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PZL-10 TURBOSHAFT ENGINE – SYSTEM DESIGN REVIEW

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Abstract

The PZL – 10-turboshaft gas turbine engine is straight derivative of GTD-10 turboshaft design by OKMB (Omsk Engine Design Bureau). Prototype engine first run take place in 1968. Selected engine is interested platform to modify due gas generator layout 6A+R-2, which is modern. For example axial compressor design from successful Klimov designs TB2-117 (10A-2-2) or TB3-117 (12A-2-2) become obsolete in favour to TB7-117B (5A+R-2-2). In comparison to competitive engines: Klimov TB3-117 (1974 – Mi-14/17/24), General Electric T-700 (1970 – UH60/AH64), Turbomeca Makila (1976 – H225M) the PZL-10 engine design is limited by asymmetric power turbine design layout. This layout is common to early turboshaft design such as Soloview D-25V (Mil-6 power plant). Presented article review base engine configuration (6A+R+2+1). Proposed modifications are divided into different variants in terms of design complexity. Simplest variant is limited to increase turbine inlet temperature (TIT) by safe margin. Advanced configuration replace engine layout to 5A+R+2-2 and increase engine compressor pressure ratio to 9.4:1. Upgraded configuration after modification offers increase of generated power by 28% and SFC reduction by 9% – validated by gas turbine performance model. Design proposal corresponds to a major trend of increasing available power for helicopter engines – Mi-8T to Mi-8MT – 46%, H225M – Makila 1A to 1A2 – 9%, Makila 1A2 to Makila 2-25%.

Keywords: *gas turbine, design, topology, turbo shaft, performance*

1. Introduction

The PZL-10 gas turbine engine is manufactured by Pratt&Whitney Rzeszow – former PZL – Rzeszow production plant. This engine was designed by OKMB (Omsk Engine Design Bureau). Engine has two successful variants – PZL-10S – turboprop version for M28 aircraft and PZL-10W – turboshaft variant for W-3 Sokol helicopter. Engine layout design is from the late sixties [2]. Considering system approach to design and manufacturing, for a product (airplane or helicopter) engine is a part of the system [8]. Most design teams would be minimizing a risk for a project as a whole. This pragmatic approach leads to practical approach that avoids designing aircraft and engine at the same time. Good design practice is to design an airframe and equip it with already existing engine, then after initial airframe was improvement there was a time does remotorize aircraft or helicopter. In modern approach, there is strong trend to focus on design and optimize rather than redesign and optimize. This is due an influence of engineering software developers that each version its own software product is advertised as “revolutionary” [4, 6]. Considering different helicopter gas turbine engines there is rather evolution than revolution, which is cost/efficiency solution. Despite of the reduced design cost, marginal project risk at some point of designing airframe become limited by engine and engine design become limited by application.

Tab. 1. Popular turboshaft gas turbine design [2, 3]. Selected parameters: OPR – overall pressure radio, m_{air}- engine airflow, TIT – turbine inlet temperature, SFC – specific fuel consumption, P_{PT} – power turbine available power

Origin	RF/USSR				France			USA			PL
Type	TB2-117	TB3-117	BK-2500	TB7-117	Turmo	Makila 1A/1A2	Makila 2	T700 - 401C	T700-701C	T700-701D	PZL-10
OPR	6.6	9.45	10	16	5.8	10.4			17	17	7.4
m_{air}	8.5	8.75	9.3	8	5.85	5.4					4.58
TIT	1150	1250	1300	1293		1388					1165
SFC	0.355	0.308	0.281	0.268	0.367	0.285			0.274	0.275	0.36
P_{PT}	1108	1639	1788	1862	968	1130-1226	1563		1278	1326	662
Design	10A-2-2	12A-2-2	12A-2-2	5A+R-2-2	1A+R-2-1	3A+R-2-2	3A+R-2-2	5A+R-2-2	5A+R-2-2	5A+R-2-2	6A+R-2-1
Introd.	1964	1973	2001	1997		1973	1984		1970		1968

Analysing data collected in Tab. 1, there are the most popular turboshaft design from three major origins. Engine design in most cases is related to the airframe selected for a type. For example, engines of French origin are related to the Puma / Super Puma helicopter. First design the Turmo engine gas generator has its origin in oversized Turbomeca Pallas design. Major drawback of this design is relative low-pressure ratio – 5.8 with affects overall cycle efficiency and slightly small pressure margin to expand in pressure turbine. Due its pressure limitations 1A+1R-2-1 with one stage of power turbine is more than enough for this design. Similar to Turmo family low OPR pressure ratio affects rotor design of Soloview D-25 in the same manner. Engine, which is redesigned Turmo series, is Makila family. The Puma helicopter was at first remotorized with Makila turbines (SA 330S helicopter) and then Puma airframe was redesigned due to improved performance to the Super Puma and its derivates. Major drawback of remotorization is to keep engine overall dimensions to fit engine compartment in the airframe, and engine size depends on airflow which is almost similar. Considering Russian school of design helicopter turboshaft engines there is similar to French approach. First design was Mi-8 airframe with TB2-117 turboshaft. This design is so successful that almost closes production line of new generation Mi-38 helicopter. Early school of design medium size turbo shafts relies on axial compressor design. That provides compact engines but the major drawback is downsizing axial compressor in comparison to turbojet/turbofan – twelve stage compressor design riches its limits due a blade height, which has less than 14 mm and become aerodynamic inefficient (Fig. 1a). In general, Klimov design bureau considering engines that are worthy to produce that must be improved by minimum 25% in terms of performance. TB3-117 series engine was selected as family of engines for different airframes (Fig. 2). In addition, that is similar approach to the US GE-T700 gas turbine, which is common to vary of airframes – Seasprite/Blackhawk/Apache.

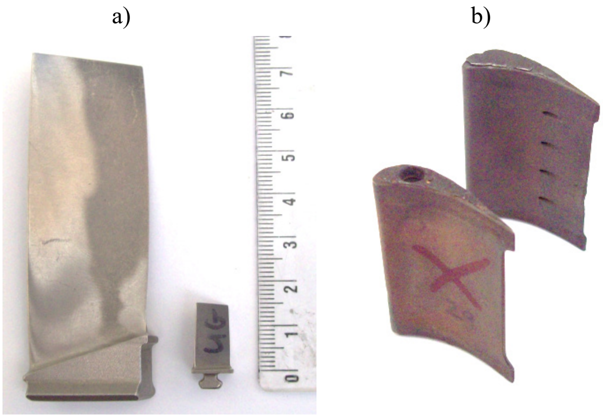


Fig. 1. TB3-117 gas turbine design development issue: a) axial compressor blade height, b) first stage compressor turbine NGV cooling solution for TIT increase

Fig. 2. TB3-117 gas turbine design timeline

The requirements for more powerful engine were related to the unification of engine fleet. There was also requirement for marine (Ka-27/29/32/Mi-14), gunship (Mi-24/28, K-50/52) and transport (Mi-8MT/Mi-17/Mi-171/Mi-172) [3]. Major drawback of different airframe applications is requirement to the engine control system. TB3-117 series has a classic hydromechanics control unit which fuel-regulator pump needs to be redesigned by each application. This drawback was eliminated by last redesign BK-2500 which is equipped by BARK78 FADEC system, which allows fasting program update due different helicopter application.

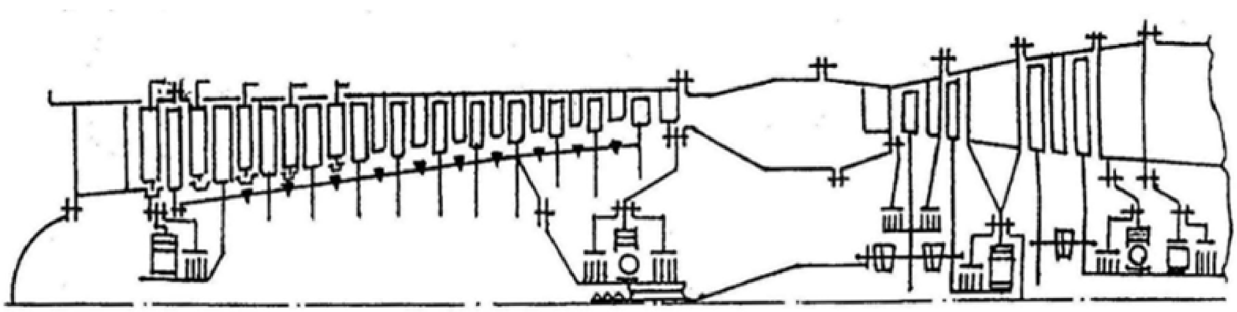
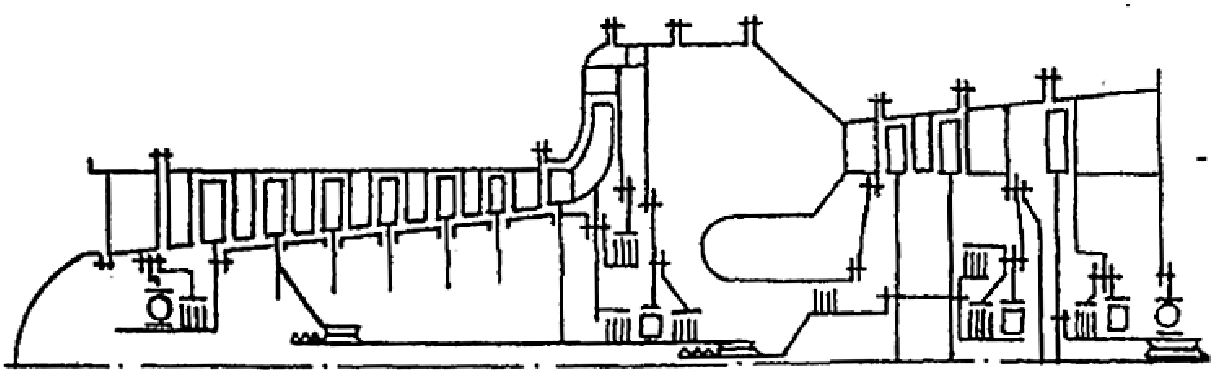


Fig. 3. TB3-117 gas turbine design layout [2]

This engine is an example of classic approach with symmetric turbine design (Fig. 3). Major improvements of this engine are compressor rotor, which is drum-disk consisting front shaft and additional disk and spacers welded together, and connected by bolts back shaft. This two part systems reduces assembly time and makes compressor compact size. Due to its relative long shafts each gas generator support is equipped with damper to avoid vibration propagation. Power turbine is a classic design with fourth support bearing of axial-radial type and fifth support of radial type. The short power turbine shaft requires only vibration damper on axial-radial support.

The PZL-10 engine already has a modern FADEC system then main effort should be focus on performance improvement due an engine age. This engine is worth to compare with TB7-117 (1997 – design) engine which shares axial radial compressor design and it is relatively new. Both engine differs in terms of power shaft requirements – front TB7-117 / back – PZL-10 (Fig. 4).

a)



b)

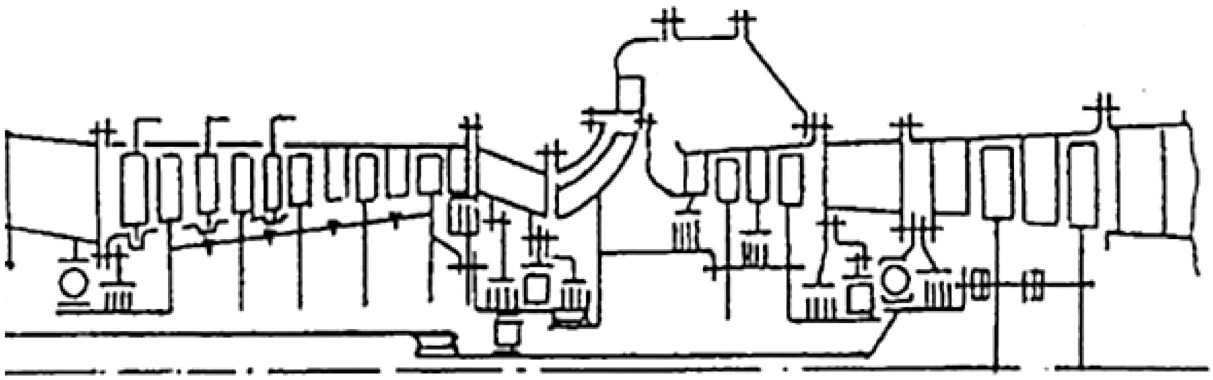


Fig. 4. Design layout of gas turbine engines [2]. a) PZL-10, b) TB7-117

Major advantages of TB7-117 are OPR, which is 16:1 in comparison to 7.4:1 of PZL-10. However, PZL-10 engine has a potential to modernize its compressor – sharing similar compressor topology.

Two modernization variants are considered:

First which is simple modification with:

- welding compressor rotor components should be considered due weight reduction,
- improve performance due higher hot section temperature with safe margin (uncooled first stage turbine blades – temperature below 1200 K [1, 9, 10].

Second with advanced modification

- welding compressor components with weight reduction,
- reduce axial size from 6 stages to 5 stage design as it is in TB7-117/GE-T700,
- redesign centrifugal compressor stage with curved compressor blades and solid impeller, lower compressor hub to provide greater OPR,

– increase of OPR up to 9.4:1 and 10.5:1,
– introduce simple cooling system for first stage compressor turbine NGV,
– increase TIT by ~100 K,
– redesign power turbine from single stage to symmetric approach.

There is general recommendation for PZL-10W engine type to move axial-radial bearing to the fourth support and equipped it with a damper, to extend component life.

2. Engine performance study

For proposed modification, thermodynamic performance of an engine was estimated (Fig. 5). Numerical model is a simplified one to the Bryton cycle approach, which is common to engine performance studies [7, 10, 11]. This approach has its limitations due model simplicity:
– fluid is considered as an ideal gas,
– engine is considered as a axisymmetric with averaged parameters at selected cutaways.

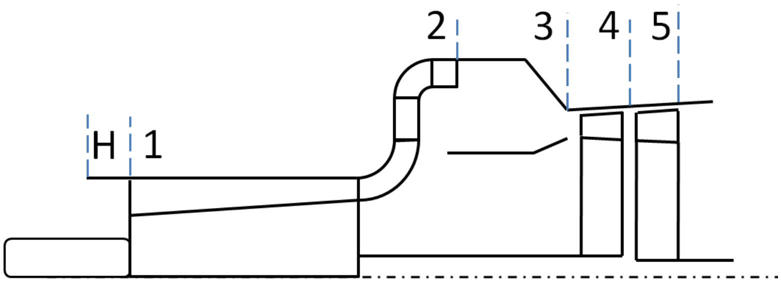


Fig. 5. PZL-10 gas turbine performance model important sections; engine cross-sections : H – ambient air conditions, 1 – compressor inlet, 2 – compressor outlet, 3 – combustor exit, 4 – compressor turbine , 5 – power turbine

The main goal of this model is to estimate requirements for expansion ratio for compressor and power turbine. The calculation approach has three stages:
1. estimate turbine inlet temperature TIT, by knowing engine overall pressure ratio OPR, and specific fuel consumption SFC;
2. estimate expansion ratios for power compressor Π_{TC^*}, Π_{TP^*};
3. improve gas turbine performance by applying symmetric turbine design (2-2).

Initial conditions for a model:
– ambient conditions (static temperature – 288 [K], static pressure – 1.013 [bar]),
– efficiency coefficients (inlet pressure loss coefficient – 0.98; combustor pressure loss coefficient – 0.96; combustor heat emission coefficient – 0.97; compressor isentropic efficiency -0.82; power turbine isentropic efficiency – 0.91; free turbine isentropic efficiency – 0.92),
– engine fuel properties – similar to Jet-A1 kerosene.

Tab. 2. Engine performance for different variants

Engine	Parameter												
	OPR	T_{2^*}	T_{3^*}	T_{4^*}	T_{5^*}	P_{TC}	P_{TP}	P_{TPM}	Π_{TC^*}	Π_{TP^*}	n_{TC}	n_{TP}	SFC
		[K]	[K]	[K]	[K]	[kW]	[kW]	[kW]					[kg/kWh]
Base	7.43	563	1142	919	764	1251	872	653	1.63	2.16	2	1	0.3664
mk.I	7.43	563	1200	980	807	1251	983	738	1.59	2.27	2	1	0.3585
mk.II	9.4	607	1225	972	780	1451	1100	824	1.70	1.6	2	2	0.3207
mk.III	10.5	629	1260	991	783	1553	1198	898	1.73	1.65	2	2	0.3046

Considering model similarity to the real engine [12], difference between power generated by real engine and estimated is less than 1.5% (Tab. 2). Difference on SFC is less than 2.5%, which are accepted values for performance study.

Engine configuration mk.I corresponds to the base design, difference is in TIT (T_{3*}) which is increased by 58 K. This value is limited by uncooled NGV blades that are limited do 1200 K for continuous operation. Engine configuration mk.II had increased overall pressure ratio OPR up to 9.4:1, which is moderate values for turboshaft engine by modern standards. TIT is increased by 83 K which requires cooled first stage compressor turbine NGV (Fig. 1b). For this configuration, any of cooling techniques would fit even conventional cooling. Engine configuration mk.III follow's French Makila turboshaft development trends. OPR is increased up to 10.5:1, TIT is increased but still is at safe margin for simplest cooling method [1, 10]. Turbine expansion ratios are low so the aero thermodynamic load should be moderate. Main benefit from this configuration is engine evolved to 1000 HP class turboshafts.

3. Summary

Presented gas turbine engine the PZL-10 is suitable for variety of modernisation. Compressor rotor design is capable for modernisation – 6A+R design should be replaced by 5A+R. Removing fifth compressor stage provides room for redesign centrifugal compressor – even using analytical modelling is possible to design radial stage with PR 6:1 [5, 7, 9]. Combining radial with axial part proposed overall pressure ratio (OPR) for mk.II and mk.III engine configuration is possible to archive without sophisticated design tools. Configurations with symmetric turbine layout 5A+R-2-2, requires redesign of power turbine. Turboshaft engines with free power turbine configurations usually operates at speeds of 96% ±4% which simplifies all calculation for mechanical stresses to one numerical case with 100% load. Benefit from engine proposed modernisation is potential increase of available power by 26 up to 37%, which is possible – proven by Makila 1A to Makila 2 redesign. Predicted SFC reduction is at 12 up to 16.8%. Redesign version of PZL-10 engine would be interesting proposal for upgraded W-3 helicopter. Engine operational benefits are improved performance for hot and high mission profile second and increased flight endurance time by 40 min. for standard configuration.

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