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OPTIMIZATION OF WORKING PROCESS PARAMETERS OF GAS TURBINE ENGINES LINE ON THE BASIS OF UNIFIED ENGINE CORE

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ABSTRACT

The selection of working process parameters of three-shaft turbofan is described. The possibility of creating a line of gas turbine engines of various thrust based on the selected engine core is studied as well as the effectiveness of unified engine core as a part of gas turbine power-plant with two-cascade core.

Keywords: unified engine core, optimization, parameters, gas turbine engine.

INTRODUCTION

Integration of domestic economics into the world economics has raised the issues of competitiveness of domestic aviation in the world market that are of special urgency and importance.
One of the most important trends is an advance creation of optimal engine core that is used for creation of a competitive line of gas turbine engines varying in thrust levels. This approach reduces release time of new engines, improves their reliability and efficiency and reduces costs.

STATEMENT OF PROBLEM

Generally, the problem of optimizing the parameters of turbofan working process is to find the tradeoffs area of using the set of criteria for evaluating the engine as a subsystem of the aircraft system [1].

The mathematical formulation of this problem is as follows. The optimum values of turbofan parameters by the local criteria Yi are calculated:

$$X_{opt_i} = \{\arg\min Y_i \mid Y_i = F_i(x, p)\},$$

where $Y_i = \{M_0, C_{\text{т.км}}, a, ...\}$ = set of evaluation criteria; $X = \{T^*_{\text{г}}, m, \pi^*_{\text{к}}, \pi^*_{\text{в}}\}$ = set of working process parameters of gas turbine engine to be optimized; p = set of initial data.

The area of locally optimal solutions by criterion (Yi) is determined by following expression:

$$X_i = \Big\{X \mid Y_i\big(X_{opt}, p\big) \le Y_i\big(X, p\big) \le \\ \le \big(1+\Delta Y_i\big) Y_i\big(X_{opt}, p\big)\Big\},$$

where ΔYi = value of maximum permissible relative deviation of the i-th criterion from its optimum.

The tradeoffs area for the set of criteria is defined as an intersection of areas of the locally optimal solutions:

$$X_{\cap} = \bigcap_{i=1}^{n} X_i .$$

The higer level system (aircraft) effectiveness criteria are used as a target functions for optimizing parameters of the turbofan workflow. These criteria, on the one hand, should represent the main purpose of the aircraft, as well as the conditions and restrictions of its operation; on the other hand, they should correlate with the parameters and characteristics of the object that are to be investigated or optimized.

Three criteria were used during the investigation described in this paper: the total weight of the power plant and the fuel in the aircraft tanks (Me+f); fuel consumption for the transportation of a ton of cargo for a distance of a kilometer (Ct-km); the cost of transportation (a). In addition, for comparative analysis of the results of research the criteria characterizing the efficiency of the engine only - the specific fuel consumption at cruising mode (SFCcr.) was used.

The following parameters were optimized: total pressure ratio of the compressor

π*k.sum.cr; secondary flow pressure ratio π*f.s.cr $\pi^*_{\text{вII. кр}}$; bypass ratio m.

Flight Simulation and calculation of aircraft efficiency criteria was carried out as described in [2] using an computer-aided system of thermogasdynamic calculation and analysis "ASTRA" [3, 4].Computer-aided system for thermogasdynamic calculation and analysis (ASTRA) of gas turbine engines and power-plants is an integrated environment for the joint resolution of the gas turbine engine initial design phase tasks.

It allows to solve all the tasks of thermogasdynamic designing of the gas turbine engine [5, 6, 7, 8, 9, 10], as well as its gas-dynamic development [11, 12, 13, 14, 15].

OPTIMIZATION RESULTS

The line of gas turbine engines in this study was developed on the basis of the engine core of three-shaft

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bypass turbofan with a thrust of P0 = 295kN at takeoff mode.

Selection of bypass turbofan workflow parameters values was carried out at the first stage of the study.

Optimal values of π*f.s.cr.opt, π*k.sum.cr.opt and mopt, the corresponding values of workflow parameters of bypass turbofan and the criteria values were determined using the following initial data:

- turbine inlet temperature T*0 $T^*_{г0}$: 1550, 1600, 1650K;
- combinations of flight range Lf and payload Mpl: 120t - 4200km, 80t - 7300km, 40t - 10500km.

The results of optimization are presented in Tables 1-4. Maximum deviation of 2% from the optimal value was used for the determination of the tradeoffs area (Figure-1).

Table-1. Influence of turbine inlet temperature on the optimized parameters of bypass turbofan during the optimization of specific fuel consumption at cruising mode.
SFCcr → min

Parameter	**Value**		
T*0, K	**1550**	**1600**	**1650**
π*f.s.cr.opt	1,255	1,256	1,25
π*k.sum.cr.opt	59,58	63,83	75,81
Mopt	18,60	19,36	19,62
T*cr, K	1487	1534	1581
SFCcr, kg/(kN*hr)	50,95	51,02	51,26

Table-2. Influence of turbine inlet temperature and flight range Lf on the optimized parameters of turbofan during the optimization of the total weight of power plant and fuel.
Me+f → min

Parameter	**Value**		
T*0, K	**1550**	**1600**	**1650**
Lf$L_п$=10500km, Mpl$M_{к.н}$=40t			
π*f.s.cr.opt	1,406	1,406	1,405
π*k.sum.cr.opt	43,27	44,93	47,36
mopt	10,99	11,48	11,97
T*cr, K	1425	1471	1518
Me+f, ton	180,5	181,3	182,3
Lf=7300km, Mpl=80t			
π*f.s.cr.opt	1,441	1,442	1,440
π*k.sum.cr.opt	39,66	41,29	44,65
mopt	10,34	10,75	11,17
T*cr, K	1418	1464	1411
Me+f, ton	143,5	144,0	144,7
Lf=4200km, Mpl=120т			
π*f.s.cr.opt	1,436	1,441	1,442
π*k.sum.cr.opt	33,30	36,65	38,94
mopt	10,89	11,03	11,34
T*cr, K	1420	1464	1510
Me+f, ton	103,5	103,7	104,2

VOL. 9, NO. 10, OCTOBER 2014 ISSN 1819-6608

ARPN Journal of Engineering and Applied Sciences

Table-3. Influence of turbine inlet temperature and flight range Lf on the optimized parameters of turbofan during the optimization of fuel consumption for the transportation of a ton of cargo for a distance of a kilometer.

Ct-km→min

Parameter	**Value**		
T*0, K	**1550**	**1600**	**1650**
Lf=10500km, Mpl=40t			
π*f.s.cr.opt	1,353	1,352	1,355
π*k.sum.cr.opt	49,92	57,27	58,19
mopt	12,51	12,75	13,34
T*cr, K	1439	1485	1532
Ct-km, kg/(ton*km)	0,344	0,346	0,349
Lf=7300km, Mpl=80t			
π*f.s.cr.opt	1,340	1,336	1,339
π*k.sum.cr.opt	50,22	57,68	58,93
mopt	13,24	13,67	14,18
T*cr, K	1445	1492	1539
Ct-km, kg/(ton*km)	0,184	0,185	0,186
Lf=4200km, Mpl=120t			
π*f.s.cr.opt	1,321	1,320	1,321
π*k.sum.cr.opt	50,80	58,04	59,95
mopt	14,45	14,71	15,23
T*cr, K	1452	1500	1546,61
Ct-km, kg/(ton*km)	0,135	0,136	0,137

Table-4. Influence of turbine inlet temperature and flight range Lf on the optimized parameters of turbofan during the optimization of transportation costs.

a → min

Parameter	**Value**		
T*0, K	**1550**	**1600**	**1650**
Lf=10500km, Mpl=40t			
π*f.s.cr.opt	1,351	1,352	1,354
π*k.sum.cr.opt	40,61	41,46	45,09
mopt	13,41	13,99	14,34
T*cr, K	1443	1490	1536
a, rubles/(ton*km)	3,166	3,200	3,240
Lf=7300km, Mpl=80t			
π*f.s.cr.opt	1,328	1,330	1,329
π*k.sum.cr.opt	41,17	42,13	45,50
mopt	14,72	15,33	15,85
T*cr, K	1453,	1500	1542
a, rubles/(ton*km)	1,685	1,702	1,722
Lf=4200km, Mpl=120т			
$\pi^{*}_{\text{вп.кр.opt}}$ π*f.s.cr.opt	1,317	1,317	1,319
π*k.sum.cr.opt	41,13	42,23	45,31
mopt	15,51	16,27	16,63
T*cr, K	1460	1507,8	1554
a, rubles/(ton*km)	1,227	1,238	1,251

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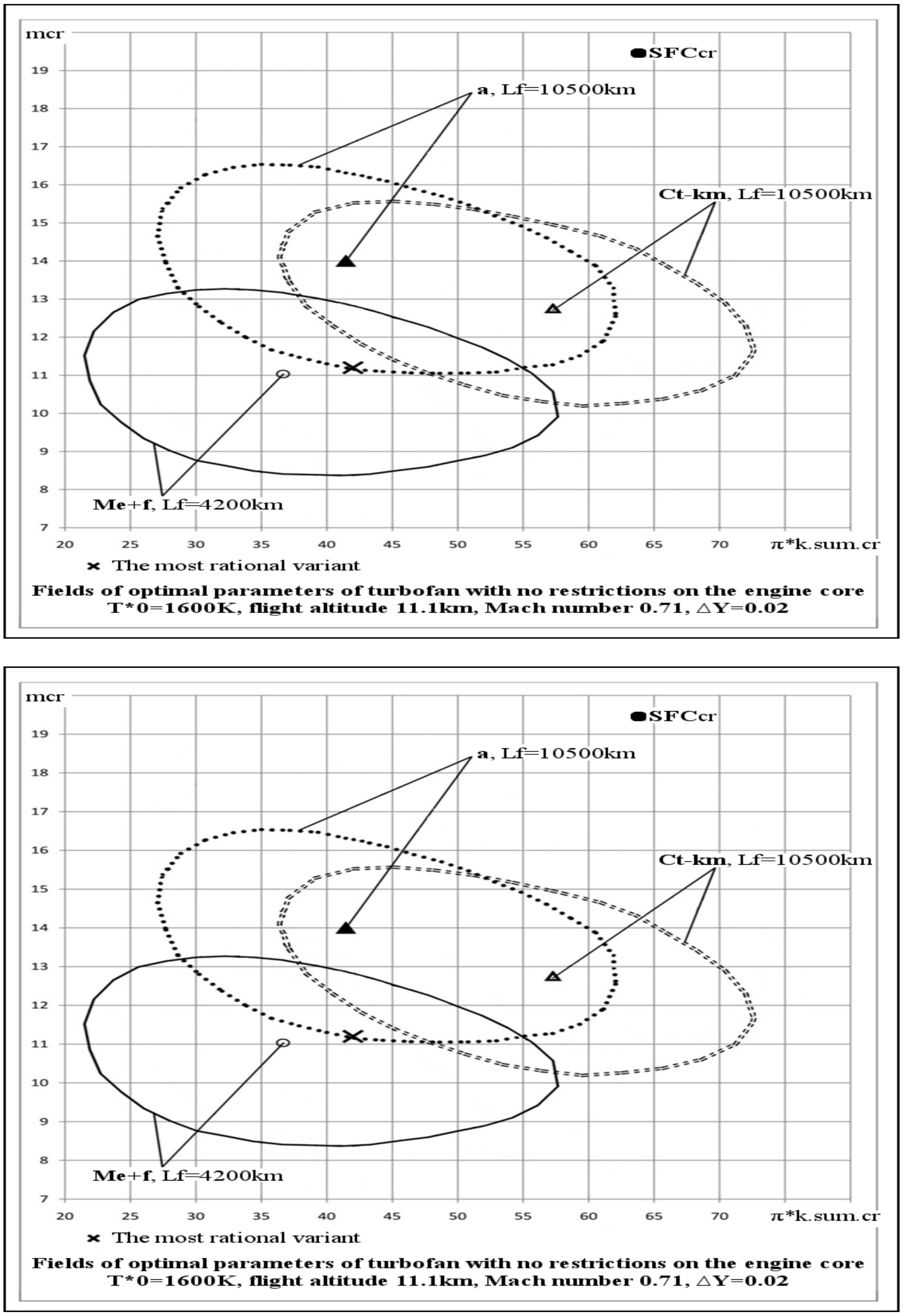

Figure-1. The most rational variant
Fields of optimal parameters of bypass turbofan with no restrictions on the gasifier.
Areas of locally optimal parameters, optimization with no constraints
for the engine core.

Based on these results the rational variant of turbofan with the following combination of workflow parameterswere chosen:

maximum turbine inlet temperature =1600K, π*k.sum.cr.=42, M=11,2 and π*f.s.cr.=1,44.

At the second stage of the work the possibility to create a line of turbofan engines of different thrust levels and power-plants using the selected parameters of the engine core was examined. The problem statement of optimizing the parameters of the turbofan working process with a given engine core is described in [5].

The line of turbofan engines (with no added stages) with a thrust varying from 250 kN to 310 kN was developed by means of bypass ratio changing with a subsequent optimization of secondary flow pressure ratio using the specific fuel consumption at the cruise mode of operation as an optimization criteria.

The geometry of the air-gas channel of the engine core and the characteristics of its parts, as well as the maximum turbine inlet temperature remained unchanged. Correlation between the main parameters of turbofan and the bypass ratio is shown in Figures 2-4.

The change of bypass ratio at cruising mode for providing such a change in engine thrust is from 6.25 to 13.4.

The specific fuel consumption SFC cr. vary from58.4 to 53.9 kg / (kN *hr), and the optimal value of secondary flow pressure ratio- from 1.65 to 1.37.

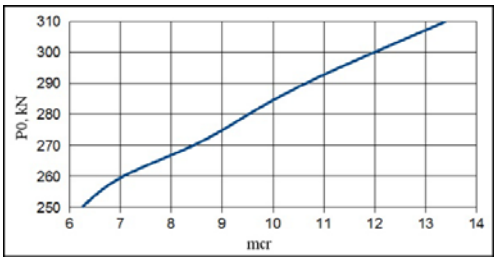

Figure-2. Bypass ratio at cruising mode influence upon the takeoff thrust of a turbofanwith a unified engine core.

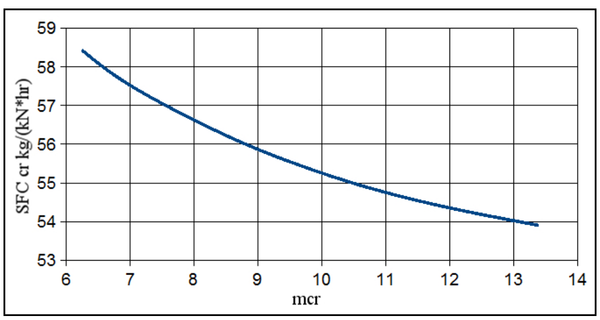

Figure-3. Bypass ratio at cruising mode influence upon the specific fuel consumption at cruising mode of a turbofan with a unified engine core.

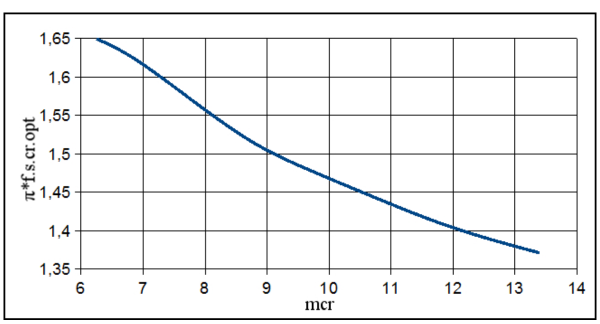

Figure-4. Bypass ratio at cruising mode influence upon the optimal value of secondary flow pressure ratioat cruising mode of a turbofan with a unified engine core.

A further thrust increase of a turbofan with unified engine core may be achieved by adding the stages and a further increasing of the bypass ratio.

The effectiveness of a unified engine core as a part of gas turbine power-plant with two-cascade core was also examined. Throttle performance graphs are shown in Figures 5-6.

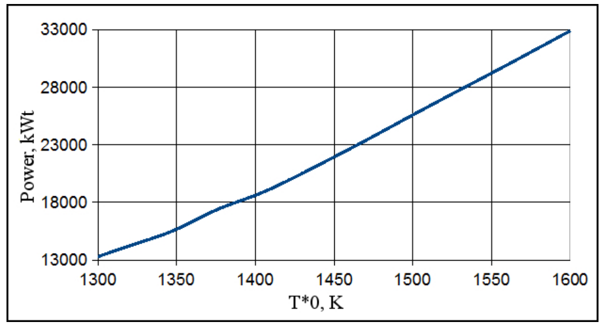

Figure-5. Turbine inlet temperature influence upon the power output of the gas turbine power-plant with a unified engine core.

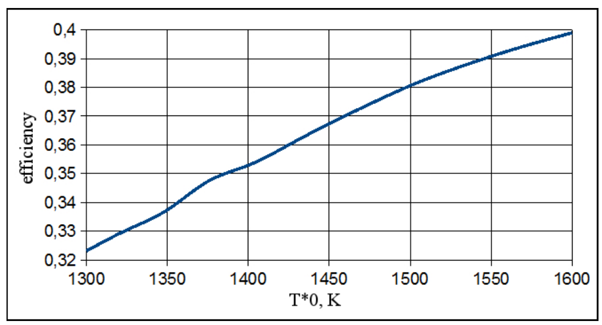

Figure-6. Turbine inlet temperature influence upon the efficiency of the gas turbine power-plant with a unified engine core.

The results have shown that by changing the turbine inlet temperature from 1300 K to 1600 K it is possible to obtain the required power output from 13 to 33MW. Effective efficiency of the power-plant meanwhile vary from 32% to 40%.

SUMMARY

The proposed variant of the engine core allows the development of different variants of turbofan engines and power-plants, having the required levels of efficiency and thus can be selected as a unified engine core for a line of gas turbine engines.

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