KEY FEATURES FORECAST OF BYPASS TURBOJET ENGINE WITH MIXING FOR PERSPECTIVE AVIATION COMPLEXES

D. A. Akhmedzyanov, A. E. Kishalov, K. V. Markina, V. D. Lipatov
USATU – Ufa State Aviation Technical University, Russia

Introduction

The modern aircraft engine (AE) is a highly complex technical system, equipped with large number of ancillary units, mechanisms, devices and service systems. A characteristic feature of aviation gas turbine engines (GTE) is a combination of enormous power with rather low weight and small dimensions.

The main stages of development of GTE are characterized by the change of generation engines, each of which is differs the basic parameters of the cycle, the design features its components, materials and technologies of their production [1].

With the change of generation engine greatly are changed its specifications influencing on efficiency. To date, AE used in military aircraft are mostly Two Spool Mixed Flow Turbofan.

Tracking change engine parameters according to the year of their development and generation, of the scheme, such as operating principle, constructional features can be detected some tendencies and regularities on the basis which it is possible to predict the main parameters of perspective AE [2].

Analysis of the parameters of engines of different generations

For the analysis were chosen engines made by the scheme and produced by with turbofans 60s to the present years. Total analyzed the 73 of the engine. Table 1 gives analyses engines their manufacturer and use.

As basic characteristic typical parameters of the engines for the analysis is selected the following parameters: specific fuel consumption (*SFC*) at the maximum and forced regime, specific weight, specific thrust, turbine entry temperature (*TET*), compressor pressure ratio (*CPR*) and the bypass ratio (*BPR*), for example, the sources [3–7]. Analysis was made for the parameters engines the listed in the dimensionless form.

Table 1. Analyzing engines

Year of development	Engine	Manufacturer	Major applications
1	*2*	*3*	*4*
1961	NK-144	JSC "Kuznetsov"	Tu-144
1963	Spay 201 (RB.168-25R)	Rolls-Royce	"Phantom" 2F-4K, F-4M
1964	TF30-P-1 (JTF10A-20)	Pratt&Whitney	F-111A
1965	Spay R.Sp 25R	Rolls-Royce	F-4K, F-4M
1966	RB.153-61	Rolls-Royce/MAN	VJ101D
	TF30-P-3 (JTF10A-21)	Pratt&Whitney	F-111, F-14, A-7
1967	F100-PW-100	Pratt&Whitney	F-15, F-16

Table 1. Continuation

1	2	3	4
1967	M53-02	Snecma	Mirage 2000
	M53-5		Mirage 2000, Mirage 4000
1968	RB199-34R (Mk.101)	Turbo-Union	"Tornado"
	RB199		"Panavia Tornado"
	RM8A	VolvoAero	SAAB Viggen, J-35F, J-35E, J-35XT
1969	NK-22/NK-23	JSC "Kuznetsov"	Tu-22M, Tu-144
1970	F101-GE-100	General Electric	B-1A
	F101-GE-102		B-1B
	RM.8B	Volvo Aero	SAAB JA 37 Viggen
	TF30-P-7 (JTF10A-27D)	Pratt&Whitney	FB-111A
1971	NK-144A	JSC "Kuznetsov"	Tu-144, Tu-22M
1973	TF30-P-9 (JTF10A-36)	Pratt&Whitney	F-111D
1974	F404-GE-400	General Electric	F/A-18, F-117
1976	F100-PW-220	Pratt&Whitney	F-15, F-16
	F401-PW-400		F-14
	PW1128		F-16
	TF30-P-12 (JTF10A-27A)		F-111B
1977	F110-GE-100	General Electric	F-16
	F110-GE-400		F-14
	F404-GE-100		F/A-18, F-117
1978	M.53-P2	Snecma	"Mirage" 2000, 2000N, 4000
	TF30-P-412 (JTF10A-27F)	Pratt&Whitney	F-14A
1979	D30-F6	Perm Engine Company UEC	MiG-31
1980	PW1120	Pratt&Whitney	"Lavi", "Novi Avion", "Phantom", IAI, F-4
	TF30-P-412A		F-111, F-14, A-7
	M88-2	Snecma	Rafale
	M88-15		Rafale
	XG-20	Chase Aircraft	C-123
1981	RD-33	JSC "Klimov"	MiG-29
	J79-GE-119	General Electric	F-16/79
1982	RB.199-67R	Turbo-Union	P,110
	M85	Volvo Aero	F-18
	XG-40	Rolls-Royce	Eurofighter
	RB.199-34R (Mk.103)	Turbo-Union	"Tornado"
	TF30-P-100 (JTF10A-32C)	Pratt&Whitney	F-111F, "Combat Lancer"
1983	YF120-GE-100(GE37)	General Electric	ATF

Table 1. Continuation

1	2	3	4
1984	TF.306	Snecma	"Mirage"
1985	F110-GE-129	General Electric	F-15E, F-16C/D
	F100-PW-229	Pratt&Whitney	F-15, F-16
	RB.199-34R (Mk.104)	Turbo-Union	"Tornado"
1986	AL-31F	NPO Saturn	Su-27, Su-30, Su-37, Su-33
1987	F404/RM.12 (F404J)	General Electric	JAS-39 Gripen
	R79V-300	TMDB «Soyuz» JSC	Yak-141
	EJ200	Eurojet Turbo	Eurofighter
1989	AL-41F	NPO Saturn	MFI
	RD-33MK	JSC "Klimov"	MiG-29K, MiG-29M
	R79FM-300	TMDB «Soyuz» JSC	Yak-41M
1988	AL-31FP	NPO Saturn	Su-30MKI, Su-30MKM
1990	J101/SF (F127-GE-100)	General Electric	IDF "ChingKuo"
	R119-300	TMDB "Soyuz" JSC	T-60S (Su)
1991	IPE-92	Pratt&Whitney	F-15, F-16
	F119-PW-100 (PW5000)		F-22
1992	IPE-94		F-15E, F-16C/D
1995	F135		F-35 JSF
1996	M88-3	Snecma	Rafale, Mirage, Gripen
1997	JSF119	Pratt&Whitney	Lockheed Martin
	M88-4	Snecma	Mirage 2000
	F136 (JSF-F120)	GeneralElectric	F-35
1998	F414-GE-400	General Electric	F/A-18E/F
2000	F110-GE-129 EFE		F-16
	F110-GE-132		
2001	R145-300	TMDB "Soyuz"	PAK FA (T-50)
	F100-PW-229A	Pratt&Whitney	F-16
	M88-3C	Snecma	Rafale
2005	AL-41F1	NPO Saturn	PAK FA (T-50), Su-35
2013	AL-41F2		PAK FA (T-50)

To determine the missing of parameters and characteristics of analyzed engines performed their simulation in system simulation Dvigw (Fig. 1) [8]. Fig. 1 shows the topological model AE with structural elements (SE).

In Fig. 2 – 10 are presented approximate the dependence of the parameters of engines: *SFC*, *CPR*, *TET* specific thrust (F_s), specific weight (γ) and *BPR* division to maximal value of parameter of each indicator, depending on the year of development. Here *SFC*, F_s and γ analyzed for the maximum (*max*) and the forced regimes (*f*).

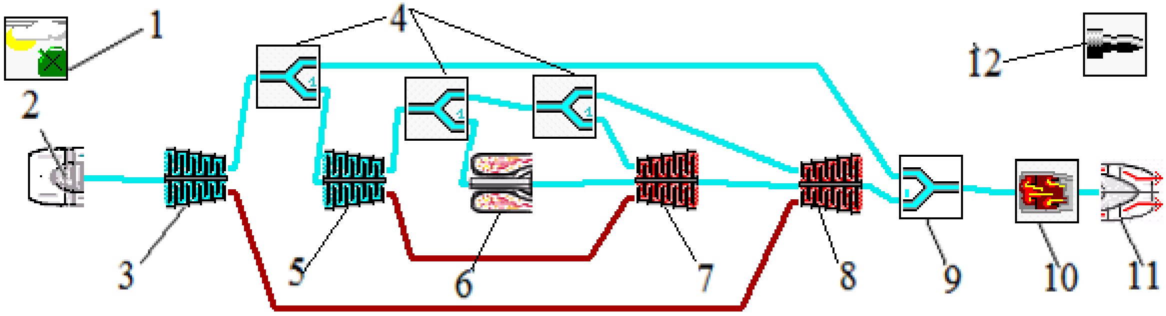

Fig. 1. Topological Model F100-PW-229 turbofans, where 1 – SE initial conditions; 2 – SE air intake; 3 – SE LPC; 4 – SE selection of air; 5 – SE HPC; 6 – SE combustion chamber; 7 – SE HPT; 8 – SE LPT; 9 – SE mixer; 10 – SE afterburner; 11 – SE jet nozzle; 12 – SE overall results

Identified the main regularities of change of engine parameters according to the year of development, allowing predicting the characteristics of prospective turbofan [1, 2]. Nondimensionalization *SFC* is computed by formula

$$\overline{SFC}_f = SFC / SFC_f \,. \tag{1}$$

Other dimensionless parameters engines are calculated in a similar way by formula (1).

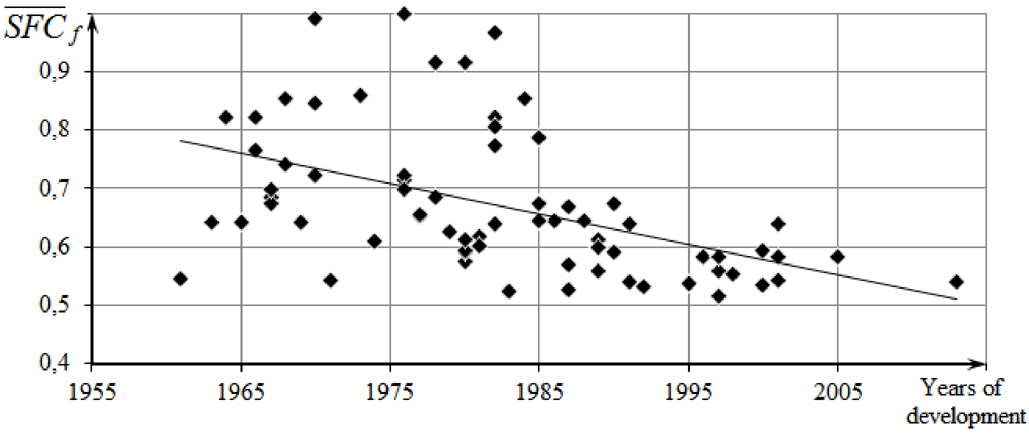

Fig. 2. Change the *SFC* to forced regime, depending on the year of development

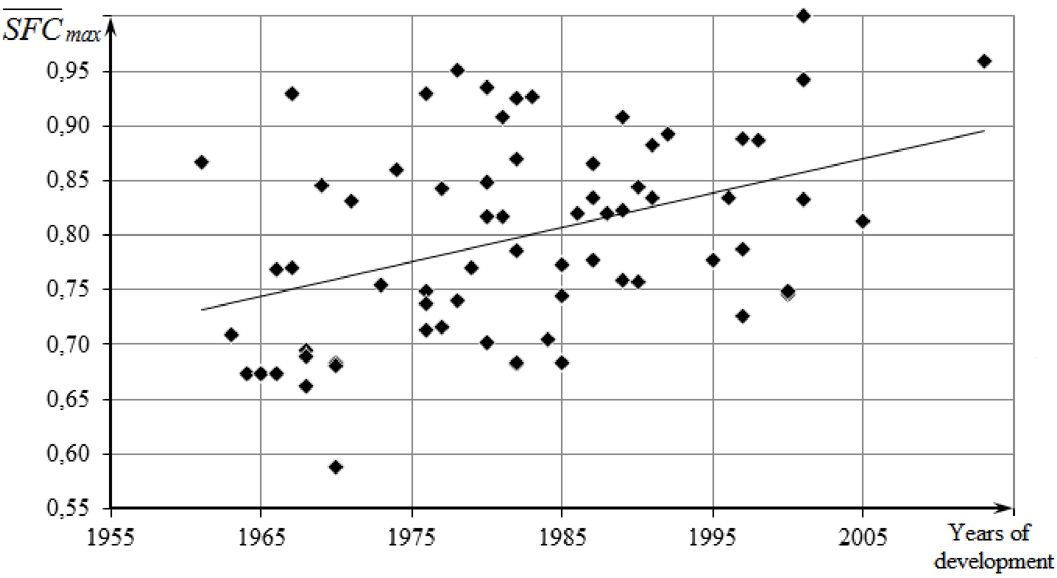

Fig. 3. Change the *SFC* to maximum regime, depending on the year of development

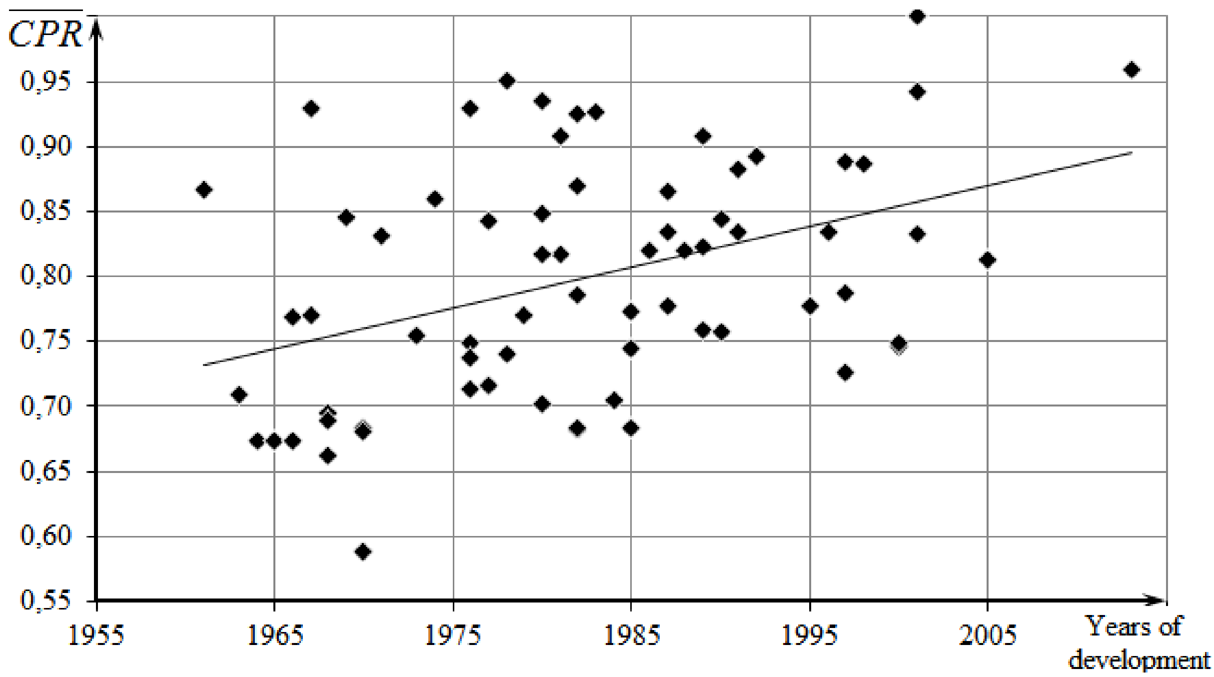

Fig. 4. Change of *CPR*, depending on the year of development

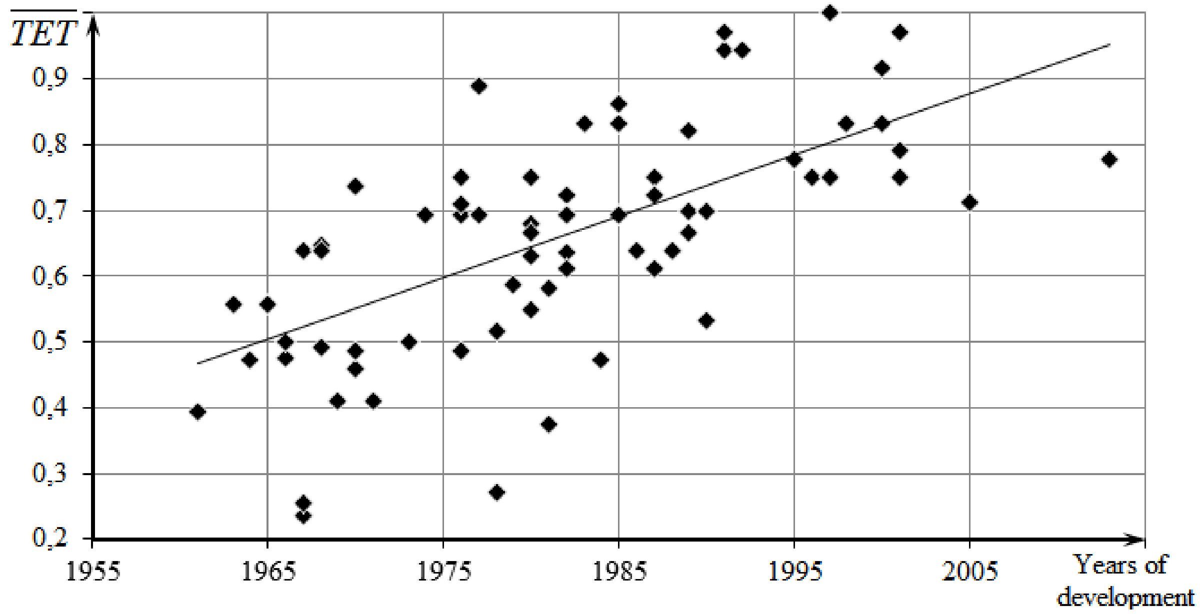

Fig. 5. Changing the *TET*, depending on the year of development

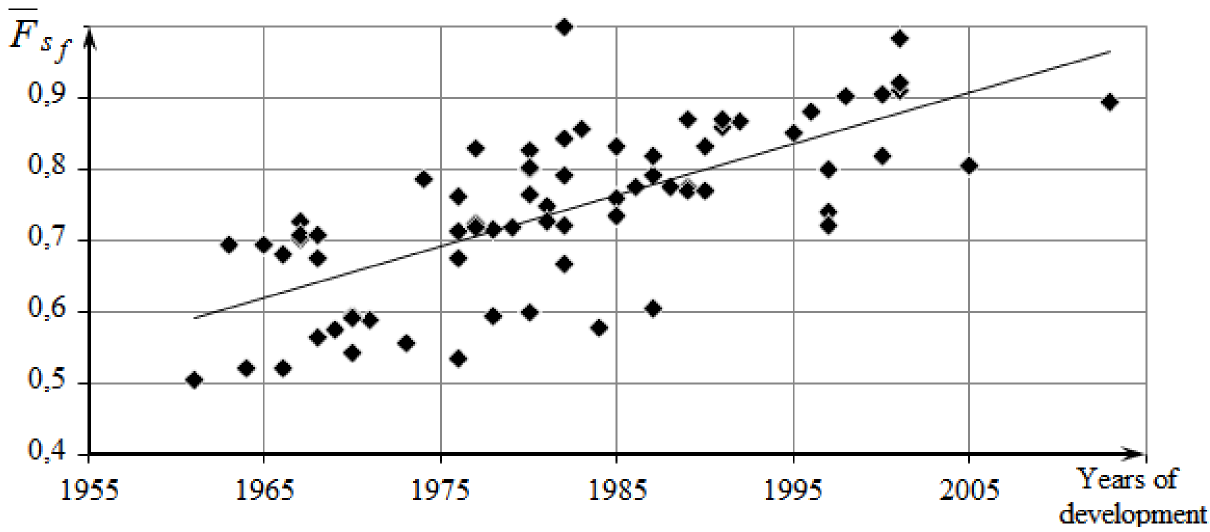

Fig. 6. Changing specific thrust on the forced mode, depending on the year of development

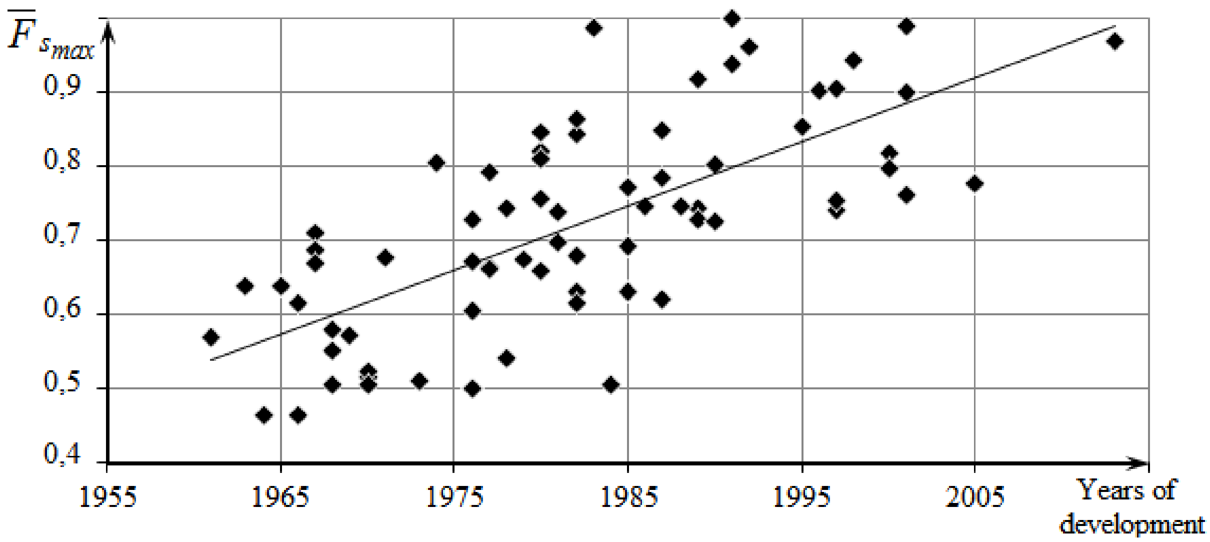

Fig. 7. Changing specific thrust at maximum capacity, depending on the year of development

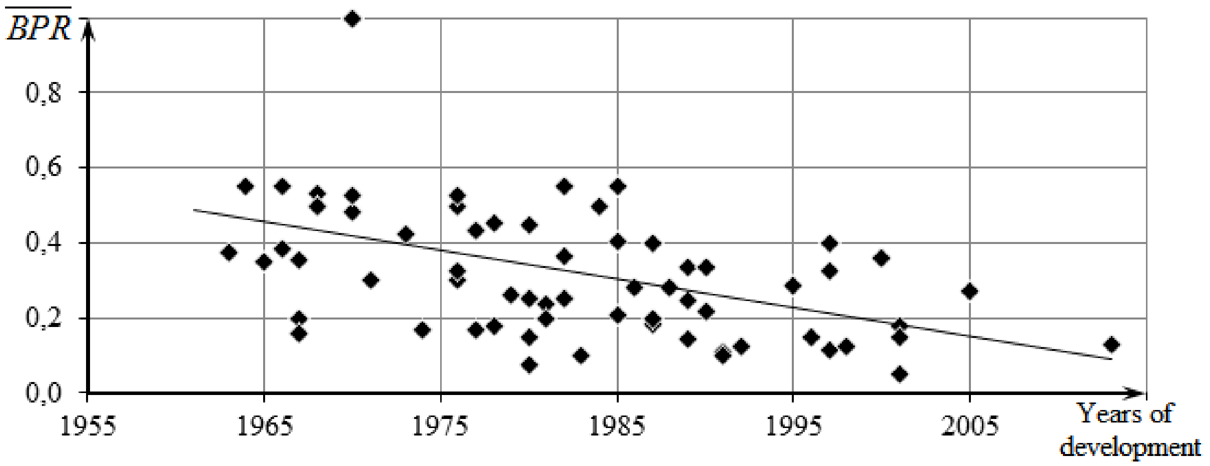

Fig. 8. Changing *BPR*, depending on the year of development

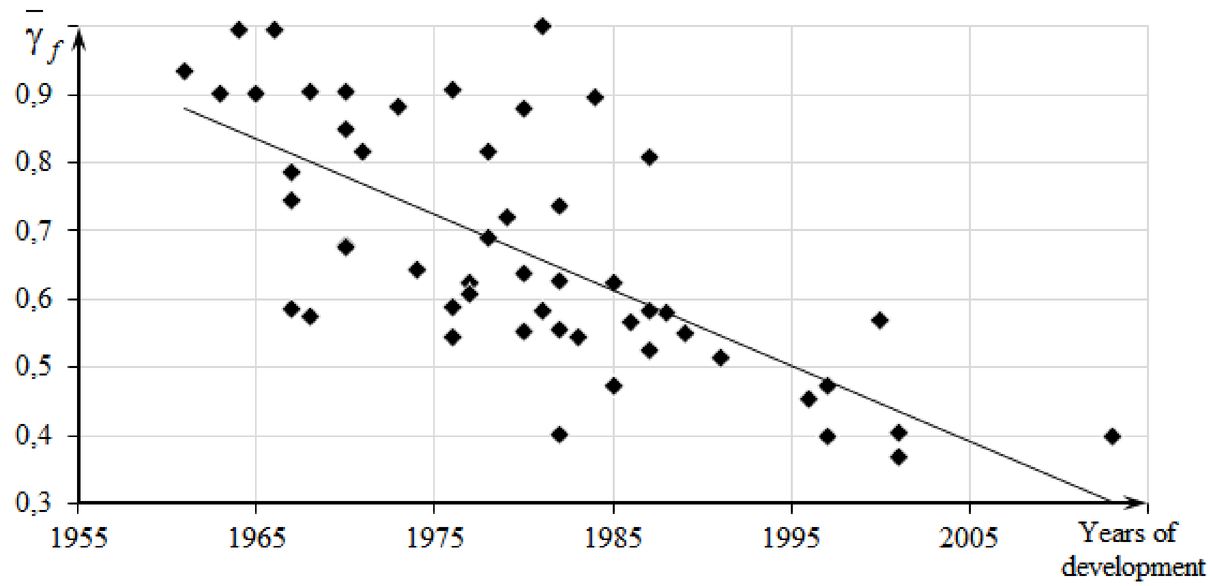

Fig. 9. Changes specific weight in the forced regime, depending on the year of development

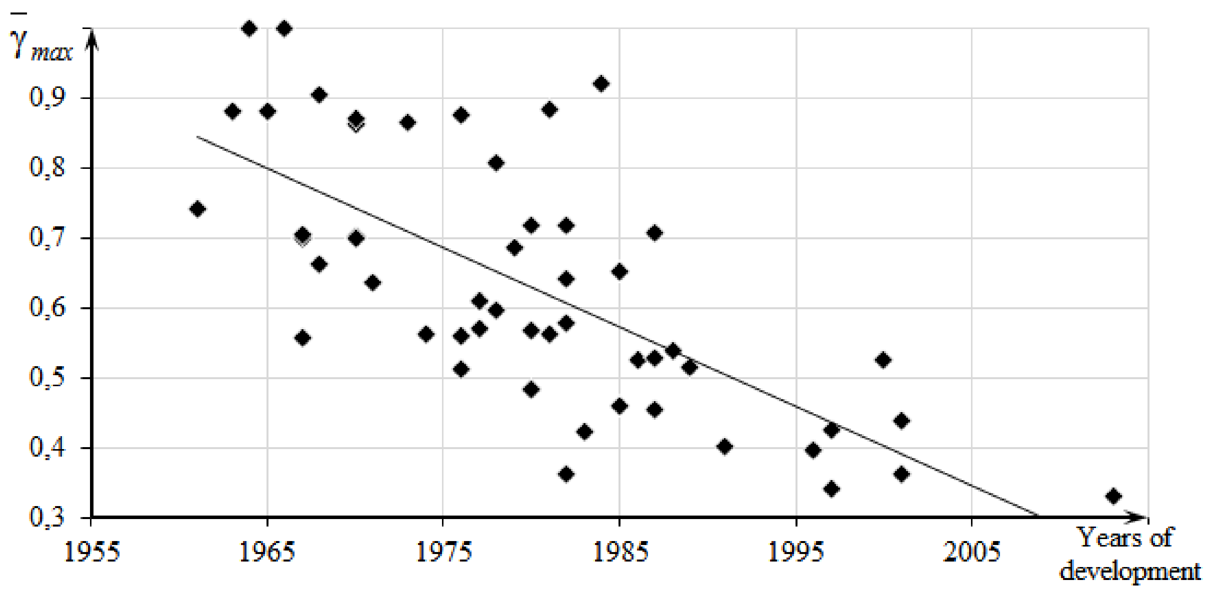

Fig. 10. Changes specific weight at maximum regime, depending on the year of development

According to research, obviously traced the correlation between the consideration of the characteristics of the engine and the year of its development. For description of each particular sample by a linear function for each parameter has been estimated correlation coefficient [8]

$$r_{\tau Y} = \frac{\Sigma\left(\tau - \bar{\tau}\right)\left(Y - \bar{Y}\right)}{\sqrt{\Sigma\left(\tau - \bar{\tau}\right)^2 \left(Y - \bar{Y}\right)^2}}, \qquad (2)$$

where $\bar{\tau} = \frac{1}{n}\sum_{i=1}^{n}\tau_i$ and $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n}Y_i$ – mean values of samples the development τ and the analyzed the parameter of the engine Y.

The nearer value of the quantity of the correlation coefficient to unity, the more accurate the approximation is considered according to a linear function of the variables. From the sign of the correlation coefficient depends on the angle of the approximating line to the abscissa (the year of development).

For each of the approximate dependency was evaluated maximum (ε_{max}) and medium ($\overline{\varepsilon}$) the relative errors (Table 2) between the real and theoretical values.

$$\varepsilon = \frac{Y_i - Y_{imeop}}{Y} 100\% \quad , \qquad (3)$$

where Y_i and Y_{teor} real and theoretical (obtained with the aid approximating dependence) values of the analyzed parameters of the engine.

It can be assumed that the obtained error approximating dependencies ε_{max} and $\overline{\varepsilon}$ are valid also for all the predicted values the basic parameters of perspective turbofans.

The calculated correlation coefficients, approximating dependence, predicted values (for τ = 2016) the average and maximum the relative errors are shown in Table 2.

Table 2. The approximating dependences of parameters of engines and the predicted values

Approximate depence	Coefficient correlation	Predicted value	Relative error	
			ε_{max}, %	$\overline{\varepsilon}$, %
$\overline{SFC}_f$ = –0.0052τ+11.004	-0.495	0.161 kg/(N·hr)	47.75	12.98
$\overline{SFC}_{max}$ = 0.0031τ–5.4234	0.384	0.079 kg/(N·hr)	27.49	10.58
$\overline{CPR}$ = 0.0093τ–17.796	0.622	34.3	120.2	18.37
$\overline{TET}$ = 0.0052τ–9.3846	0.730	2087 K	32.84	8.29
$\overline{F}_{s_f}$ = 0.0072τ–13.534	0.712	1.387 kN·s/kg	30.32	9.58
$\overline{F}_{s_{max}}$ = 0.0087τ–16.461	0.709	0.991 kN·s/kg	58.37	14.90
$\overline{\gamma}_f$ = –0.0111τ+22.672	-0.705	6.502 kg/kN	66.84	16.63
$\overline{\gamma}_{max}$ = –0.0114τ+23.125	-0.714	5.390 kg/kN	46.74	16.63
$\overline{BPR}$ = –0.0077τ+15.525	-0.984	0.15	99.64	34.90

Conclusion

A result of research gives an overview of the parameters turbofans with their followed by analysis, goal of which was determination interconnection between the parameters of the engine and the year of its development. Are revealed approximating dependences describing change the basic parameters of the engines according to the year of their development, which is a linear dependence. In order to establish reliability of approximation dependencies in using a linear function of the correlation coefficients were determined.

Established that the dependence the specific fuel consumption at maximum and forced regime linear relationship described by poorly ($r_{\tau Y}$= 0.384 and -0.495,accordingly) for all other parameters the correlation coefficient lies between 0.622 to 0.984, that allows to consider obtained dependence to a sufficient degree of certainty.

The error of the predicted values of basic parameters of prospective turbofan indirectly estimates the amount of the maximum and medium relative error. The average relative error of the basic parameters of perspective turbofans in the range of 8% to 35%, the maximum - from 27 % to 120% (for compressor pressure ratio).

On the basis of identified regularities were made predictable values of main parameters of perspective GTE on the maximum and the forced takeoff regimes (SFC_{max}= 0.079 kg/(N·hr)) SFC_f=0.163 kg/(N·hr), accordingly), specific weight (γ_{max}= 5.390 kg/kN и γ_f =6.502 kg/kN), specific thrust (F_{smax}= 0.991 kN·s/kg и F_{sf}= 1,387 kN·s/kg), turbine entry temperature (*TET* = 2087 K), compressor pressure ratio (*CPR* = 34.3), bypass ratio (*BPR*=0.15).

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