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IDENTIFICATION OF DESIGN PARAMETERS FOR MICROGASTURBINE ENGINES

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Abstract

The research object consists study of simplified turbojet engine known as a Schreckling design. Simplified layout is related to single centrifugal compressor and single axial turbine design (1R-1T). Presented design is favoured in model gasturbines that uses common compressor rotor from automotive turbochargers. Input data for further calculations was obtained from Garret turbo systems compressor performance maps. Total pressure and total to static stage efficiency was assumed from map of contours at maximum stage efficiency. Additional data from database allowed determining outer diameter and rotational speed of the compressor rotor. Collected data was applied to gasturbine thermogasdynamics model. Decision variables: mass flow rate from 0.1-0.8 [kg/s] range, and exhaust gas temperature from 800-1200 [K] range was taken into account. Turbine expansion ratio was calculated with thermo-mechanical coupling conditions for engine continuous operation. Calculated engine thrust and specific fuel consumption was presented in reference to AMT Netherlands microgasturbine range. Presented results allow to rapid identification of design parameters at early stage of design Obtained results allow to omit thermogasdynamics calculations and focus on the design of the individual engine components. Number of computational models is reduced by 20-30% in reference to given assumptions.

Keywords: *turbine engines, gasturbine, micro, propulsion*

1. Introduction

The design process of microgasturbine turbojet engine is subject to a number of restrictions. At the outset “well known” restrictions was taken into account. Term “well known” should be understood as a limitation whose designer is conscious before the design process starts. These restrictions include:

- Limited number of people involved in the project (microgasturbines are produced by micro / small business companies),
- Reverse engineering is commonly used practice (majority of microgasturbine engines is derivative of KJ-66 engine – outer size ~110 mm),
- Simplified engine layout promotes favouring of experiment over detailed calculation,
- Incoherent calculation methods are commonly used.

2. Knowledge database

Microgasturbine turbojet engines provide thrust between 5-40 daN. The thrust is related to the air mass flow rate through the engine flow channel. Originally, in RC turbine design a dedicated compressor stage was used (Fig. 1a). This practice was abandoned due to the reduction in engine construction costs and availability rotors centrifugal compressors originating in sets of automotive turbochargers repair (Fig. 1b) [3]. The construction knowledge base was created. Compressors from company Garret was analysed [7].

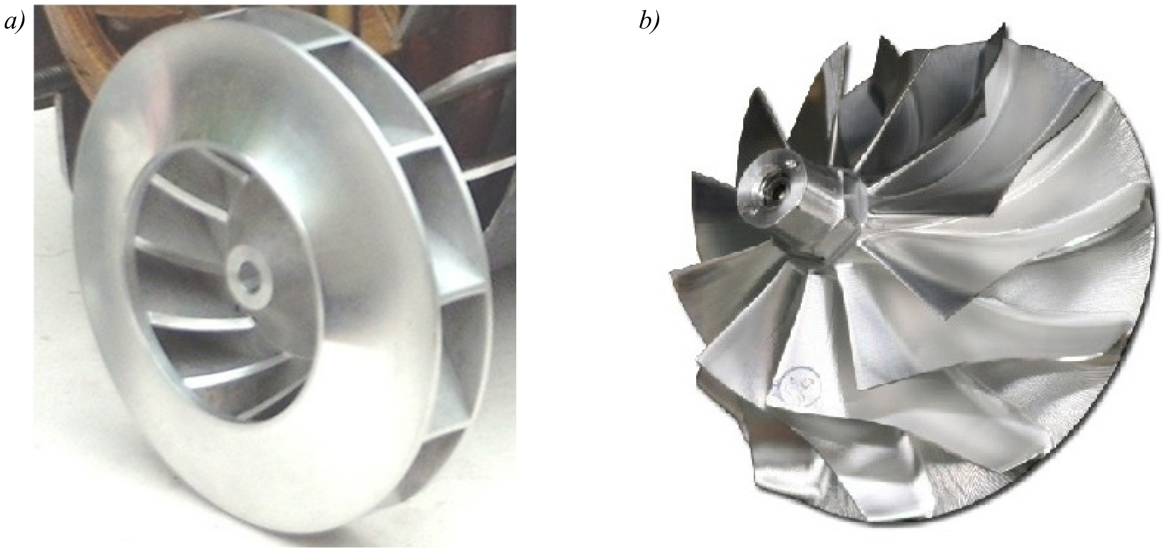


Fig. 1. Compressor rotor of microgasturbine engines: a) dedicated design (FD3-64 [6]), b) turbocharger repair kit rotor

Selection of a single company was dictated because it focuses on the identification of the compressor pressure ratio and isentropic efficiency as a function of mass flow rate. This allows to the rapid identification of selected parameters of the rotor at early stage concept research.

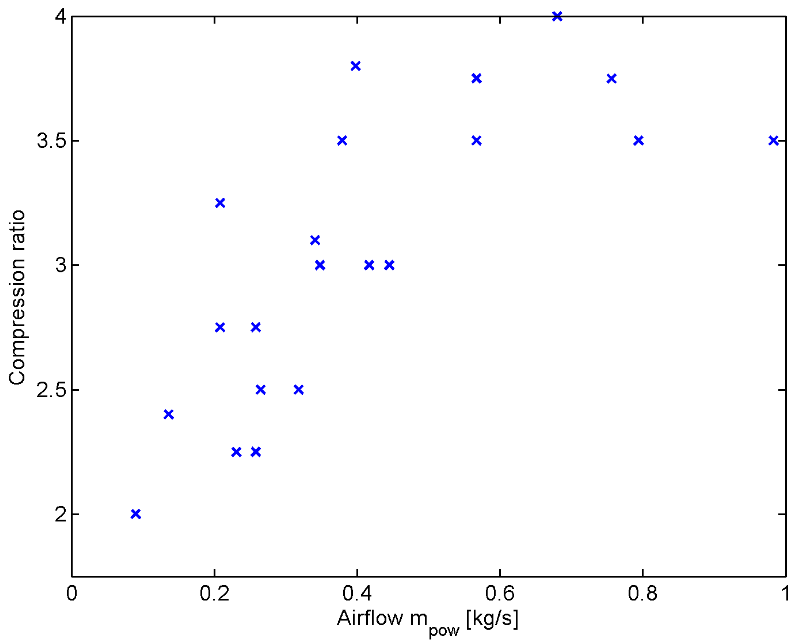


Fig. 2. Centrifugal compressor rotor database (manufacturer Garret)

The compressor database consists 20 different rotors with mass flow rate of 0.1 up to 1 [kg/s] range (Fig. 2). Effective isentropic compressor efficiency was identified as a value area surrounded by high-efficiency contours from compressor flow map. The leads to the approximation formula that is simplifies and shortens the time of calculation (skipping similarity numbers Re-criteria, Nu). Effective isentropic efficiency of a single compressor stage can be estimated using the equation (Fig. 3).

$$\eta_C = 0.7552 \cdot m_{air}^{0.0146}, \tag{1}$$

where m_{air} is engine design airflow.

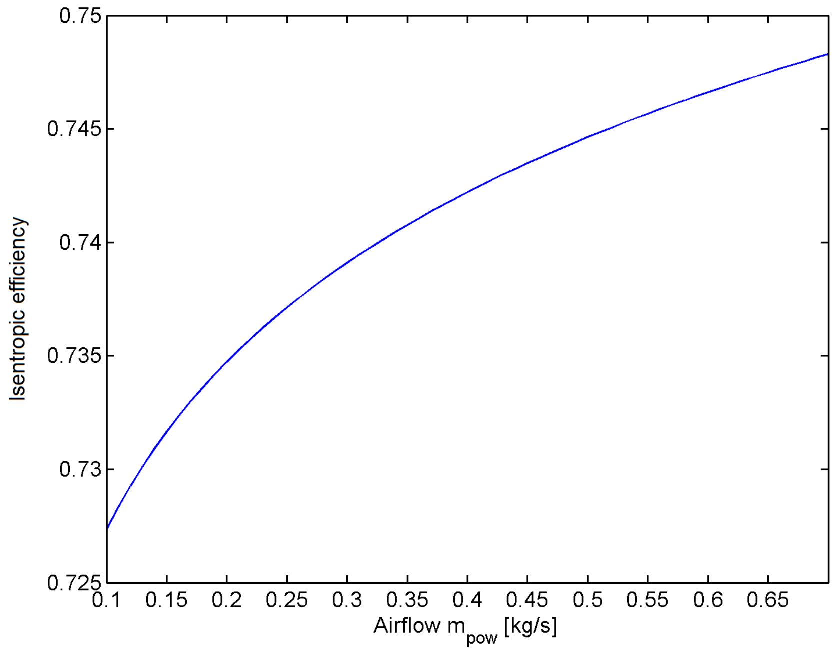


Fig. 3. Single centrifugal stage efficiency for microgasturbine engines

In the manner, overall centrifugal compressor stage pressure ΠC (Fig. 4) was described the following relationship:

$$\Pi_C = 0.8656 \cdot \ln(m_{air}) + 3.97 \, . \tag{2}$$

Overall compressor stage pressure ratio (OPR) was compared with the real values for the family AMT engines (Fig. 4). It should be noted that estimated OPR was for the rotors widely available. The company Garret has also rotors designed for motor sport with improved parameters marked with symbols of RS. The difference between the AMT and the approximation differs due to the individual characteristics of the design. The difference in results should be identified as a feature of different design. Main difference between turbocharger compressor and turbojet engine is design of a stator. Turbocharger uses volute, turbojet consists bladed diffuser (Fig. 5) [5].

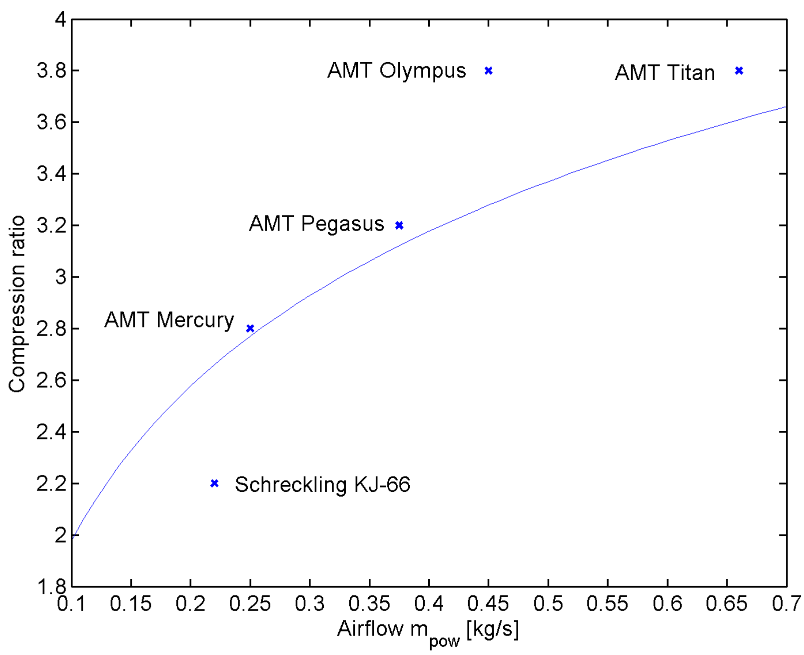
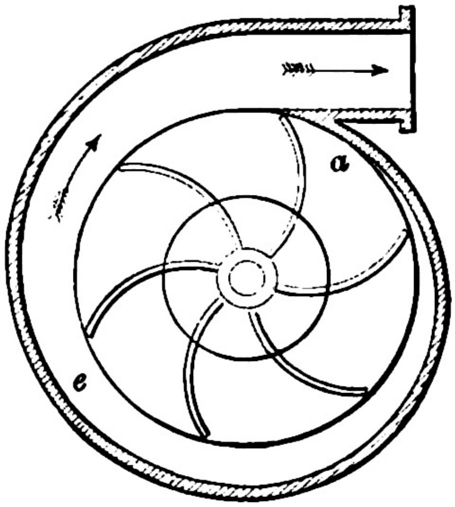


Fig. 4. Single centrifugal stage overall pressure ratio (OPR)

a)



b)

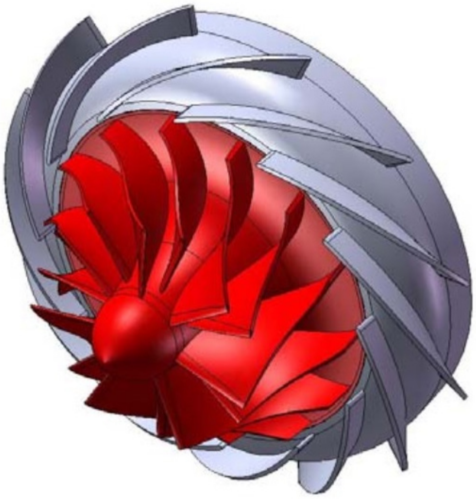


Fig. 5. Centrifugal compressor stage diffuser layout: a) turbocharger, b) turbojet [1]

3. Numerical model

Numerical model which was built at the initial stage of design were used to perform simplified analysis without identification of the individual (unknown) and secondary traits. The purpose of the construction of this computational model is to identify the microgasturbine hot sections parameters. It is important to identify:

– T_4^* exhaust gas temperature EGT (that characterized thermal loads of the engine),
– turbine expansion ratio Π_T turbine stage (that describes geometry of the turbine stage).

Numerical model verification was based on the identification of the thrust generated by the engine and fuel consumption. Engine model corresponds to the design layout presented in Fig. 6.

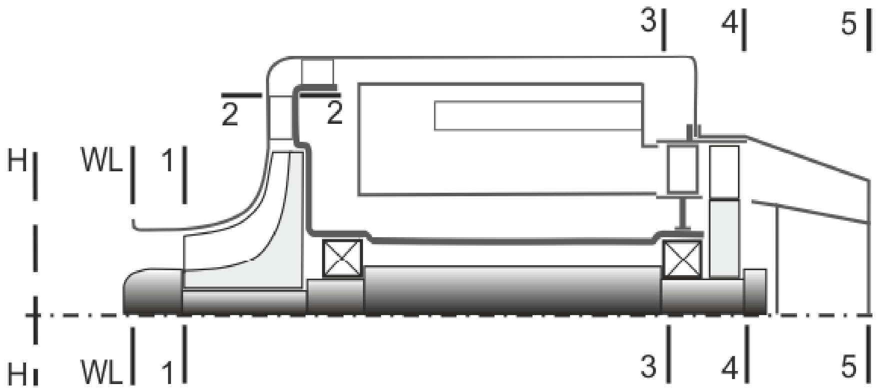


Fig. 6. Microgasturbine turbojet engine layout: WL-1 – inlet, 1-2 – compressor, 2-3 – combustor, 3-4 – turbine, 4-5 – exhaust nozzle

Microgasturbine thermodynamics model was developed by adopting the following simplifying assumptions that are used in the initial modelling [4]:

1. One dimensional computational model where adopted and parameters of the working medium is described by its averaged values.
2. Lack of stationarity in the working processes and the accumulation and dissipation of energy in cooperating teams of the engine was omitted.
3. Exceptions to the actual process of introducing the process of comparative adjusted loss factors (e.g. total pressure loss coefficient).
4. Heat exchange between the working fluid and engine elements was omitted.
5. The model of the working fluid is taken as an ideal gas.

The following simplifying assumptions were adopted to the model:

1. Engine units efficiency factor was lowered due the miniaturized design in reference to commercial engines.
2. Engine jet pipe operates under critical expansions ratio due the low OPR ration (OPR < 4 with high-pressure loss in components).
3. Expansion in exhaust nozzle will be held into ambient pressure.

4. Results

In case of microgasturbine turbojet engine design exhaust gas temperature (EGT) must be identified. The observed increase in exhaust gas temperature is a consequence of the growth of the compressor overall pressure ratio and demand for mechanical power (Fig. 7).

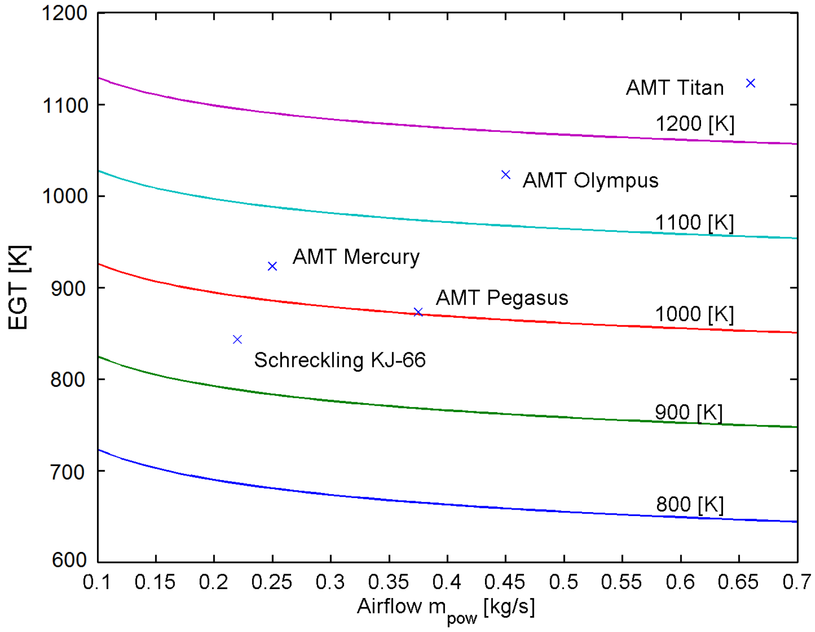


Fig. 7. Identification of microgasturbine exhausts gas temperature

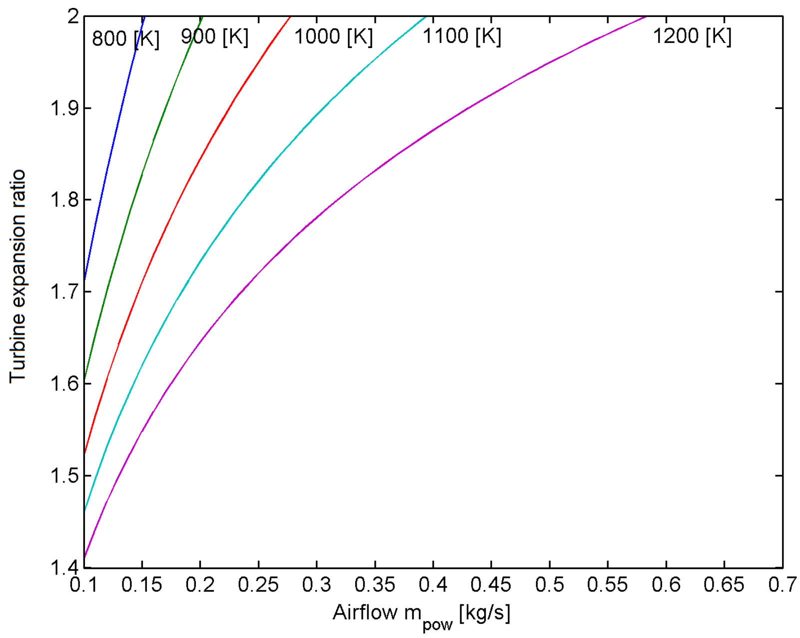


Fig. 8. Identification of microgasturbine turbine expansion ratio Π_T

With calculated EGT is possible to identify axial turbine stage expansion ratio. It should be noted there is majority of microgasturbine layouts are single-stage axial turbine Π_T design [3, 6]. For chosen design expansion ratio was limited to the $\Pi_T < 1.95$ and becomes “well known” restriction (Fig. 8) [2].

Presented model was validated by its outputs. Easiest way to identifying of turbojet engine is with thrust and fuel consumption, since these are the parameters that can be measured using of scale sensor and the fuel flow meter (Fig. 9 and 10).

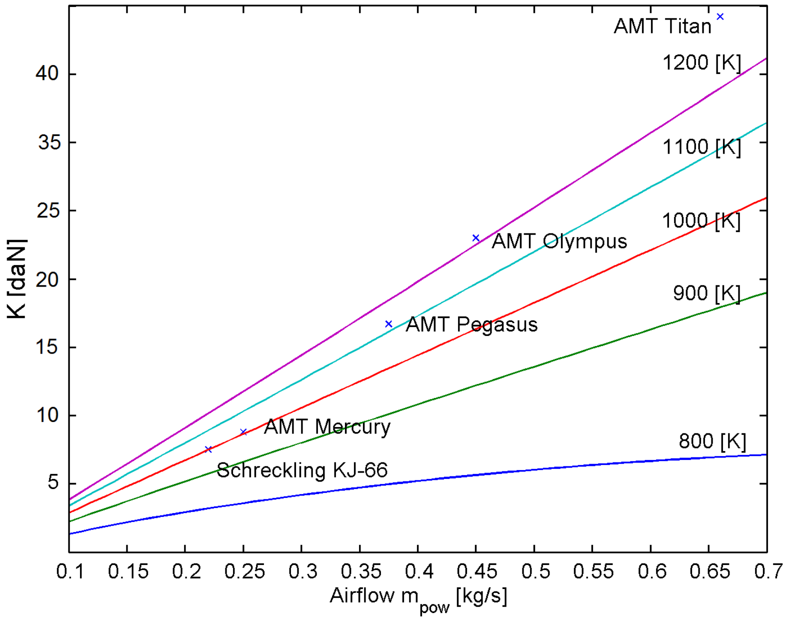


Fig. 9. Identification of microgasturbine thrust

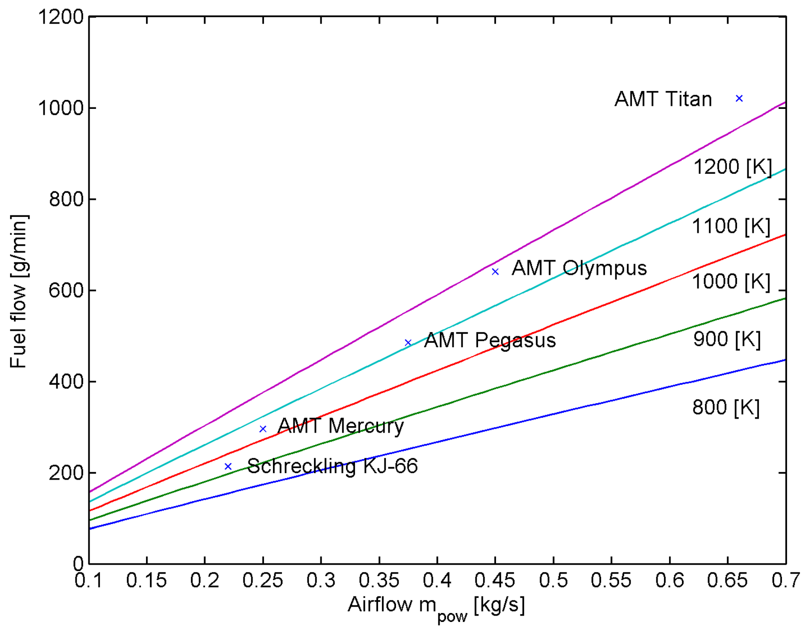


Fig. 10. Identification of microgasturbine fuel consumption

5. Summary

Presented results allow to the quick identification of basic microgasturbine parameters such as overall pressure ratio, compressor isentropic efficiency, turbine expansion ratio and exhaust gas temperature. Divergence in the temperature range to the presented results from AMT gasturbines range comes from simplified measurement equipment. EGT sensor due the price criterion is limited to single thermocouple. Temperature field nature in the exhaust nozzle is a swirling and acceptable in the field of pulsations temperature ±150 degrees [K]. Information from the digital engine control system DEC could be used as an information only (Fig. 7). Admission to the calculations EGT from similar design may cause that turbojet does not meet the thermogasdynamics requirements and engine performance will be limited. The highest exhaust gas temperature should be taken as an initial parameter from Fig. 7 and 8. This will provide adequate torque to power turbine and compressor. Comparing temperature range in Fig. 8-10 presented results should be considered as coherent. Obtained results shortens design process due the possible omitting basic thermogasdynamics calculations (for the construction of a simplified layout 1R-1T) in favour of design its vital components. In case of single stage turbojet turbine design, exhaust gas temperature operating range contains in the operating characteristics of the material Inconel 713LC. Accordingly, the work on further efficient turbine wheel in the first place should focus on improving the geometry of the flow channel. In reference of the micromotor, low technical operating time damage from creep should not expected.

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