APPLICATION OF THE ANALYTICAL MODEL ON THE MICRO TURBOJET ENGINE

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Summary. The paper is dedicated to describe application of thermodynamic analytical mathematical equations on the micro turbojet engine Jetcat P80. That analytical thermodynamic mathematical model composes and is derived from basic thermodynamic laws that describes gas and air behavior in each part of the jet engine generally. Basically the jet engine principle is based on the Bryton thermodynamic cycle that compose from two adiabatic lines and two isobaric lines. Because of the micro turbojet engine simplicity it is pretty close to ideal shape of the thermodynamic cycle. The Simplicity and similarity means, no compressor air bleed, no afterburning, no variable vane angle and other systems used on the modern aircraft engines. But If we want accurate thermodynamic mathematical model we need to describe all parts separately and to get the model more accurate we add the flow equations, loss coefficients, reaction level and use of the other physical laws like mass conservation law. Except of that variables into this analytical thermodynamic model enters construction parameters of the turbojet engine parts.

Main part of this paper is to determine that loss and other flow and thermodynamic coefficients and test their usability on micro turbojet engines. That coefficients are in the range that was experimentally determined by engineers and scientists who was aimed on turbojet engines development. For example pressure loss coefficient in combustion chamber is from 0.90 to 0.98 and it describes how much isobaric is combustion in the main combustion chamber.

Analytical mathematical model will be compared and evaluated with measured and provided data from manufacturer. After this we will know if that model can be used and transformed into Matlab Simulink. For transformation was used Matlab function box, which can be used to simulate mathematical equations in simpler form (less blocks number).

Thus prepared analytical model can be used for many purposes.

Keywords: analytical model, micro jet engine, matlab-simulink, thermodynamics

1. INTRODUCTION

The history of the micro turbo jet engines is relatively short, all that starts at eighties of past century when Swedish engineers constructed first real usable micro turbojet engine that can be real used on RC plane. In past time the development of micro turbojet engines noted considerable progress and now it is widely used as RC plane propulsion.

One aim of that paper is to investigate the applicability of the thermodynamic equations (cycle) that is used on bigger turbo compressor engines on the micro turbo compressor engines. Detailed thermodynamic model was transformed and wrote into Matlab/Simulink soft and compared with measured and data from manufacturer.

Nowadays is the mathematical modelling of almost possibly anything very popular and helpful, especially in the jet engines development, because model have possibility to know engine features before that will be made[3]. Using simulations we can make various experiments with which we can prevent engine design faults. All that reduces development time and cost.

Analyzed micro turbo compressor engine is composed from subsonic inlet, one stage radial compressor, annular combustion chamber with vaporizers, one stage axial gas turbine and convergent

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exhaust nozzle. This is probably simplest construction of the jet engine. It is one rotor jet engine that can be driven up to 120 000 RPM.

Table 1 Jetcat P80 technical data [10]

Engine maximal thrust	$F_{T,MAX}$ = 93,5 N
Weight including starter	G = 1,318 kg
Lenght	L = 315 mm
Max. diameter	D_{MAX} = 112 mm
Compressor RPM range	n = 35 000 – 120 000 RPM
EGT	t = 580 – 690 °C
Max. Fuel consumption	c = 0,256 kg/min
Fuel type	Jet A1, Kerosin 1-K
Lubrication	Syntetic oil added into fuel in ratio 1:20
Maintenance interval	Every 25 hour

The micro turbo compressor engines are in principle only the smaller turbo compressor engines, their design is almost identical only simplified. Also the engine systems are simplified or replaced for example oil system in that engine is replaced by fuel system that also serving as an oil system.

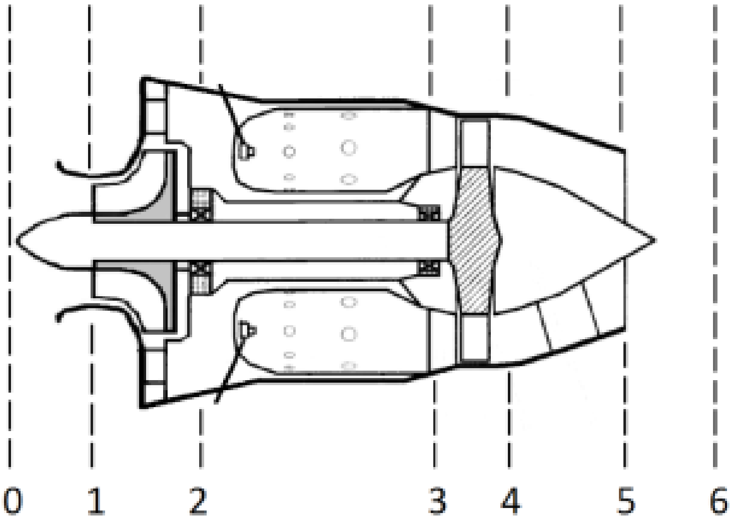

Figure 1 Principial scheme of the Jetcat P80

Fig. 1 describes each part of the Jetcat P80 micro jet engine and that is devided into 8 parts.

– 0 Ambient atmosphere,
0 – 1 engine inlet,
1 – 2 radial compressor,
2 – 3 main combustion chamber,
3 – 4 axial gas turbine,
4 – 5 exhaust nozzle,
5 – 6 area affected by engine exhaust gasses,
6 – ambient atmosphere.

1.1 Engine in the laboratory

In our laboratory we have engine placed on test bed with all needed sensors and computer gear to realise our measurements. Our laboratory is dedicated to the aircraft engine intelligent control system design. We have four jet engines two small jet engines [2] [8] suitable for ultra-light aircrafts and two micro jet engine suitable for RC models.

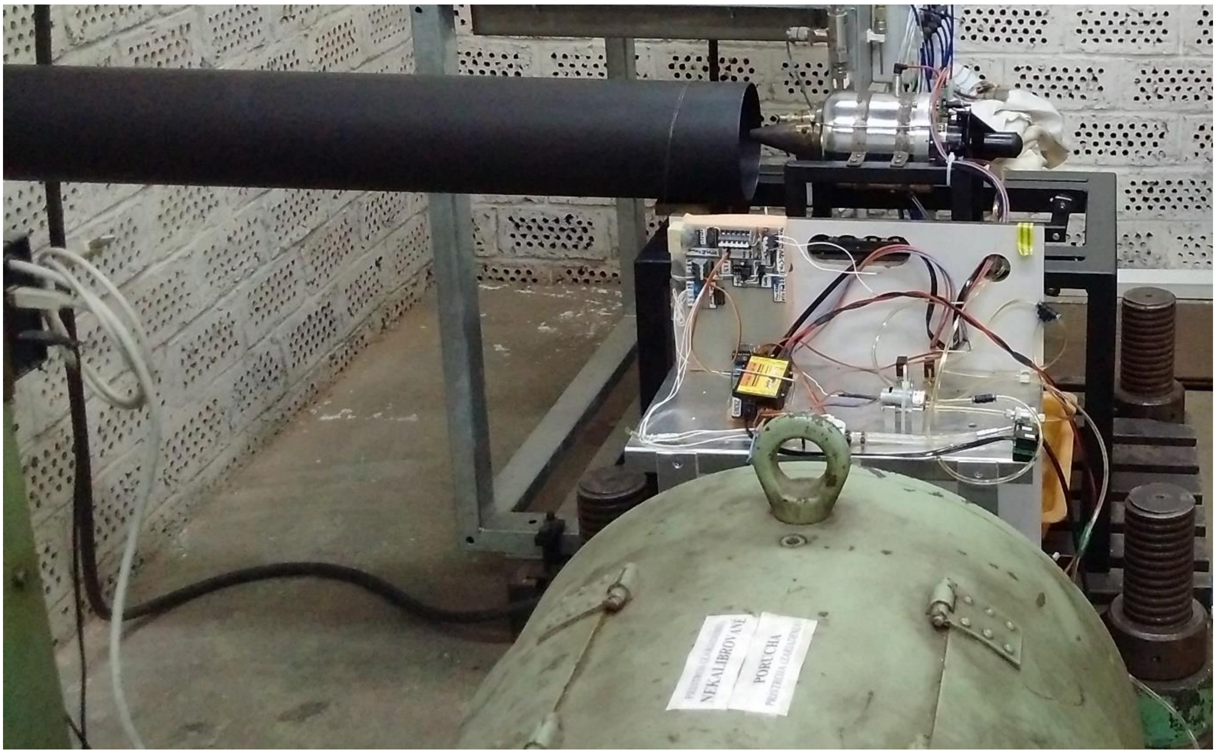

Figure 2 Micro jet engine JETCAT P80 placed in our Laboratory of Intelligent Control Cystems of Aircraft Engines

On this jet engine JETCAT P80 we have default from manufacturer only two measured parameters, engine RPMs and exhaust gas temperature (EGT). That is enough for simple jet engine control system but in future we want to design intelligent control system. To do this we need to measure more jet engine parameters like engine pressures, temperatures, fuel and gas flow and thrust.

The measured data will be collected in Matlab/Simulink and LabVIEW software to perform simulations and experiments. All data will be transferred from sensors to measurement cards from National Instruments and then into the mentioned software tools. The created thermodynamic models will be compared with measured data to confirm its suitability.

2. SIMPLIFIED MODEL METHOD

In this section we describe little bit simpler thermodynamic model that is omitted for many details, such as flow speed, some loss coefficients, reaction level and more. It is Bryton cycle corrected with Mach number, speed of flight and using some construction parameters as inlet pressure loss coefficient, combustion chamber pressure loss coefficient and more [9]. This model was used only for verification of the thermodynamic basic model validity. Because of the model length there will be only a few equations for example almost all equations is in many sources such as books [5][6][7].

$$p_{0c} = p_0 \cdot \left(1 + \frac{\kappa - 1}{2} . M_0^2\right)^{\frac{\kappa}{\kappa - 1}} \text{ [Pa]} \qquad (1)$$

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$$T_{0c} = T_0 \cdot \left(1 + \frac{\kappa - 1}{2} \cdot M_0^2\right) [\mathrm{K}] \qquad (2)$$

$$p_{1c} = \sigma_{rv} \cdot \sigma_D \cdot p_{0c} \, [\mathrm{Pa}] \qquad (3)$$

$$T_{1c} = T_{0c} = T_0 + \frac{c_0^2}{2 \cdot c_{p,v}} [\mathrm{K}] \qquad (4)$$

Where:

P_{0c} - total pressure in area 0
T_{0c} - total temperature in area 0
T_0 - temperature in area 0
p_0 - pressure in area 0
κ - air poisson's ratio
M_0 - air speed Mach number
σ_{RV} - pressure loss in inlet due to sonic shock
σ_D - pressure loss in inlet due to inlet shape
c_0 - airspeed
$c_{p.v}$ - air specific heat constant at constant pressure

Equation 1 and 2 describe total pressure and temperature before engine inlet, it is corrected for Mach number where is hidden air speed. Equation 3 and 4 is total pressure and temperature before compressor, pressure is computed only from correction parameters of inlet and temperature depends on air speed.

In whole computation figures 20 parameters that describes engine and its ambient conditions [7]. Some parameters like pressure loss coefficient, effectiveness describe engine and that we choose to create enough accurate model. Results and deviations are displayed in table 2.

Table 2 results from simple model

	Manufacturer data	Computed data	deviation
Thrust [N]	93,5	94,33	0,89%
Specific fuel consumption $[kg.N^{-1}.h^{-1}]$	0,160	0,1574	1,6%
EGT [°C]	700	707,46	0,77%

While we reach very good results using testing simple model we tried complex model that is very detailed.

3. THE COMPLEX MODEL

Trying simpler model we found out that the thermodynamic model is usable even with correction coefficients. The complex model have much more parameters that can be chosen like, flow friction coefficient, reaction level, also complex model depends on construction parameters like compressor diameter, gas turbine blade lengths and many other that wasn’t mentioned because of space. All parts of the jet engine are computed separately with respect of the micro jet engine construction. Main task of the complex model adaptation is to choose parameters from the common range used by scientist and engineers for many years. For more details about complex thermodynamic models see books like [5][6][7].

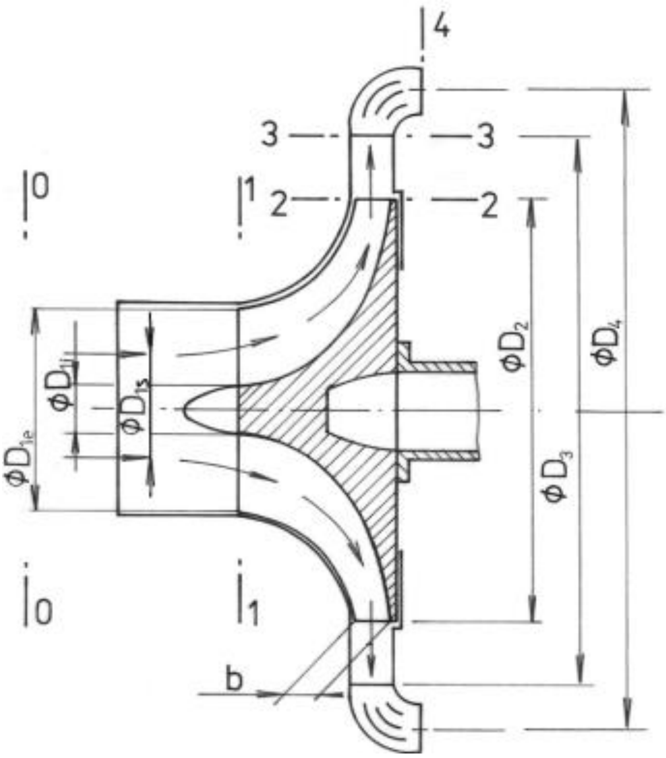

Figure 3 Fundamental radial compressor scheme

We took as an example radial compressor, where on fig. 2 is shown how many construction parameters figure in complex thermodynamic model. All input data an equation was transformed into matlab function [1] and tuned to get most accurate results as its possible. Whole micro jet engine is composed from 7 subsystems, where each represents one part of the engine.

Fig. 3 represent input subsystem as simplest part of complex model. Model was also modified to describe micro jet engine operation on whole operation from idle to maximum.

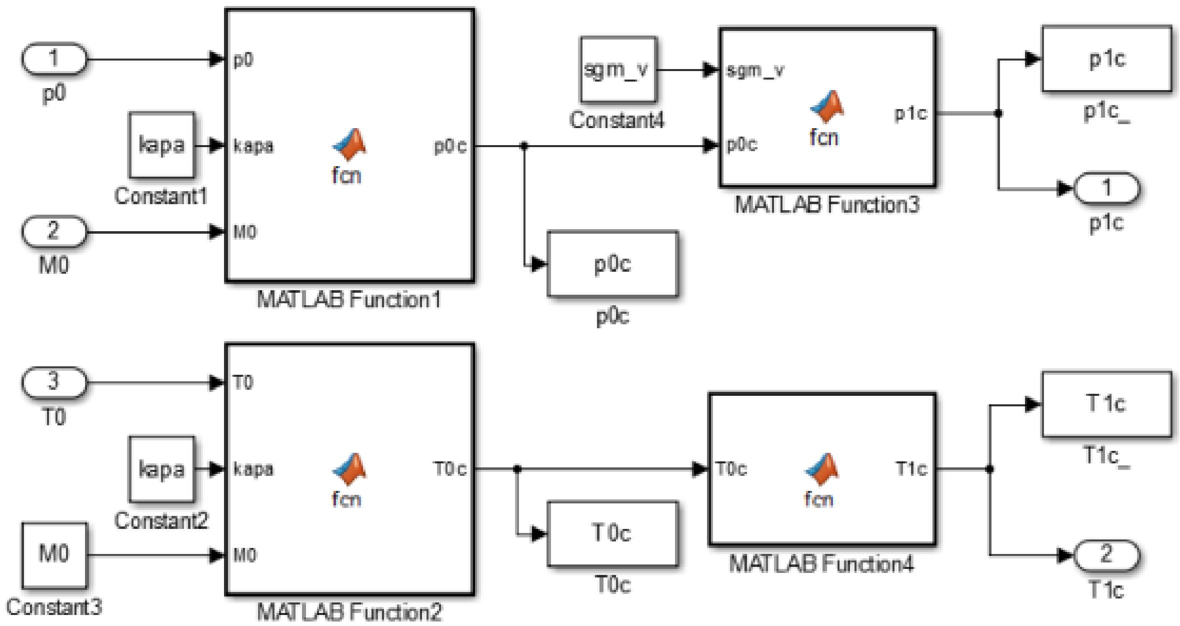

Figure 4 Micro jet engine input system transformed into Simulink subsystem

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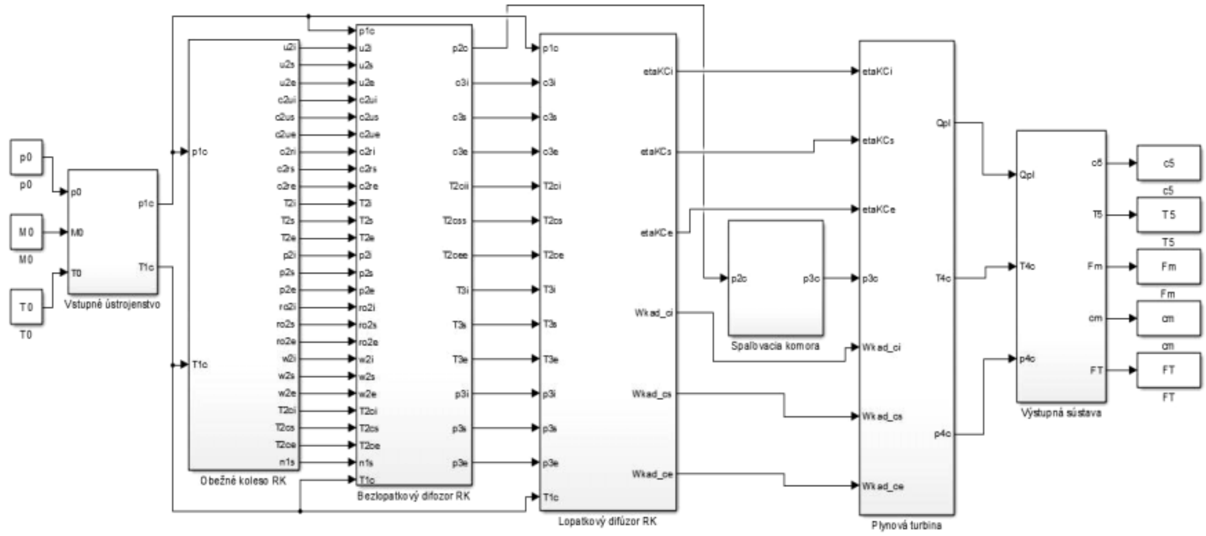

Figure 5 Whole micro jet engine complex thermodynamic model

Complete complex model have only three inputs that represent ambient conditions where the micro jet engine works. Model is shown on fig. 4 left side are inputs and it is Mach number that represent flight speed (or airspeed), ambient pressure and temperature. Outputs are on the right side of figrure and there is displayed five outputs but used for experimental comparation was only one because Jetcat P80 have only two measured parameters and that are RPMs and EGT (exhaust gas temperature). Other parameters is only compared with manufacturer data.

4. CONCLUSION

Micro turbo compressor engines are slightly different to normal turbo compressor engines used in commercial aircraft main difference is in simplicity of construction and subsystems that can be replaced by simpler subsystems or omitted. Thermodynamic complex model describes very well the engine behavior even micro turbo compressor engine used in RC planes. We must use only small customizations but in common range. Matlab function creation gave us very good data source while we make micro jet engine more measurable and controllable. The complex thermo dynamic model can be also used as diagnostic tool and as sensor redundancy.

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