeds is very small and increases significantly with the increase in engine thrust (GŁOWACKI, SZCZECIŃSKI 2011). In European Union countries, it is estimated that aviation contributes 3% to total greenhouse gas emissions. The average increase in greenhouse gases produced in European Union countries is approximately 4.3% (CAPOCCITTI et al. 2010, FLEUTI 2005, SCHUMANN 2005, RAMANATHAN, FENG 2009).

As part of the "Fit for 55" package, the European Union, based on the ReFuelEU application, intends to introduce SAF (Sustainable Aviation Fuels) fuel admixtures. The aim is to gradually reduce exhaust emissions by increasing the content of the above-mentioned admixtures in fuels to 70% in 2050.

The study presented in this paper was undertaken for two reasons. The first reason is the desire to create a hybrid turbojet engine in the future. The second reason is the lack of information in the literature about the engine used. There are no experimental and theoretical studies related to its characteristics.

Therefore, the aim of the study was to determine the polynomial of the change in specific thrust and specific fuel consumption in the range of rotational speeds used. The analysis was carried out on the basis of 4 measurement samples. The resulting stand characteristics are intended to be a reference for measurements planned in the future using a hydrogen admixture.

Materials and methods

Experimental tests were carried out on the GTM400 MOD turbojet engine from JETPOL, which is shown in Figure 1. It is a miniature single-flow engine powered by JET A-1 aviation kerosene. The engine has a single-stage axial turbine. It is started using an electric starter. An example of another analysis of a miniature engine can be found in the literature (DOUGLAS, SAARLAS 1996).

The principle of operation of a turbine jet engine is to increase the speed of the air stream flowing through the engine. An increase in the gas temperature in the combustion chamber and an increase in its volume result in the velocity at the nozzle outlet being higher than the air velocity at the engine inlet. Thus, during engine operation, a thrust force is created, Figure 2, which is expressed in the following relationship (MATTINGLY 1996, ROTARU 2017, SANKAR et al. 2020):

$$K = \dot{m}' c_5 - \dot{m} c_1 \tag{1}$$

where:

$\dot{m}$ – air mass flow,

$\dot{m}'$ – mass flow of exhaust gases flowing from the engine,

c_1 – air speed in the inlet,

c_5 – velocity of exhaust gases flowing from the engine.

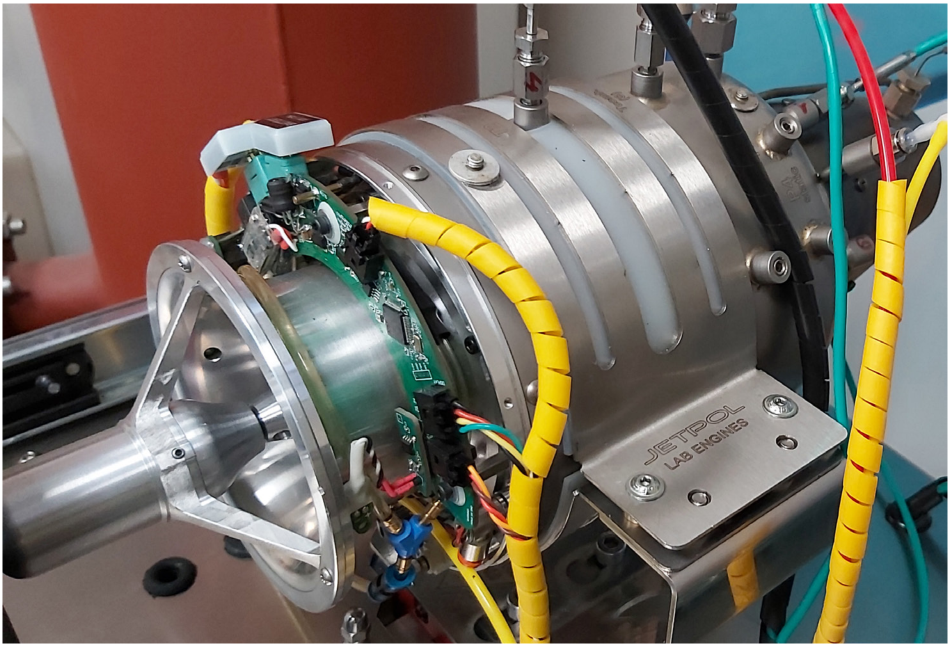

Fig. 1. GTM400 MOD engine

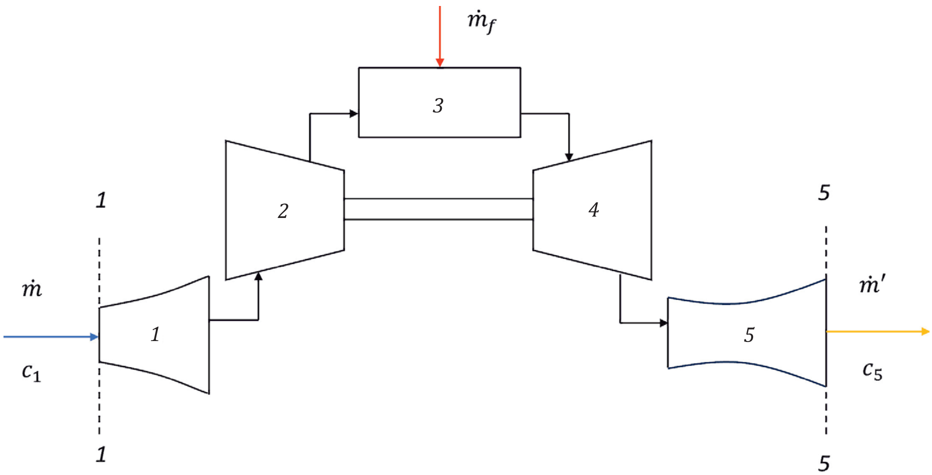

Fig. 2. Diagram of a turbine jet engine: *1* – inlet, *2* – compressor, *3* – combustion chamber, *4* – turbine, *5* – outlet nozzle

Very important parameters of aircraft engines are their unit parameters. Using them, it can be compare processes occurring in different engines, as well as their design perfection. The basic parameter of a turbojet engine is thrust. The specific thrust depends on the engine pressure, the exhaust gas temperature at the exit from the combustion chamber, and the efficiency of compression and expansion in the engine. This parameter is directly proportional to the generated thrust force and inversely proportional to the air mass flow used

$$k_j = \frac{K}{\dot{m}} \tag{2}$$

Another very important parameter for comparing engine operation is specific fuel consumption. This parameter determines the efficiency of the engine in terms of the amount of fuel consumed in relation to the generated thrust force. Additionally, it is necessary to determine the range and duration of the aircraft's flight. The specific fuel consumption results from the following relationship (ROGERS 2017):

$$c_j = \frac{\dot{m}_f}{K} \tag{3}$$

where:

$\dot{m}_f$ – fuel mass flow.

The specific thrust and specific fuel consumption for full-scale aircraft engines are presented in Figures 3 and 4 (CHACHURSKI 2018).

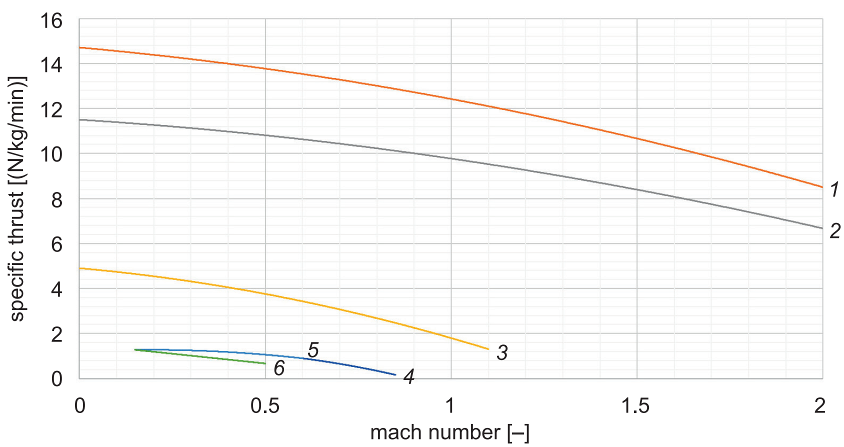

Fig. 3. Specific thrust: *1* – turbojet engine, *2* – turbofan engine with low by-pass ratio, *3* – turbofan engine with high by-pass ratio, *4* – turboprop engine, *5* advanced turboprop engine, *6* – conventional turboprop engine

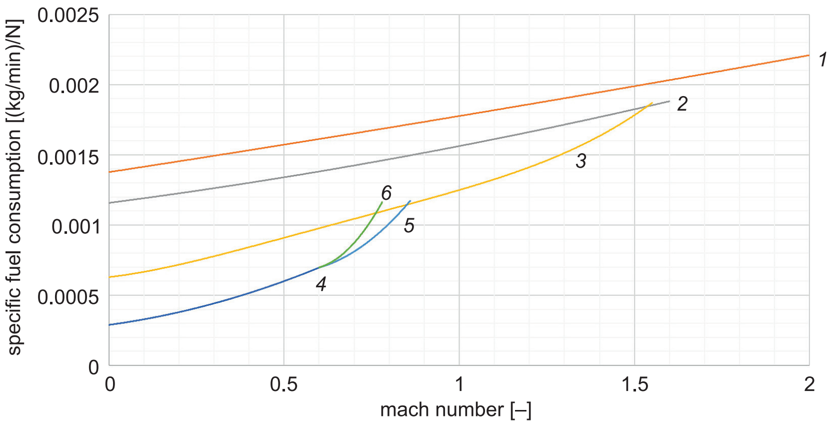

Fig. 4. Specific fuel consumption: *1* – turbojet engine, *2* – turbofan engine with low by-pass ratio, *3* – turbofan engine with high by-pass ratio, *4* – turboprop engine, *5* – advanced turboprop engine, *6* – conventional turboprop engine

Results

During the tests, a pressure of 101,240 Pa was recorded. The average temperature during the four measurements was 23.3°C. For the prevailing atmospheric conditions, the average thrust curve was presented in Figure 5.

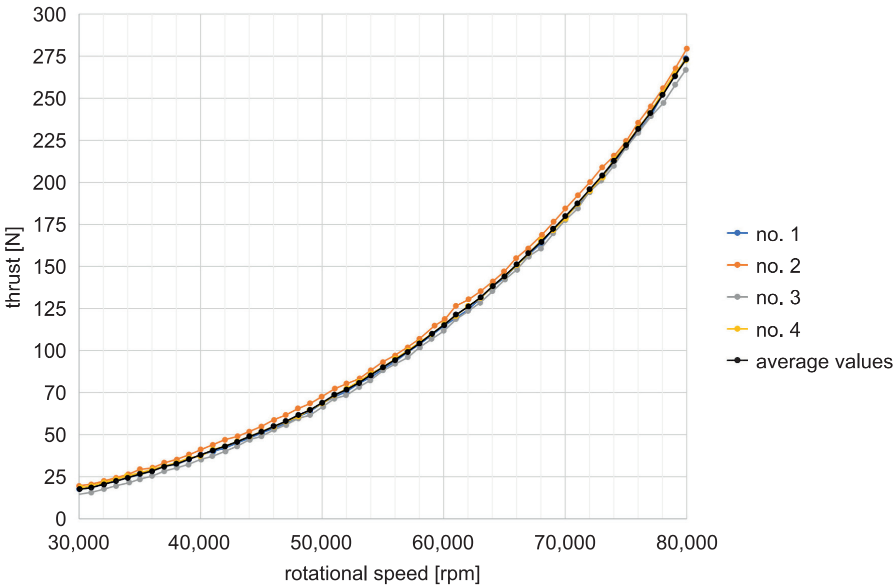

Fig. 5. The thrust as a function of rotational speed

Fuel consumption was recorded while the engine was running. Figure 6 shows them in the form of a mass stream fed to the combustion chamber. Its values were estimated based on the fuel analysis certificate of the Orlen SA concern. On its basis, it was assumed that the density of JET A-1 aviation kerosene was 796 kg/m³.

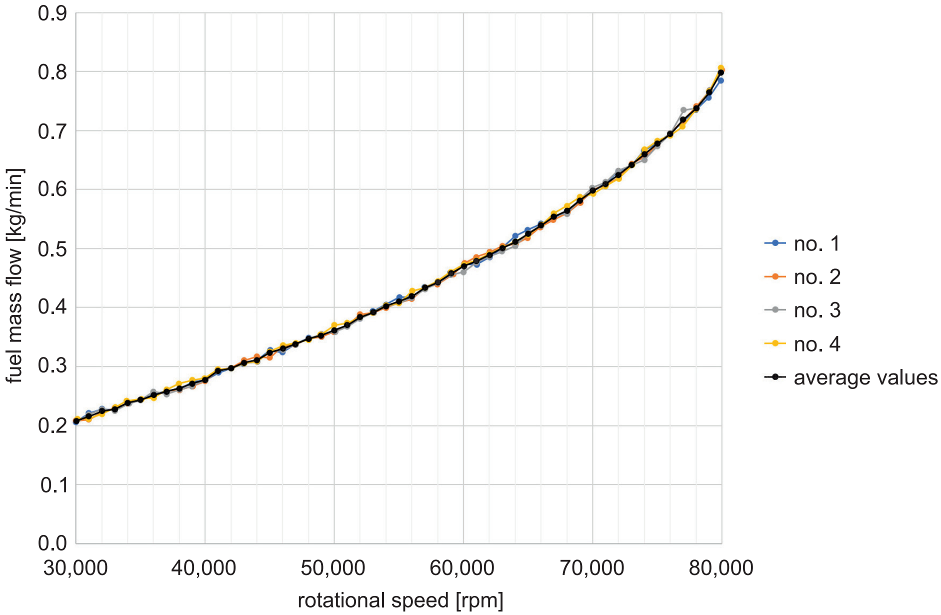

Fig. 6. The minute fuel consumption as a function of rotational speed

Their unit values were determined based on the recorded thrust and the measured minute fuel consumption. The distributions of these parameters along with curves representing sixth-degree polynomials were presented in Figure 7.

For the assumed conditions and rotational speed function, the polynomial describing changes in the unit thrust is:

$$k_j = -2 \cdot 10^{-25} n^6 + 7 \cdot 10^{-20} n^5 - 9 \cdot 10^{-15} n^4 + \\ + 7 \cdot 10^{-10} n^3 - 3 \cdot 10^{-5} n^2 + 0.6022n - 5{,}186.4 \tag{4}$$

while the polynomial of specific fuel consumption describes the relationship:

$$c_j = 10^{-30} n^6 - 5 \cdot 10^{-25} n^5 + 8 \cdot 10^{-20} n^4 - 7 \cdot 10^{-15} n^3 + \\ + 3 \cdot 10^{-10} n^2 - 9 \cdot 10^{-6} n + 0.1146 \tag{5}$$

where:

n – rotational speed.

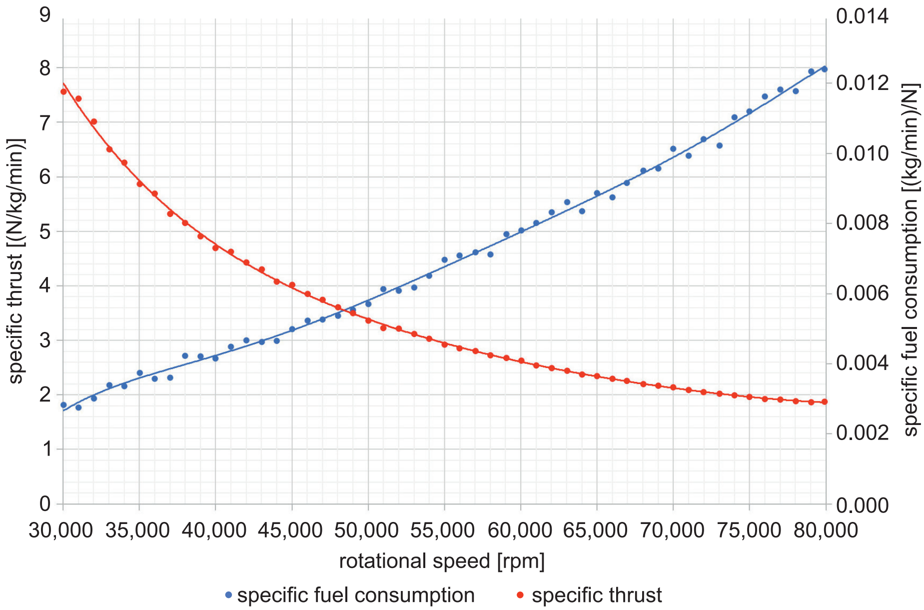

Fig. 7. The specific thrust and specific fuel consumption as a function of rotational speed

Conclusions

During the prevailing weather conditions, the GTM 400 MOD engine generated an average thrust force ranging from 18 N at a speed of 30,025 rpm to 273 N at a speed of 79,925 rpm. During operation, the engine consumed fuel in the same speed ranges from 0.208 kg/min to 0.798 kg/min. It follows that the reserve of thrust at sea level during the stand test was 255 N in relation to the lowest rotational speed. It should be bear in mind that to fully produce thrust, fuel consumption will increased by 0.59 kg/min.

Based on the experimental tests performed on the engine, the trend function for changes in specific thrust and specific fuel consumption was determined as a function of rotational speed. While increasing the speed, the specific thrust increased by 77%. At the same time, specific fuel consumption is reduced by 75%.

The created stand characteristics made it possible to determine the performance parameters of the aircraft on which the tested engine will be installed. These characteristics also allowed for the determination of changes in thrust and fuel consumption when admixtures or alternative fuels are used.

Acknowledgments

The research performed using the GTM400 MOD engine station was supported by a subsidy from the Polish Ministry of Science and Higher Education

References

CAPOCCITTI S., KHARE A., MILDENBERGER U. 2010. *Aviation Industry – Mitigating Climate Change Impacts through Technology and Policy*. Journal of Technology Management & Innovation, 5(2): 66-75. https://doi.org/10.4067/S0718-27242010000200006

CHACHURSKI R., TRZECIAK A., JĘDROWIAK B. 2018. *Comparison of the Results of Mathematical Modeling of a GTM 120 Miniature Turbine Jet Engine with the Research Results*. Combustion Engines, 173(2): 30-33. https://doi.org/10.19206/CE-2018-205

DOUGLAS R., SAARLAS A. 1996. *An Introduction to Aerospace Propulsion*. Prentice Hall, Upper Saddle River, New Jersey.

FLEUTI E. 2005. *Aircraft Ground Handling Emissions at Zurich Airport*. AERONET WorkShhop, Stockholm.

GŁOWACKI P., SZCZECIŃSKI S. 2011. *Turbinowy silnik odrzutowy jako źródło zagrożeń ekologicznych*. Prace Instytutu Lotnictwa, 4(213): 252-257.

KOTLARZ W. 2004. *Turbinowe zespoły napędowe źródłem skażeń powietrza na lotniskach wojskowych*. Air Forces Academy, Dęblin.

KOTLARZ W., RYPULAK J., PIASECZNY L., ZADRĄG R. 2006. *Testy toksyczności spalin turbinowego silnika lotniczego dla warunków startu i lądowania* [*Tests of exhaust gas toxicity of jet turbine engine for take off and landing phases of flight*]. Combustion Engines, 127(4): 61-73.

LEFEBRE A. 1998. *Gas Turbine Combustion*. Second Edition. Taylor & Francis, Philadelphia.

MATTINGLY J.D. 1996. *Elements of Gas Turbine Propulsion*. McGraw-Hill, New York.

RAMANATHAN V., FENG Y. 2009. *Air Pollution, Greenhouse Gases and Climate Change: Global and Regional Perspectives*. Atmospheric Environment, 43(1): 37-50. https://doi.org/10.1016/j.atmosenv.2008.09.063

ROGERS G.F.C., STRAZNICKY P., COHEN H., SARAVANAMUTTOO H.I.H., NIX A. 2017. *Gas Turbine Theory*. 7th Edition. Pearson, London.

ROTARU C. 2017. *Analysis of Turbojet Combustion Chamber Performances Based on Flow Field Simplified Mathematical Model*. AIP Conference Proceedings, 1836(1): 020047. https://doi.org/10.1063/1.4981987

SANKAR B., GOUDA G., JANA S., IYENGAR V.S. 2020. *Study of Design Modification Effects through Performance Analysis of a Legacy Gas Turbine Engine*. Journal of Aerospace Technology and Management, 12: e0720. https://doi.org/10.5028/jatm.v12.1097

SCHUMANN U. 2005. *Formation, Properties and Climatic Effects of Contrails*. Deutsches Zentrum fiir Luft- und Raumfahrt, Köln.