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Gas temperature distribution in the evaporator of GTM400 turbojet engine

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Abstract The paper presents the results of measurements carried out in the GTM400 turbojet engine with a changed combustion chamber geometry. The available publications lack more detailed information on the temperature distribution in evaporators, which are part of the combustion chamber of small turbojet engines. As the results of the analysis showed, this is not simple, because the research takes place in very small spaces. The reason for the work carried out is to check whether the temperatures in the evaporators are high enough. This allows to determine whether the fuel is evaporating properly. Therefore, an analysis was carried out to determine the temperature distribution in the area of the inlet to the evaporator. Thanks to the modification of the combustion chamber, it was possible to measure temperatures, which in the engine literature are simulated using numerical analysis. The analysis described in the paper is one of the stages of preparing the engine for operation with hydrogen. It is modified as part of a project to build a hybrid engine burning traditional JET-A1 fuel and alternative fuel, i.e. hydrogen.

Keywords: Turbojet engine; Combustion chamber; Evaporators

1 Introduction

Miniature turbojet engines are a source of increasing interest among designers of unmanned aerial vehicles [1–3]. This is primarily due to the continuous increase in the production of these aircraft and their increasing use in

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the military industry [4–8]. The tasks they perform include, among others: imaging the battlefield for commanders at various levels at sea and on land, searching, detecting and pointing out objects using a laser pointer, directing fire, e.g., artillery, anti-aircraft defense, destroying ground, surface and air objects. Most aircraft are powered by electric motors or internal combustion piston engines [9–11]. Despite the relatively high fuel consumption, turbine jet engines have a large reserve of thrust, which makes them attractive wherever this parameter is important [12–16]. The miniaturization of these engines allows to think about their serious use in small unmanned aerial vehicles, which, as mentioned above, have a very wide range of applications.

The paper includes temperature tests in evaporators that occur in small turbojet engines. Placing thermocouples in these places forced a change in the engine geometry due to its incorrect operation. The test allows to indicate areas with lower and higher temperatures, which may indicate whether the fuel evaporation process is correct or which area of the engine is warmer. Evaporators are the part of the engine into which fuel is injected. It is transported together with part of the air into the combustion chamber [17, 18]. The special role of evaporators is that they evaporate the fuel, resulting in a homogeneous gaseous air-fuel mixture at the outlet. This is the reason why the engine is required to warm up well in the first phase of operation before it starts working properly [19]. The warm-up phase is necessary because in small engines the compressor pressure is not high. This involves the use of centrifugal compressors. The consequence of this is a relatively low temperature at the inlet to the combustion chamber, approximately 152°C. Due to its small dimensions, the process of evaporation and atomization of fuel must be quick and simple. Advanced technological solutions would increase the already high price of this type of engines.

Proper work of evaporators is important because it is one of the factors directly influencing the achieved combustion efficiency as well as the amount of NOx emission reduction. In turn, the improvement of operation is influenced by the larger length and diameter of the evaporator, as well as the reduction of the average diameters of fuel drops when a larger amount of air is supplied to the combustion chamber [20].

2 Test stand

The most important components of the test stand are: GTM400 engine with automatic start using JET-A1 fuel, gear fuel pump, fuel start solenoid valve, main fuel solenoid valve, Fig. 1 [21]. During operation, the engine is placed under a polycarbonate cover. The station also has equipment for measuring static thrust, i.e. a strain gauge sensor, an amplifier for the MD11 measuring bridge systems, and a strain gauge beam. The whole thing is mounted on a steel base, to which control and measurement equipment with data acquisition, a fuel tank and a battery are attached.

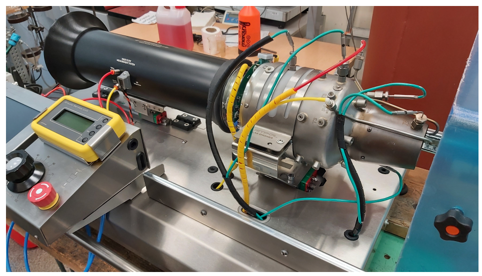

Figure 1: Test stand of GTM400 engine.

The JETPOL engine has measuring ports in various sections, e.g., the combustion chamber. The basic version is characterized by the following parameters:

thrust: 15–400 N,
rotational speed: 30000–88000 rpm,
mass air flow 0.47 kg/s,
fuel consumption 0.98 kg/min.

After engine modification, its parameters changed as follows:

thrust: 15–300 N,
rotational speed: 30000–81000 rpm,
mass air flow 0.59 kg/s,
fuel consumption 0.82 kg/min.

The dimensions of the engine are as follows: diameter 0.15 m, length 0.39 m, and weight is 2.9 kg.

There are twelve evaporators in the engine, and it is possible to perform measurements in half of them. An example of the location of a thermocouple is presented in Fig. 2. Evaporators have the shape of tubes whose axis of symmetry is not parallel to the axis of symmetry of the combustion chamber. In the case of shorter combustion chambers, evaporators bent in the circumferential direction or with a shape similar to the letter S are used [22].

K-type thermocouples (outer diameter of 0.0015 m) were used to measure the temperature inside the evaporators, which can operate in the temperature range −40°C to 1000°C [23]. In the first stage of the research, the

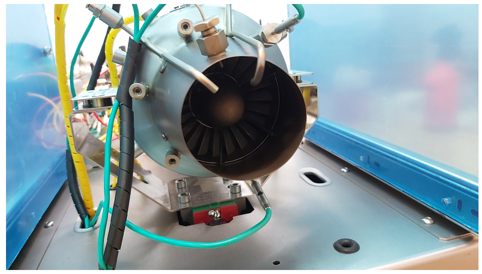

Figure 2: Temperature tappings.

sensors were inserted into the evaporators to the maximum distance, i.e., 0.07 m. In the next three stages, this distance was reduced by 0.01 m each time.

The given distance takes into account the length of the sleeve, nut and screw. The nut is screwed onto a threaded sleeve permanently located in the engine casing. A screw with a hollow hole for the sensor locks it. The sleeve, nut and screw together form the sensor mount, and their total length is 0.0365 m. This is well illustrated in Fig. 2, where the thermocouple is also inserted into the outlet nozzle (the mounting in the evaporator is the same, only smaller elements are present).

The indicated distances also include the reversal channel, the length of which (measured along the axis of symmetry) is 0.02 m. The evaporators (Fig. 3) are 0.08 m long. Therefore, when the sensor was fully inserted, a junction of the thermocouple in the evaporator was at a depth of 0.0135 m.

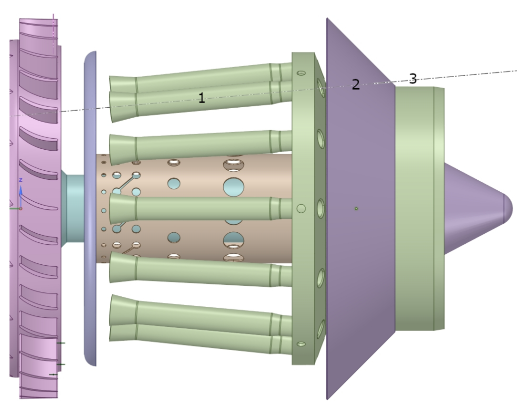

Figure 3: Part of the engine, where the test places are shown on the example of one of the evaporators (the glow tube and part of the engine casing are not visible): 1 – evaporator, 2 – reversing duct, 3 – sensor mounting on the engine casing.

3 Measurement analysis

During the measurements, the ambient temperature ranged from 21°C to 24°C. Measurements were made in evaporators according to the numbering (entries to the evaporators placed circumferentially every 60°), as in Fig. 4.

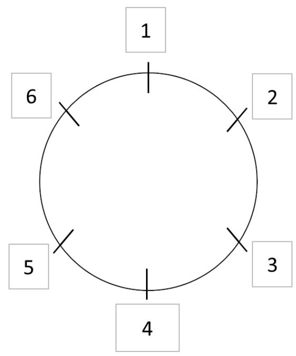

Figure 4: Numbering of evaporators.

The results of the first stage of the research are presented in Fig. 5. The temperatures in individual evaporators differ significantly. They range from approximately 170°C to 330°C.

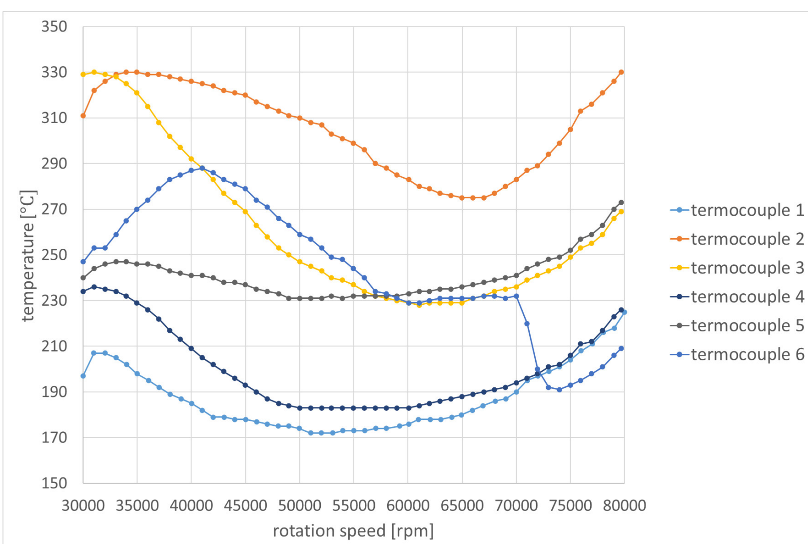

Figure 5: Temperature distribution in evaporators – measurement at a distance of 0.07 m.

The curves shown provide some basic information. The most important ones include:

- the direction of temperature change, i.e., whether it increases throughout its course or not;
- temperature values, as well as the differences observed between individual thermocouples.

With the exception of evaporator 2 and 6, in each function the values first decrease and then increase. The measurement in evaporator 3 showed that the highest temperature appeared there for the lowest rotational speed range. This is related to the gravitational falling of fuel condensate onto the lower areas of the combustion chamber. In this way, the area of the most intense combustion is concentrated there. As the temperature increases, this effect disappears because all the fuel evaporates in the evaporators.

In the second stage of the research, the sensors were inserted to a distance of 0.06 m. Shortening the distance by 0.01 m is associated with the appearance of significantly lower temperatures, which reach just over 200°C, Fig. 6. In contrast to the first stage of the research, the results show much greater consistency in the course of the values. This is especially noticeable after exceeding 65 000 rpm.

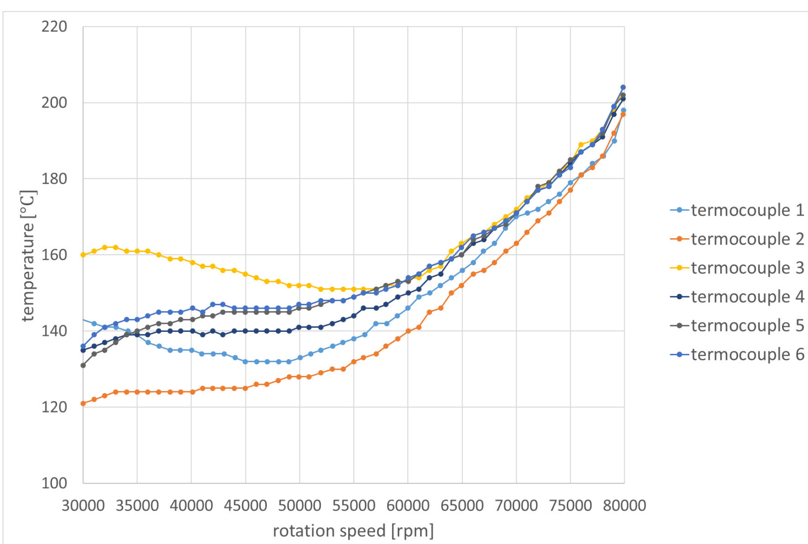

Figure 6: Temperature distribution in evaporators – measurement at a distance of 0.06 m.

Changing the location of the measurement point by another 1 cm did not bring any significant changes in temperature patterns. They are in similar ranges, i.e. 120–210°C, Fig. 7. The maximum temperatures are higher, as in the previous stage of research, but the obtained functions are characterized by even greater consistency in the nature of their course.

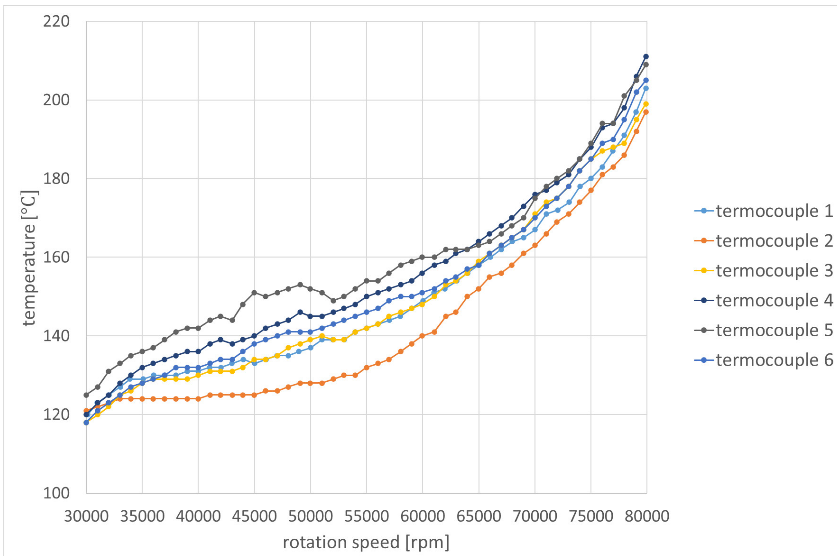

Figure 7: Temperature distribution in evaporators – measurement at a distance of 0.05 m.

In the last stage of the research, measurements in evaporators were made at a distance of 0.04 m, Fig. 8. Compared to measurements made at a distance of 0.05 m, the obtained temperatures are lower, especially in the range of lower rotational speeds. However, they do not represent such consistent courses, which is due to significant differences in the recorded temperatures.

During the measurements, it turned out that there is a serious risk of obtaining incorrect measurements in evaporators using thermoelectric sensor. The purpose of the measurements was to obtain the temperature values recorded in the gas-filled space inside the evaporators. Due to the small dimensions of the turbojet engine, the diameter of the evaporators is 0.008 m. This increases the risk of a situation where the sensor inserted into the evaporator will touch the inside of its wall. This is well illustrated in Figs. 9 and 10, which present an example of the repeatability of measurement values in two selected evaporators. The resulting error is large

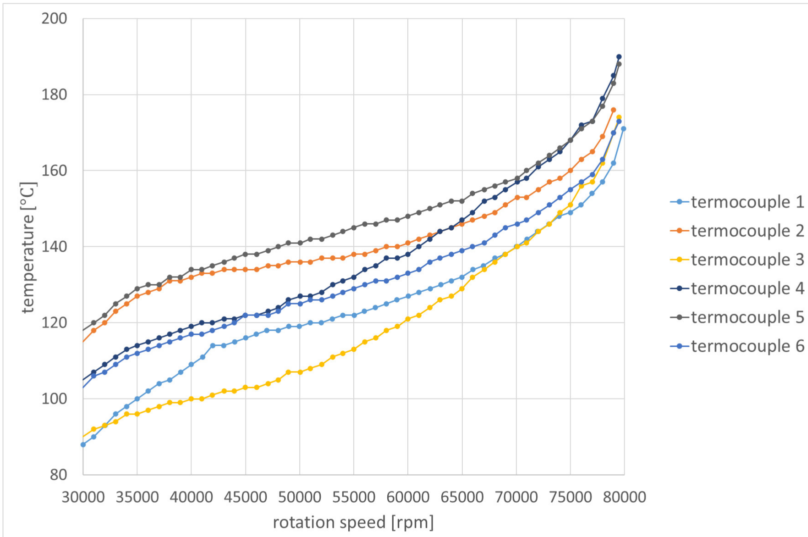

Figure 8: Temperature distribution in evaporators – measurement at a distance of 0.04 m.

because the evaporators are immersed in the hot combustion area, which causes an increase in temperature on the surface of their walls.

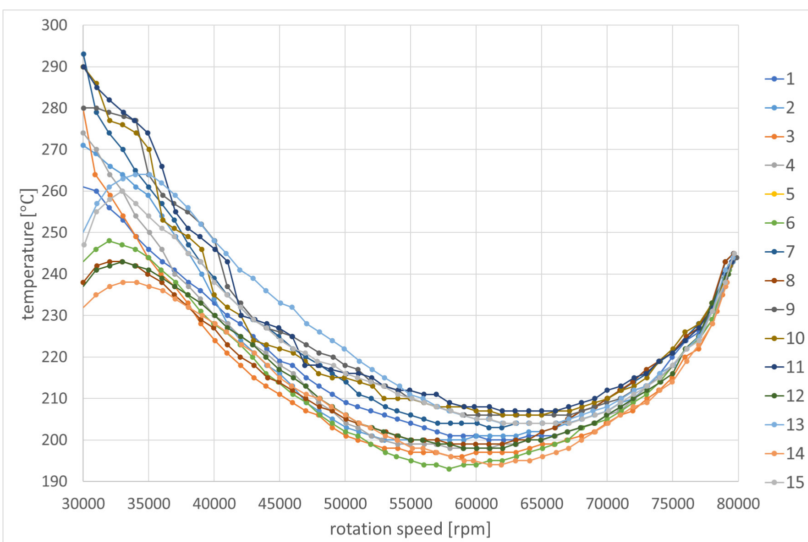

Figure 9: Temperature comparison in evaporators 1 (15 measurements) – measurement at a distance of 0.07 m.

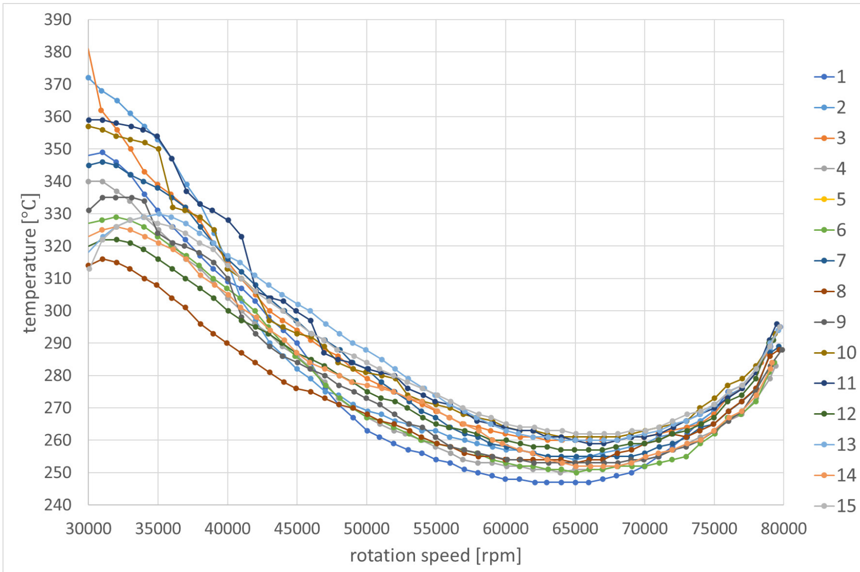

Figure 10: Temperature comparison in evaporators 3 (15 measurements) – measurement at a distance of 0.07 m.

4 Conclusions

The study made possible to obtain information regarding the temperature range as a function of rotational speed in two flow areas. The first one was the reversing duct, where the probe was inserted to a length of 0.05 m and 0.04 m. The second were evaporators, where a junction of the thermocouple, after inserting a distance of 0.06 m, was located at the entrance to the evaporator and a distance of 0.07 m, where it was slightly deeper. The last two measurements were crucial from the point of view of the conducted analysis.

The range of observed temperatures corresponds to boiling points, which for this fuel are 90–320°C. From this point of view, it can be seen that the temperature in the return channel is appropriate to initiate the process of evaporation of the fuel that is introduced into the evaporator. The indicated temperatures measured at a depth of 0.0135 m of the evaporator are clearly higher and correspond to the full range of the mentioned boiling points. This indicates that the process of fuel evaporation begins early, already at the inlet to the evaporator.

The temperature range at which fuel auto-ignition occurs is between 220°C and 250°C. However, it should be remembered that this phenomenon is unlikely to occur due to the fuel and air mixture being too lean.

Difficulties in building miniature flow engines result from their scale. The fluid movement as well as the combustion process take place in a very small space. In such a case, the influence of the measurement sensors increases and may cause local speed changes in the reversing channels, which further results in temperature changes in the combustion area. This also makes it difficult to take measurements. An example is the research carried out which confirmed the risk of incorrect readings of the measured parameter. They may be affected by probe deflection due to dynamic gas flow. This may happen even if (before the measurement) it is checked whether the probe is not bent. In some places it is difficult to be sure that the measurement is correct. This is because at the end and the beginning of the evaporator (i.e., in the return channel) the flow is more disturbed and it is difficult to assess whether the temperature differences result from the nature of the flow or as a result of the sensor touching the evaporator wall. It can be assumed that the deeper the probe is inserted, the greater the risk of incorrect reading, because it is easier to touch the wall of the evaporator.

The test results preliminary indicate that from the point of view of temperature distribution, the process of fuel evaporation in the evaporator is carried out correctly. It would certainly be interesting to study temperatures over a longer distance. From the point of view of the above-described problem regarding inserting thermocouples into evaporators and their possible contact with the evaporator wall, temperature measurement will be burdened with a greater risk of error. However, this would be supplementary knowledge about how much the temperature increases in the lower areas of the evaporator. After several inspections by the engine manufacturer, it turned out that the colour of the evaporators had not changed, which may indicate that no combustion process was taking place deep inside them. The analysis also showed, that the variation in the temperature field in a miniature turbojet engine can be significant.

Indirect tests, such as measurements in evaporators, are not a sufficiently accurate way to obtain the temperature distribution in the combustion chamber of a turbojet engine. However, they can additionally indicate the directions of impact of hotter areas, as well as illustrate what is happening in further parts of the combustion chamber. In the next stage of testing, the analysis of checking the correct operation of the engine should be expanded with thermovision, as well as testing with an S-type sensor of sample points in the central part of the chamber where the flame appears.

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References

[1] Gieras M.: *Miniature Turbojet Engines*. Oficyna Wyd. PW, Warszawa 2016 (in Polish).

[2] Nelson R.J., Dix M.D.: *Development of engines for unmanned air vehicles: some factors to be considered*. Institute for Defense Analyses, Alexandria 2003.

[3] Goraj Z., Frydrychewicz A., Świtkiewicz R., Hernik B., Gadomski J., Goetzendorf-Grabowski T., Figat M., Suchodolski S., Chajec W.: *High altitude long endurance unmanned aerial vehicle of a new generation – a design challenge for a low cost, reliable and high performance aircraft*. Bull. Pol. Acad. Sci. Tech. Sci. **52(**2004), 3, 173–194.

[4] Barnhart R.K., Hottman S.B., Marshall D.M., Shappee E.: *Introduction to Unmanned Aircraft Systems*. Taylor & Francis, 2012.

[5] Dinc A.: *NO_x emissions of turbofan powered unmanned aerial vehicle for complete flight cycle*. Chin. J. Aeronaut. **33**(2020), 6, 1683–1691.

[6] Technical Report, Ver. 0.1: *Unmanned Aircraft System (UAS) Service Demand 2015 – 2035*. United States Air Force 2014.

[7] Turkay M., Gürgen S., Keskin G., Durmus S.: *Research on applications of mini-turbojet and turbojet engined military UAVS*. In: Proc. 21st Int. Conf. AFASES, Scientific Research and Education in the Air Force, Braşov 2019.

[8] Kelly C., McCain C., Bertels J., Weekley S., Moody K., Utley L., Copher G., Totty C., Booth T., Spaulding L., Jdiobe M., Rouser K.: *Design of a geared turbofan module for small unmanned aircraft applications*. AIAA Scitech Forum 2021. doi: 10.2514/6.2021-0262

[9] Kreps S.E.: *Drones. Introduction. Technologies. Usage*. PWN, Warszawa 2019 (in Polish).

[10] Becmer D., Skorupka D., Duchaczek A.: *Development trends in unmanned aerial systems*. Wojskowy Instytut Techniczny Uzbrojenia **136**(2015), 4, 19–40 (in Polish).

[11] Becmer D.: *Class I-II unmanned aerial systems in the future combat system*. Zeszyty Naukowe Wyższej Szkoły Oficerskiej Wojsk Lądowych **143**(2007), 1, 34–44 (in Polish).

[12] Łapucha R.: *Combustion Chambers of Turbine-jet Engines: Processes, Calculations, Research*. Wydawn. Naukowe Instytutu Lotnictwa, Warszawa 2004 (in Polish).

[13] Sieniawski J.: *Criteria and Methods of Assessment of Aircraft Turbine Engine Components*. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 1995 (in Polish).

[14] Pawlak W.I.: *Turbine Jet Engine: Simulation, Control and Monitoring Elements.* Wydawnictwo Naukowe Instytutu Lotnictwa, Warszawa 2011 (in Polish).

[15] Benets D.J., Mockler T., Maldonado J., Harp J.L., King J.F., Schmitz P.C.: *Propulsion systems for very high altitude subsonic unmanned aircraft.* NASA, Aerospace Power Systems'98, Williamsburg, 21-23, Apr. 1998 (NASA TM-1998-20663).

[16] Zhang B., Song Z., Zhao F., Liu C.: *Overview of propulsion systems for unmanned aerial vehicles.* Energies **15**(2022), 2, 455, 1–25.

[17] Gawron B., Białecki T.: *The laboratory test rig with miniature jet engine to research aviation fuels combustion process.* J. KONBiN **36**(2014), 4, 79–90.

[18] Levy Y., Sherbaum V., Nadvany V., Nekhamkin Y.: *Modified vaporizer for improved ignition in small jet engine.* J. Propuls. Power **22**(2006), 4, 828–834.

[19] Montazeri-Gh M., Fashandi S.A.M., Jafari S.: *Theoretical and experimental study of a micro jet engine start-up behaviour.* Technicki vjesnik–Technical Gazette **25**(2018), 3, 839–845.

[20] Levy Y.: *Environmental protection: EASA noise and emissions certification.* In: Proc. COSCAP-GS Conf., Dubai, 2014.

[21] JETPOL Tomasz Kiciński. https://jetpol.tech/ (accessed 17 May 2023).

[22] Czarnecki M., Orkisz M.: *Preliminary design of micro scale turbojet.* J. KONES Powertrain Transport **15**(2008), 3, 83–87.

[23] Krawczyk P., Badyda K., Szczygieł J., Młynarz S.: *Investigation of exhaust gas temperature distribution within a furnace of a stoker fired boiler as a function of its operating parameters.* Arch. Thermodyn. **36**(2015), 3, 3–14.