FLIGHT CHARACTERISTICS OF HELICOPTER TURBOSHAFT ENGINE WITH FREE TURBINE

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Abstract

Numerical model for selected turboshaft engine is highly required by helicopter and aircraft designers. Presented paper includes key features for turboshaft numeric model builders. The study of the real performance and estimated results showed that presented method is exact for higher throttle levels. Presented method will be useful for preliminary design when is no need to acquire real test data. Numerical model was build for steady state operations, because maintenance manual for selected engine includes tests records only at its state. In that case helicopter turboshaft manuals are very similar, steady state was used widely for testing in TB3 and T700 family engines. Steady state reduced effect of rotor head positions which was influencing total engine performance.

TB3-117 helicopter turboshaft engine, engine cutaway sections, first step – expansion ratios, second step – on the ground calculations for different throttle position, engine inlet mass flow ratio as a function of maximum allowable EGT, and throttle position, third step – on the ground calculations for different throttle position, second step – on the ground calculations for different throttle position, performance charts for RR-250 BJ turboshaft, and for TB3-117 M/MT – Mi-14/17, TB3-117 III-series Mi-24 are presented in the paper.

Keywords: propulsion, engine, turboshaft, helicopter, performance, ceiling

1. Introduction

The most important and useful information for helicopters designer are engine characteristics charts, because overall helicopter performance strictly depends from characteristics of the engine. Main parameter is power, generated by free turbine (P_{FT}) in function of throttle position (α_T). In general are used two types of operational characteristics: speed characteristics $(P_{FT} = f (Ma))$, and ceiling performance $(P_{FT} = f (H))$. Useful is only ceiling performance characteristics data acquired from chart which are used to calculate helicopter rotor and in next step to calculate helicopter basic performance.

Fig. 1. TB3-117 Helicopter turboshaft engine [7]

Because vertical flight and hovering is the most important advantage of the helicopter, speed performance calculations for the engine could be abandoning but there are strong interactions between swirl from rotor and air suck into the inlet. Accurate numeric model of selected turboshaft engine should be very suitable. The consolidation of aeroengines industry took effect of number engines used in regular maintenance. The most popular modern engines US-made are General, from EU, Electric GE-700 *(AH-64, UH60, SH-2G)*, Rolls-Royce-Turbomecca RTM-322 (Super Lynx, PAH-2, NH-90, EH-101) and from Russia Klimov TB3 (Mi-14/17/24/28). Polish Army using TB3 engines and performance of this engine will be calculated.

1. Numeric model

Numerical model was build for steady state operations, because maintenance manual for selected engine contains tests records only at it state. In this case helicopter turboshaft manuals are very similar, steady state is used widely for testing in TB3 and T700 family engines. Steady state reduced effect of rotor head positions which is influencing total engine performance. Engine cutaway sections used in numeric experiment are presented in figure 2.
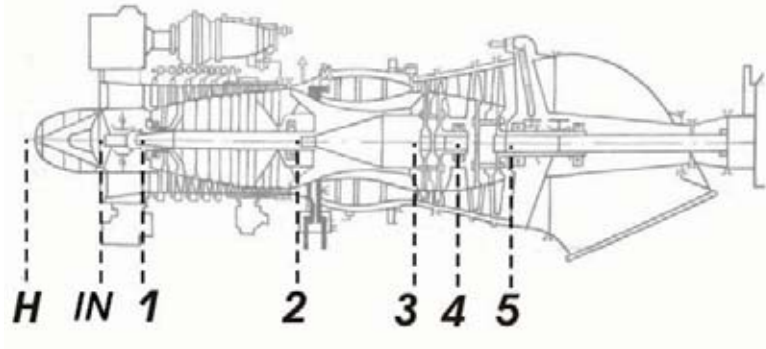

Fig. 2. Engine cutaway sections [3]

2. Index

For flexibility and for easy understanding of the problem below are main values and appropriate description:

$\dot{m}$ - mass flow ratio,
P - power,
T - temperature,
Π - compression/decompression ratio,
α_T - throttle level,
ζ_{CB} - heat coefficient,

indexes :

*   - total pressure / temperature,
'   - exhaust gases,
1,2,3,4,5   - for cutaway sections (Fig.2),
M   - maintenance,
T   - throttle,
H   - atmosphere (Fig 2 section H),
IN   - inlet (Fig.2 section 1-2),
C   - compressor (Fig.2 section 1-2),
CB   - combustor (Fig.2 section 2-3),
CT   - compressor turbine (Fig.2 section 3-4),
FT   - free turbine (Fig.2 section 4-5).

There are three steps for build turboshaft ceiling characteristics. In first step, turbine expansion ratio (Π_{CT}, Π_{FT}) for both engine turbines was calculated. This calculation was made "on the ground" which means "zero velocity", "zero ceiling" *(V,H = 0)* and full throttle $(\alpha_T = \max = takeoff)$. In details first two steps for that model is described in [1].
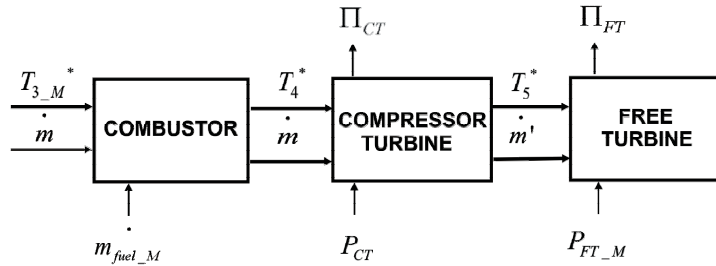

Fig. 3. First step – Expansion ratios

Second step consist calculations of engine mass flow ratio for different positions of throttle level and for maximum allowable turbine inlet temperature. The main principle contains equality of the power taken by output – rotor and deliver by free turbine shaft.
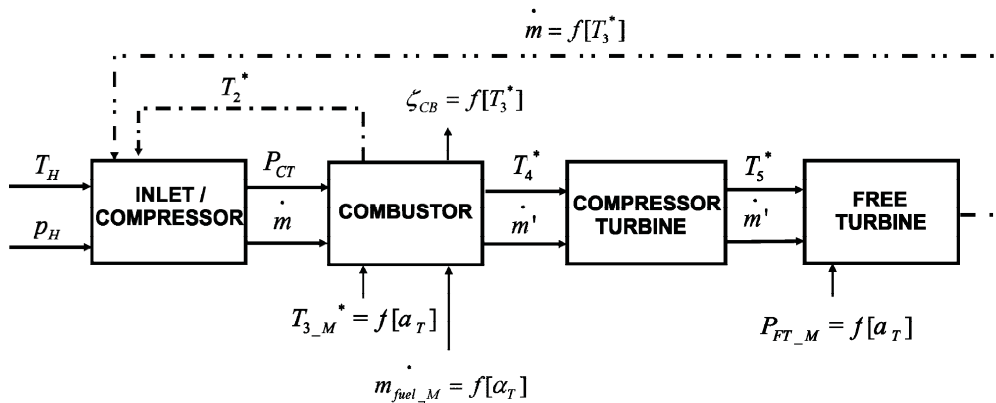

Fig. 4. Second step – On the ground calculations for different throttle position

The most important figure is presented below. With help of this method it is possible to calculate current engine mass flow rate ($\dot{m}$), that makes possible to calculate real engine compression ratio (Π_C).
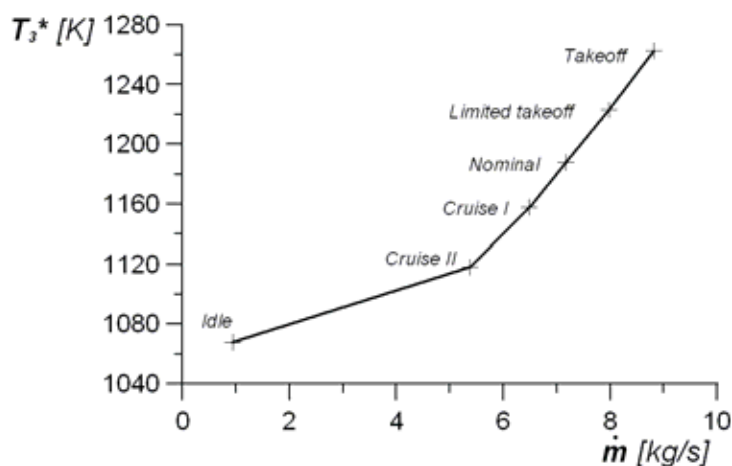

Fig. 5. Engine inlet mass flow ratio as a function of maximum allowable EGT, and throttle position

$$\dot{m} = f[\alpha_T, T_3^*, H]$$

$$T_2^*$$

$$T_H = f[H]$$

$$p_H = f[H]$$

INLET / COMPRESSOR

$$P_{CT}$$

$$\dot{m}$$

COMBUSTOR

$$T_4^*$$

$$\dot{m}'$$

COMPRESSOR TURBINE

$$T_5^*$$

$$\dot{m}'$$

FREE TURBINE

$$P_{FT} = f[\alpha_T, T_3^*, H]$$

$$T_3^* = f[a_T]$$

$$\zeta_{CB} = f[T_3^*]$$

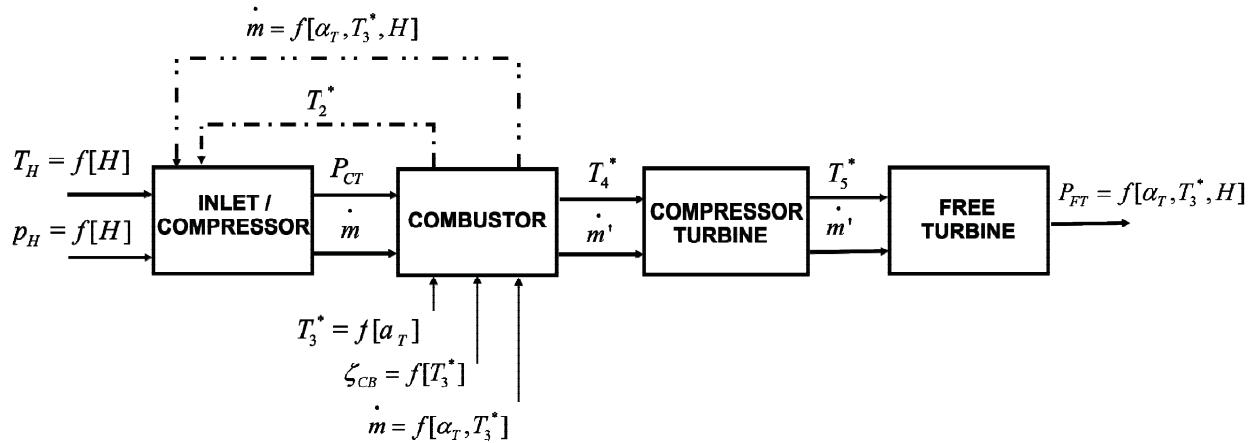$$\dot{m} = f[\alpha_T, T_3^*]$$

Fig. 6. Third step – On the ground calculations for different throttle position

The last step is using calculations of atmospheric parameters at the inlet. Calculations of atmosphere parameters are based on second chapter of the [2]. Calculation at second point for different throttle angle and based on maintenance manual data, gives possibility to made full basic ceiling characteristics including ceiling changes.

3. Results

The results of our calculations are presented on figure 7. TB3-117 M engine responding properly for changing ceiling was modelled. Estimated results for two throttle level for "takeoff" and for "limited" takeoff are similar to the maintenance data fig.8b. During analyze of results a problem occurred that when comparing fig.7 and fig.8a, character of the power generated by free turbine is the same type, it's a partial success because fig. 8a presents ceiling performance for Rolls-Royce 250 BJ turboshaft, engine running @ 100% RPM. Figure 8b shows real performance of TB3-117 M/MT versions for Mi-14 (Haze-A) / 17 (Hip-H) and Mi-24 (Hind-D).Comparing chart 7 and 8a,8b results aren't that optimistic as expected. Key problem are operations at lower throttle levels ("nominal" and "cruise I"). There are probably two causes for that matter:
- main difference between rotor systems of Mi-14/17 and Mi-24, hypothesis I – rotor system influence directly on lower throttle levels,
- both engines possess VIGV (Variable Inlet Geometry Vanes) which had similar range for regulation, but there is main difference in FCU (Fuel Control Unit), hypothesis II – with VIGV there is possibility to increase airflow in higher velocity by program stored in FCU.

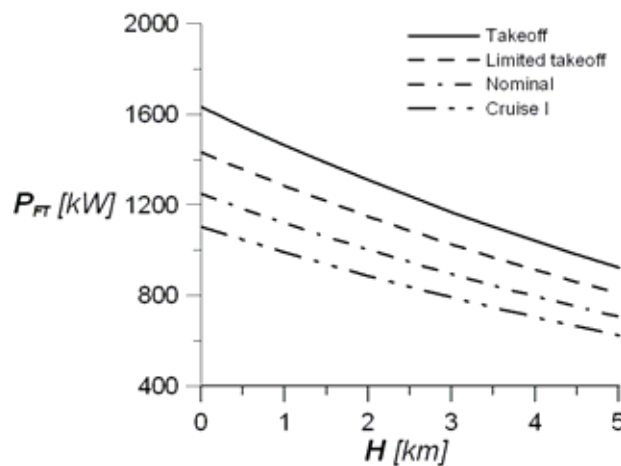In that case there is real problem which need to be solved.

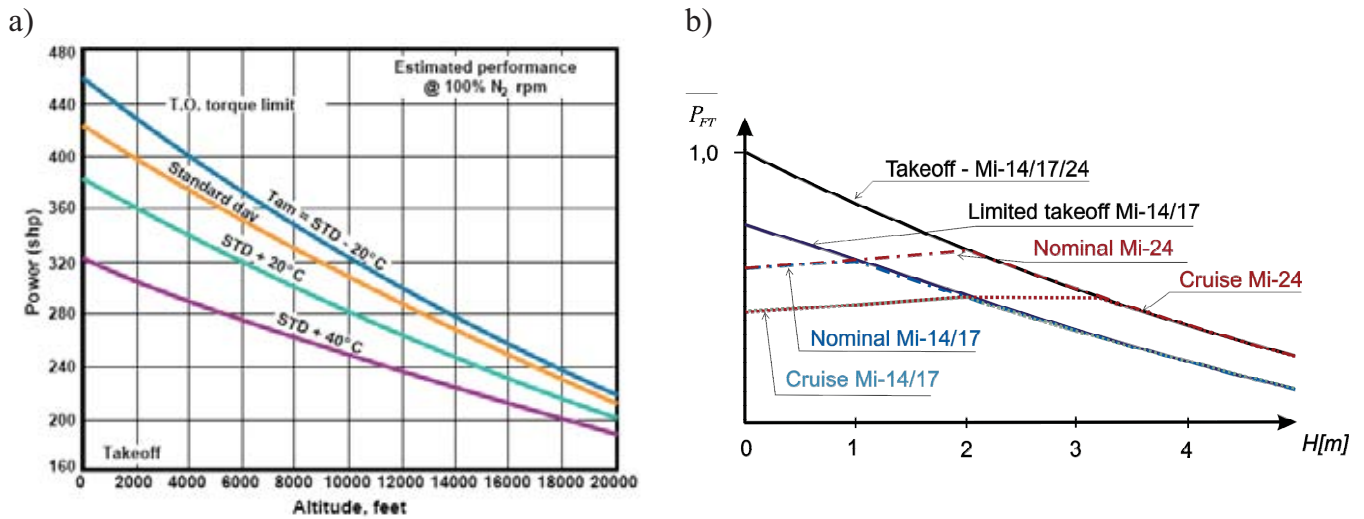*Fig. 7. Second step – on the ground calculations for different throttle position*

a)

b)

Fig. 8. Performance charts a) for RR-250 BJ turboshaft, b) for TB3-117 M/MT – Mi-14/17, TB3-117 III-series Mi-24

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