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ANALYSIS OF TRENDS AND FORECAST OF GTE DEVELOPMENT FOR SUBSONIC CIVIL AIRCRAFT

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Abstract

Conducting research for development of civil aircraft engines of 2025-2030 period – the 6th generation engines. The research purpose consists in determination of main directions of creating advanced research experimentally validated for breakthrough design and technological solutions and providing competitive development of powerplants for civil aircraft.

Development of new competitive engines is an expensive and long-lasting process. What the practice shows, the development period of new technologies lasts more than 10 years, but their mastering for using in powerplants of flying vehicles takes another 10-15 years.

New generation engines should provide for high level of technical maturity, radical reduction of fuel consumption, emissions, and noise level, as well as reduction of production cost, repair, and technical maintenance. On the basis of state-of- the-art (SOA) and development trends of civil aircraft engines have been obtained performances for passenger aircraft of period 2025-2030: fuel consumption and CO_2 emissions reduction by 60-70%; twice lower perceptible noise; 75-80% margin on NO_x emissions according ICAO-2008. These factors adopted for passenger planes of period 2025-2030 can be reached under integrated improvement of airframe and powerplant with simultaneous air traffic control updating. Powerplant contribution in reduction of fuel consumption makes up approximately 40%.

The given study covers all types of aircraft engines – turbofans, turboprops, turboptopfans - for subsonic long range civil aircraft. Designed are the concepts for advanced basic turboptopfan engine ("open rotor"), perspective engines with complex thermodynamic cycles (with intermediate air cooling at compression, with hot gas heat regeneration at its expansion), offset core demonstrator for perspective distributed powerplants, hybrid turbofan with drawing requirements to electric drive systems of aero engines.

Justification is given for reasonable growth of working process parameters of perspective powerplants providing greater requirements for engine durability and emission features. The following engine and powerplant concepts are considered:

- Turbofan with greater (in contrast with 5th generation engines) working process parameters and ultra-high bypass ration (BPR);
- Turbopropfan engine with gearless and gear drive of dual row rear propfan (the "open rotor" concept);
- Turbofan engine with complex thermodynamic cycle providing introduction in GTE working cycle of heat regeneration processes and intermediate air cooling at its compression in the compressor;
- Distributed powerplants, including offset core and several thrust fans with mechanical transmission between them;
- Hybrid jet engines with additional fan shaft drive by means of electric motor fed by onboard energy unit or electro-chemical generator on solid oxide fuel elements;
- Engines and powerplants for business (administrative) and passenger new generation supersonic jets, including variable cycle (working process) engines.

We now show justification of reasonable working process parameter growth of advanced powerplants providing increased requirements to service life and engine emissions on a turbofan example with high working process parameters.

From the standpoint of fuel economy it is necessary an agreed increase of engine cycle parameters - total compressor pressure ratio $\pi^{*}_{\text{к}\Sigma}$, gas turbine temperature $T^{*}_{\text{г}}$ (for greater flight efficiency), and increased bypass ratio m (for greater flight efficiency). Maximum $\pi^{*}_{\text{к}\Sigma}$ values to 2000 reached level of $\pi^{*}_{\text{к}\Sigma}$=40… 45, maximum $T^{*}_{\text{г}}$ values grew to level ~1800…1900K, m~8…10.. Designing 6th generation engines deals with solution of new research problems on gasdynamics, heat exchange, strength, chemistry, metallurgy, and new design technology application.

The forecast study results show that specific fuel consumption reduction required in 2025 2030 in advanced powerplants can be provided under further working process parameters increase: to $\pi^{*}_{\text{к}\Sigma}$= 55…70, turbine gas temperature (in contrast with 5th generation turbofans) by $\Delta T^{*}_{\text{г}} = 150°C$, as well as increased bypass ratio to m = 15-20 (Fig. 1).

According to design data of short-medium range aircraft (SMRA) MS-21-300 now at development the cruise turbofan engine PD-14 provides for carrying out main preset requirements. Under take-off weight near 77 tons 180-seat plane will have at flight range 5000 km transportation fuel economy about 15.0 gram/passenger–km. Assuming progress in better airframe aerodynamic and weight characteristics, complex of measures on improvement of airframe and engine to 2030, and expecting reduction of specific fuel consumption by advanced turbofan of 2030 we can expect with the same passenger number better traffic economy by 30-35%. As a result such 59-60-tons aircraft will require lesser takeoff thrust turbofan by 30-40%.

In terms of this an important feature of perspective engines is an essential their size reduction versus 5th generation turbofans due to 1.5-2 times lower desired thrust level, 1.2-2.5 times greater bypass ratio, and 1.5-1.5 times bigger compressor pressure ratio. Thereupon the turbofan core size ratio, representing core compressor reduced exit air flow, in course of aero jet engine development reflects both growing worker parameter and growing problems in the field of working process thermogasdynamics and technology area at their realization. This entails restrictions in lower specific fuel consumption because of further increase of turbofan working process parameters due to impeller machine reduced efficiency, emissions increase, and lower service life. The mentioned fact means that for engines of long range aircraft and particularly regional jets a pressing issue may be using high effective axiscentrifugal and centrifugal compressors.

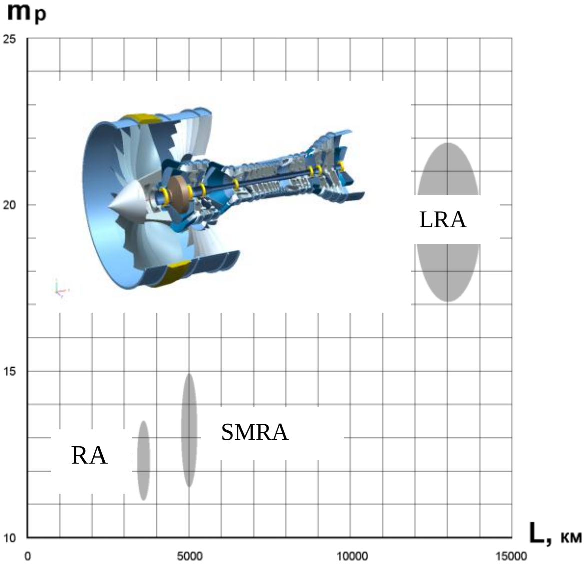

Fig.1. Expected bypass ratio turbofan values for regional and long range aircraft

Growth of bypass ratio and working process parameters renders expedient usage of a scheme with fan gearbox drive, guide vane LPC, and also outer contour variable nozzle.

A more important factor of increased aircraft fuel economy is greater turbofan design weight efficiency due to using new technical decisions, materials, and technological processes. With the aim of providing low values of specific gravity at rate γ_0 = 0.15-0.16 kg/kgs it is necessary to introduce in the fan advanced carbon composite materials, in the compressor - disks of titanium and composite materials, front stages of titanium and rear stages of nickel alloys, in the turbine - front stages of composite materials based on ceramic matrix and rear stages of nickel alloys, intermetallic titanium TiAl. Application of composite materials should be cardinally increased (carbon-filled plastic, ceramic materials on metallic and carbon-carbon matrix), intermetallides on which production-technological backlog and normative base for components certification of these materials is extremely necessary.

Results of parametric calculations illustrating specific fuel consumption variation on the engines family based on core with $T_Г^* =$ idem, $\pi^* =$ idem depending on bypass ratio and fan pressure ratio are shown on internal C_R and effective $C_{Rэф}$ characteristics (Fig. 2). Herewith inlet pressure losses and various air bleed and onboard powers are taken into account. A short-medium range 180 passengers aircraft is selected with range 5000 km with reference to cruise flight conditions: M = 0.8 and H = 11 km. One may notice that it is reasonable to choose a turbofan version having fan total pressure ratio 1.42 at design cruising flight conditions and bypass ratio ~ 14.

The critical technologies list is formed, which may be divided into technologies for ensuring turbofan components production process and integrating technologies for engine-demonstrator production.

For *compressors*: lowstage HPC (Zst=8-9) for small size core $G_{core\ corr}$ ~0.8-1.5 kg/s, high pressure ratio ($\pi^*_{HPC\ des}$≈20-25) and polytropic efficiency $\eta^*_{HPC\ pol} \geq 0.92$; introduction of efficient experimentally confirmed spatial methods of designing compressor flowpath; active flow control (casing treatment, wall local air suction); active radial clearance control system; new high effective low leak sealing; provision of steady-state and dynamic strength of design parts; production technologies of HPC low size last stages; creation of efficient control means for components mechanization.

Technologies of designing *combustors* contain ensuring lean combustion process of prepared homogenized fuel-air mixture, absence of fuel combustion zones near combustor walls, as well as using heatproof materials and advanced coatings.

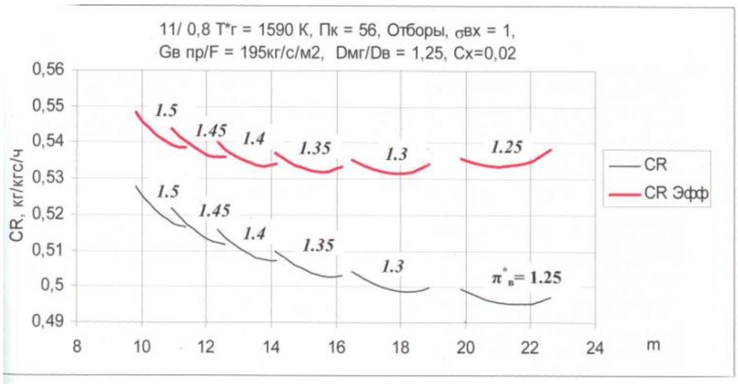

Fig. 2. Internal and efficient specific fuel consumption vs turbofan parameters

Technologies of *turbines* creation include: designing HPT first stages of composite or ceramic materials with high parameters and small corrected working body consumption $\eta^*_{HPT} \geq 0.92$; uncooled LPT with $\eta^*_{LPT} \geq 0.93$; advanced systems of cooling and internal cavities supercharge; active clearance control system; efficient air-air heatexchanger creation; new high effective low leaks sealing.

Integrating technologies for designing engine-demonstrator: small size core with high cycle parameters; low noise high efficiency light fan (polytropic fan efficiency $\eta^*_{pol} \geq 0.93$); variable nozzle with measures on jet noise reduction; variable LPC in gear turbofan; high rotation frequency bearings (D_{bear}); gearbox creation; new materials. The main problems of turbofan creation with high working process parameters are: small size core, high cycle parameters, small size blade machines efficiency; low emission combustors, cooling, and new materials. The advantages include a traditional turbofan configuration, balanced performance, level and sizes of mass characteristics.

Thereby, the key problem of creating advanced research backlog in provision of perspective high fuel economy turbofan production is technology development of low size blade machine cores with high cycle parameters, as well as studying on revision of small size flowpath of high pressure blade machines influence on their efficiency. In this respect a breakthrough efficiency rise of advanced blade machines, based on development and implementation of efficient and experimentally validated 3D design methods should be considered as one of the main factors in the problem of turbofan 2025-2030 creation. Also a key link of research backlog for advanced turbofans is creation of fireproof nonmetal structures for combustors and turbine blades, high-temperature alloys for disks, perspective low density materials and heat protection coatings.

Concerning available long range and regional planes of different seating capacity and flight range we explored application efficiency of the following aero engine configurations: turbofans with raised cycle parameters and high bypass ratios; turbopropfan with gearbox drive for twin-row rear propfan; turbofan engines of complex thermodynamic cycles and introduction in GTE working cycle of heat regeneration processes and intermediate air cooling at its compression in compressor; distributed powerplants including offset core and several thrust fans with mechanical transmission between them; hybrid turbofans with additional drive for fan shaft from an electric motor fed by electrochemical generator on solid oxide fuel elements.

When conducting integral efficiency estimation of the above mentioned powerplant configurations on efficiency criteria for available regional and long range aircraft we have developed a method for technical-economic level estimation of н unconventional powerplant schemes of available long range aircraft.

Besides, we updated thrust-economic and size-mass performance of various engine versions (turbofans, turbopropfans, distributed powerplants) of different size cruise powerplants for passenger aircraft 2025 - 2030: -twin regional jet (RA) with number $N_{pass} = 100$, flight range L = 3500 km ($M_{cruise} = 0.78$), one engine take-off thrust $R_{tareoff}$ = 6 tf; - twin SMRA with number $N_{pass} = 180$, flight range L = 5000 km ($M_{cruise} = 0.8$), $R_{takeoff}$ = 9 tf; - twin long range aircraft (LRA) with number N_{pass}= 300, flight range L = 14000 km ($M_{cruise} = 0.85$), $R_{tareoff}$= 22 tf; - hybrid turbofans are considered for aircraft generation level after 2030. Comparative analysis is organized for efficiency of the considered engine and powerplant variants on fuel efficiency and ecological factors versus technical risk regarding available regional and short-medium-long range aircraft.

Comparative estimations of fuel efficiency (fuel consumption on passenger-kilometer) executed for regional and long range aircraft with the considered alternative aero engine versions providing their thrust-economic and weight performance have shown the following: - aircraft with powerplants based on turbofans of 2025 level allow reduced fuel consumption level to 12.5-13.0 g/pass-km for regional jet; 9.0-9.5 g/pass-km for SMRA (Fig.3), and 12-13 g/pass-km for long range aircraft; - when using turbopropfans on regional aircraft one may expect additional reduction of fuel consumption in contrast with turbofans by 12% (11.0 g/pass-km)

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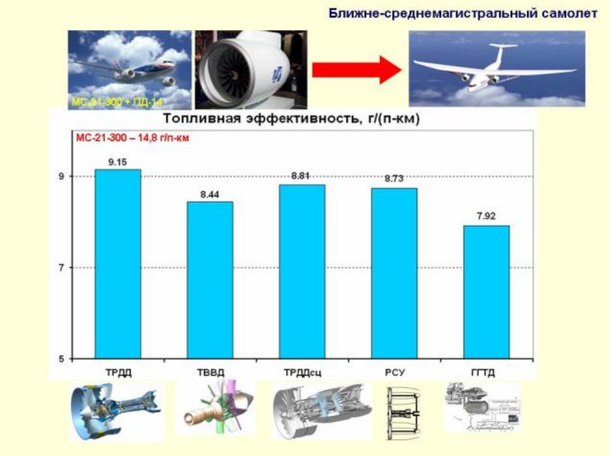

Fig. 3. Powerplant type vs SMRA fuel efficiency

For SMRA (M_{cruise} = 0.80) (Fig. 3) there is no unique expression about significant superiority of any scheme considered.

Analysis of fuel efficiency of 2025 and 2035 aircraft with turbofans and hybrid engines has shown that hybrid jet engines provide the plane an advantage in fuel efficiency in respect with turbofans aircraft in one time interval. However one should notice that hybrid engine specific weight is acceptable only with distant technologies after 2030.

Comparative analysis executed for engines and powerplants variants considered on technical-economic factors regarding the SMRA has shown that in contrast with 5th generation engines (PD-14) the usage of available engines (shown in Fig. 3) at condition of their equal procurement prices results in significantly lower expenses per standard flight and efficiency greater than by 20%.

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