STUDY OF THE PROPULSION SYSTEM CONCEPTS FOR ADVANCED SUBSONIC AIRLINERS

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Abstract

The main results of the first stage of studies on the formation of the advanced engine and propulsion concepts of commercial airliners, which may be put into service after 2025-2035 timeperiod. The subsonic airliners with different passenger capacity and flight range were considered.

1 Introduction

The U.S. and EU plans for the aviation development set the ambitious goals to create next-generation aircrafts with cardinal improved mission performance and significantly reduced noise and emission levels at 2030-2035 timeperiod. In particular, in comparison with the existing level of performance following goals are expected to achieve (Fig. 1):

- to decrease fuel consumption by 60-70%;
- to reduce perceived noise level by half;
- to reduce emission levels by 50% for CO2 and by 75-80% for NOx.

	N+1 (2015)* Reference – B737/CFM56-7B	N+2 (2020)* Reference – B777/GE90-115B	N+3 (2025)*
Noise, EPNdB (below Chapter 4)	– 32	– 42	– 71
LTO NOx emission (below CAEP6)	– 60	– 75	better than – 75
Fuel consumption,%	– 33**	– 50**	better than – 70
Field length, %	– 33	– 50	***

* The Technology Readiness Level TRL=4–6
** Additional improvement by air traffic control is possible
*** Defined by capability of megalopolis

Fig. 1. NASA target indicators for advanced aircraft [1]

Considerable contribution to achieving the stated goals for next-generation have to contribute the propulsion systems (PS) with advanced engines. Many research programs on R&TD carried out by leading engine manufacturers are aimed for the development of PS.

Researches of breakthrough design and technological solutions, which will provide the competitiveness of Russian engines and aircraft in the mentioned timeperiod are also conducted in Russia. In particular, advanced development and experimental researches of innovative technologies as well as a R&TD for engines and PS of next generation architectures are performed by CIAM.

2 Problem statement of the research task

Achievement of target indicators for the airliners of the 2025-2035 timeperiod requires a comprehensive approach to carrying out researches and covers all areas close connected with progress of aviation industry, including the use of advanced technologies, raise of aerodynamic and weight efficiency of the airplane and the PS (application of unconventional aerodynamic aircraft configurations, wide use of new alloys and composites in an aircraft and engine structures, etc.).

The airliners of three classes are considered in the work as the most actual for domestic civil aviation: 100-seater regional jet (RJ) like SSJ-100,aircraft 180-seater short- and mid-range jet (SMRJ) like MS-21-300 aircraft projected recently and advanced 300-seater twin-engine long-range jet (LRJ) like Il-96-300 aircraft.

The purpose of the first stage of the work was definition of predicted total improvements related to fuel efficiency, takeoff and landing performances, environmental and operational parameters, contribution of aircraft components (airframe and PS). The shape and main parameters of advanced PS for airliners were obtained as a result of the researches. First of all, it includes the engine size and necessary (and at the same time really achievable) level of specific fuel consumption (SFC).

3 Input data for carrying out researches

The initial data for carrying out of integrated assessment of mission performance of aircraft (MPA) for advanced airliner in order to determine their preliminary technical shape and parameters of PS were following information:

- the prediction of world and Russian air transportation to define the aircraft size and the main characteristics of the route network (Fig. 2);

- the forecast of world R&TD level of aircraft engines;

- analysis of R&TD programs as well as current and required key technologies for the development of advanced engines and PS (both conventional and unconventional architectures) for civil aviation.

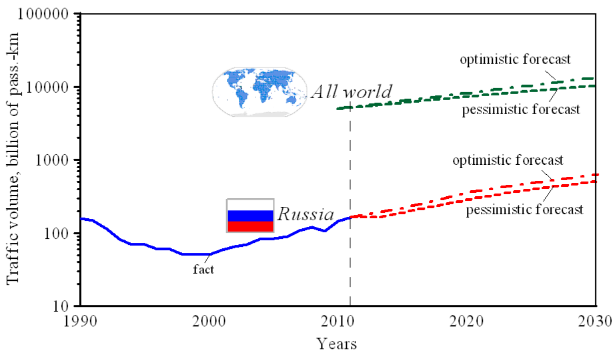


Fig. 2. A long-term forecast of passenger traffic in the Russian Federation and the world [2]

There are three main uncertainties at estimation the mission performance for airliner of long-term future:

- level of the aerodynamic efficiency, wich is mainly defined by cruise aerodynamic efficiency $(L/D)_{cr}$;

- level of the airframe weight efficiency, which is first of all characterized by the value of aircraft relative operating weight $\overline{W_{op}} = \frac{W_{op}}{TOGW}$; where W_{op} is aircraft, operating weight in kg; $TOGW$ is aircraft takeoff weight in kg;

- level of PS efficiency, which is mainly characterized by cruise SFC SFC_{cr}.

The final result will be depended on the levels of the main design parameters of aircraft and PS which is adopted for predictive calculations. Levels of aerodynamic and weight efficiencies were adopted depending on the type of the aircraft and the number of generation or time of EIS: 2020 for N+1 generation, 2025 for N+2 generation and 2030-2035 for N+3 generation. It is adopted that the greatest improvement of aerodynamic efficiency will be achieved for SMRJ and LRA with unconventional aircraft configurations and highest level of aircraft & PS integration.

Aerodynamic configurations and values of SFC_{cr} specific fuel consumption in cruise flight, SFC_{cr}..$(L/D)_{cr}$ and $\overline{W_{op}}$ for considered airliners are presented in Table 1. It is seen, that conventional aircraft configuration adopted for RJ will allow to increase aerodynamic efficiency by ~37 % (at transition from N+1 to N+3 generation) due to application of advanced technologies (such as flow laminarization, control of boundary layer, etc.). Conventional configuration with high aspect ratio wing and a wide fuselage with cross-section in the form of two combined ovals (NASA configuration for the D8.5 "Double-Bubble" project [3]), providing the increase of $(L/D)_{cr}$ by ~43 %, is assumed for SMRJ of N+3 generation. And configuration of a hybrid flying wing (the HWB project of the H3.2 NASA aircraft [3]), providing cruise aerodynamic efficiency $(L/D)_{cr}$= 27 for N+3 generation is adopted LRJ.

The following concepts of engines and PS of the airliners were considered in these researches:

Table 1 — Aerodynamic and weight efficiencies for different generations of airliners

Type of aircraft	$(L/D)_{cr}$			$\overline{W}_{op}$		
	N+1	N+2	N+3	N+1	N+2	N+3
RJ pax=100; Range = 3500 км; $M_{кр}$ = 0,74 	16,0	19,0	22,0	0,58	0,56	0,54
SMRJ pax=180; Range = 5000 km; M_{cr} = 0,76 	17,5	21,0	25,0	0,54	0,52	0,50
LRJ pax=300; Range = 10000 km; M_{cr} = 0,83 	19,0	23,0	27,0	0,50	0,48	0,46

– a conventional turbofan (TF) with the high engine cycle parameters (overall pressure ratio OPR и turbine entry temperature TET) and bypass ratio BPR;

- a propfan engine (PF or «open rotor»);

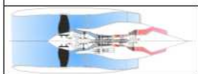
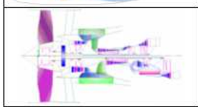
- TF with unconventional engine cycles (with heat exchanger and air intercooling in the compression process);

- the distributed PS (DPS) with separated core and thrust fans (propulsors);

- hybrid TF with the additional electromotor for the fan rotation, fed by the storage battery or power plant on fuel cells.

Engine architectures and cruise SFC levels of the engines and PS, adopted in the work are presented in Table 2. Comparison of values SFC_{cr} is carried out for cruise conditions at H=11 km; M= 0,8.

Table 2 — Concepts of considered engines and PS of the airliners and cruise SFC levels

	Engine / architecture	SFS_{cr}, kg/(kgf·h) (H=11 km, M = 0,8)
	TF with the high parameters of the working process	0,49–0,51
	TF with unconventional thermodynamic cycles	0,40–0,45
	A propfan — «open rotor»	0,35–0,40
	Distributed PS	0,40–0,45
	Hybrid TF	0,40–0,45

As it is seen on Table 2, it was assumed that it may be reached the SFC level SFCcr = 0,40–0,45 kg/(kgf·h) for engine architectures with heat exchanger and intercooling, DPS or hybrid TF. The lowest level SFC_{cr} = 0,35–0,40 kg/(kgf·h) has propfan.

4 Estimation of aircraft mission performance and development of requirements to PS

During parametric studies values of the main parameters characterizing the efficiency of "PS-aircraft" system, such as . SFC_{cr}..$(L/D)_{cr}$ and $\overline{W}_{op}$., were changed in some range (see Table 1 and 2) from a "reference" point (reference aircraft and engine) towards to their improvement. The parameters which were already achieved at existing aircrafts (like SSJ-100 and Il-96) and engines (like SaM-146 and PS-90A), or were predicted for near future (like MS-21-300 with PD-14 engine), were adopted as reference point.

Results of parametric studies of mission performance estimation and obtained isolines for takeoff weight TOGW and required takeoff and cruise thrusts (T_{cr}, T_{to}) of the twin engines PS of SMRJ depending on the accepted level of weight and aerodynamic aircraft efficiencies (..$(L/D)_{cr}$ and $\overline{W}_{op}$ = var) and a predicted level of SFC (SFC_{cr}. =var) are shown on Fig. 3.

Three points are shown on diagrams (see Fig. 3):

1) The reference points corresponding to the "reference" aircraft (MS-21-300). Here the points are marked as N+1 generation;

2) The resulting and the most optimistic points corresponded to the advanced aircraft project (N+3 generation);

3) The intermediate points, accepted as the most realistic for near-term outlook (N+2 generation). They was obtained as a result of taking into account following constraints:

– predicted level of airframe weight efficiency ($\overline{W}_{op}$ = 0,52 for SMRJ);

– airframe aerodynamic efficiency ($(L/D)_{cr}$ = 21,0 for SMRJ);

– thermodynamic efficiency of PS based on the conventional TF, but with higher engine cycle parameters (SFC_{cr}.= 0,44 kg / (kgf·h)).

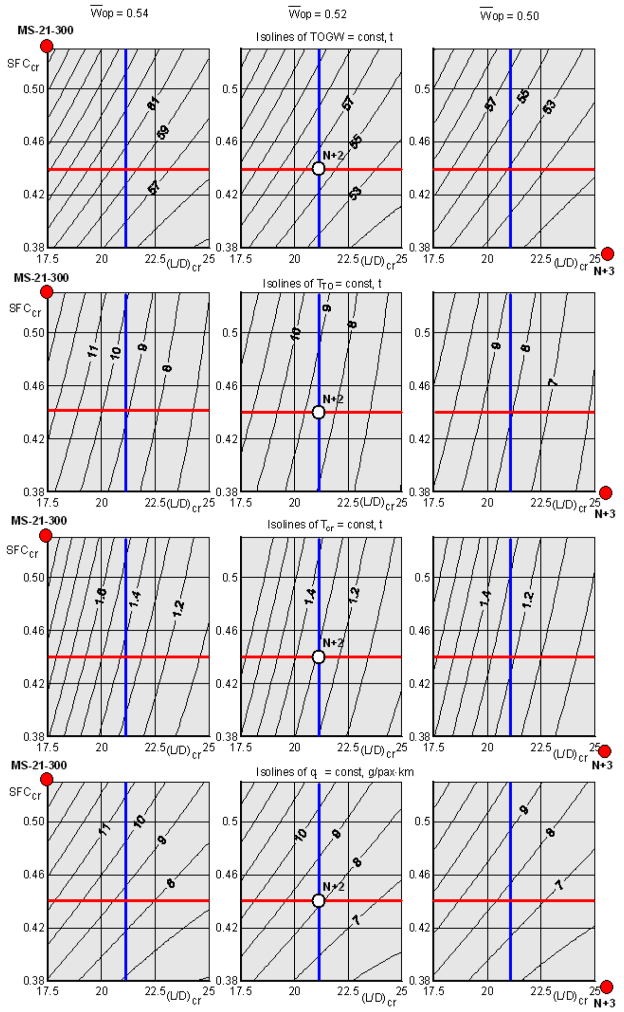


Fig. 3. Takeoff weight of SMRJ, takeoff and cruise thrusts of the SMRJ engine

These limitations are defined by expert estimations taking into account recommendations of TsAGI and CIAM specialists.

Similar dependences are obtained for RJ and LRJ. Obtained aircraft and PS parameters for all three types of the airliners and for more realistic level of parameters (N+2 points on Fig. 3) are presented in Table 3 in comparison of state of the art (SOA)levels. Values of fuel efficiency (fuel consumption per passenger*km) q_t are presented in third column.

It is seen from the Table 3 that increase of advanced PS, aircraft aerodynamic and weight efficiencies leads to considerable reduction of takeoff weight TOGW and required engine thrust (in 1,5–2 times). Along with increase of engine BPR it will result in significant decrease of core size (in ~4–6 times) in comparison of existing one. Therefore the problem of development of high-performance mixed-flow and centrifugal compressors with the small blades is becoming actual for engines of RJ and SMRJ airliners.

Table 3 — Parameters of airliners and engines for N+2 generation (in numerator) and SOA level (in denominator)

Type of aircraft	*TOGW*, t	q_f, g/pax.km	$(L/D)_{cr}$	SFC_{cr}, kg/(kgf·h)	T_{to}, t	T_{cr}, t
RJ	34–36 / 50	11–12 / 24,0	19–20 1) / 16,0 2)	0,48–0,50 1) / 0,63 2)	5–6 / 8,5	0,85–0,9 / 1,5
SMRJ	56–58 / 76,0	8–9 / 15,0	21–22 2) / 17,5 3)	0,46–0,47 2) / 0,53 3)	8–9 / 14	1,2–1,35 / 2,1
LRJ	120–150 / 230	17–18 / 25,0	22–23 4) / 19,0 3)	0,48–0,50 4) / 0,60 3)	17–20 / 36 5)	2,65 / 5,9

Notes:

1) Mcr = 0,65. 2) Mcr = 0,78. 3) Mcr = 0,80. 4) Mcr = 0,82.

5) The doubled thrust of the PS-90A engine for twin engine LRJ

Conclusions

The carried out studies allowed to develop the preliminary design of PS for advanced airliners, planed to enter into service after 2025-2030 timeperiod. Different options for passenger aircrafts and PS were obtained for different technology level of industry and corresponding technical risks for their implementation.

Detailed studies of five considered concepts of engines and PS with wide investigations of environmental, operational, etc. performances, and more precise definition of components performances and integrated parameters will be carried out on the next stages of the work. The most priority engine architectures for critical technologies will be chosen for testing on demonstrators after a reestimation of mission and fuel efficiency performances of airliners taking into account mass and dimension parameters and ranking of engines on degree of technical risk.

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