Developing a critical technologies roadmap for next generation hybrid and electric commuter airplanes

A A Sukharev1, M A Ovdienko2, A N Varyukhin2, V S Zakharchenko2, S B Galperin3, A V Fomin3

1Intersectoral Analytical Center, Moscow, Russia
2Central Institute of Aviation Motors, Moscow, Russia
3NRC “Zhukovsky Institute”, Moscow Region, Zhukovsky, Russia

E-mail: varyukhin@ciam.ru

Abstract. Using hybrid and electric propulsion systems (HPS and EPS) as part of commuter airplanes provides a wide range of opportunities for creating fundamentally new aircraft configurations. The main idea is that HPS and EPS allow for flexible aircraft energy redistribution. Therefore, the propulsion system’s efficiency increases, which leads to a decrease of its environmental impact and improves its economic performance. The main barrier to implementing new HPS and EPS commuter airplanes concepts is the inadequate level of technological advancements. This paper covers the review of promising concepts of propulsion systems, and provides the list and the required level of technical perfection for technologies necessary for future commuter airplanes.

1. Introduction

The analysis of the 9-19-seat commuter aircraft projects confirms that for the next 5-10 years the list of types and the technical shape of commuter planes as well as technological level of their propulsion systems are clearly established. The types’ range will be based on existing Russian and foreign airplanes equipped with turboprop or piston engines, as well as on similar promising planes: Italian P 2012 Traveler, Indonesian N-219, American Cessna SkyCourier and Denali, Russian TVS-2DTS, LMS-901.

In a long term perspective, a significant increase in environmental, economic and operational requirements for commuter aircraft is expected after 2030. Promising aircraft should be capable of short takeoff and landing (STOL), should have low noise level and low emissions. At the same time technical requirements of the Russian and foreign commuter aircraft markets differ significantly: while the environmental requirements aren’t so strict, a greater flight range is required for Russian conditions.

Future technical requirements to 19-seater commuter aircraft for the Russian market include:

- range – 1500 km;
- maximum payload – 2100 kg;
- cruise speed, ensuring transportation of the maximum payload at a given range – 400 km/h;
- required runway length – 500 m, aerodrome class E with runway for maximum takeoff weight;
- fuel consumption per passenger-kilometer at full load – 24 - 28 g/(passenger-km).

Using the hybrid propulsion system (HPS) is a possible way of meeting these requirements, because it allows to combine a short takeoff capability with an increased range and flight efficiency. Two key advantages that HPS has over the traditional system, are:
possibility of a significant improvement in aircraft weight perfection and cruise efficiency due to the wide choice of airframe and HPS layouts, for example, using distributed propulsion system or powered high-lift systems;

possibility of reducing the cost per seat kilometer not only by reducing fuel consumption, but also by reducing aircraft price, labor intensity and frequency of maintenance due to the propulsion system’s gas turbine part’s rated power decrease, its structural simplification and period of service increase when using a single-mode engine.

The relevance of HPS commuter aircraft development is confirmed by a significant number of similar foreign projects. In addition to new aircraft with traditional propulsion systems, attempts to develop 9-19 seat aircraft with HPS are already being made.

The U.S. company Zunum Aero is implementing a project to create 12-seater ZA10 – HPS aircraft with a flight range of up to 1300 km and a declared operating cost of 8 cents/seats mile [1], which is 60–80% lower than that of the Pilatus PC-12 aircraft of the same size. The propulsion system of ZA10 will be based on 500 kW turbine generator built as a modification of the Ardiden 3Z turboshaft engine, which Safran planned to create specifically for this project.

A French startup VoltAero [2] is developing a family of HPS-equipped Cassio 4, 6 and 9-seaters based on Cessna 337. Its main feature is propulsion system configuration flexibility: flight to a range of up to 200 km will be possible entirely on electric traction, to a range of 200 - 600 km - mainly on electric traction and 600 km to 1300 km range can be reached in HPS mode. The total power of the Cassio propulsion system will be 60kW, half of which will be provided by electric motors and the other half by a piston engine.

2. The approach to creating HPS critical technologies list

In order to formulate development priorities and create a list of HPS critical technologies, an approach based on the roadmap methodology was applied. Main points of that approach in relation to planning aviation technologies development projects are described in papers [3, 4]. The main points that have been realised are:

- variants of HPS schematic diagrams (technical solutions, TS) were created;
- components, characteristics improvement of which has a significant impact on the compliance of the final product with the forecasted requirements, were identified in each HPS TS;
- critical technologies (CT), which provide a significant improvement of the components characteristics, were identified;
- for each CT the degree of its potential impact on the fulfilment of commuter aircraft technical requirements, the predicted dynamics of technology perfection characteristics and the technology readiness level relative to the value of the 2030 technical perfection level were qualitatively assessed;
- on the basis of these studies, HPS TS and corresponding CT were ranked according to their development priority degrees.

3. Propulsion systems concepts for next generation commuter airplanes

Currently, the following HPS and EPS schemes are distinguished:

a) Fully electric.

b) Turbo-electric:

- fully turbo-electric;
- partially turbo-electric.

c) Hybrid:

- series;
- partially series;
- parallel.
The fully electric propulsion system consists of electric motors that rotate propellers. Motors are powered by electric batteries. Such a system has two key advantages: easy maintenance and a significantly lower cost of electrical energy compared to aviation fuels. The disadvantage is the still relatively small specific battery capacity that significantly limits the range of fully electric aircraft. Taking into account the forecasted performance of those components the L-410-like full-electric 19-seater won’t have range of more than 200 km even by 2030-2035. That excludes the possibility to meet the range of 1000-1500 km required for 19-seat commuter aircraft to operate in Russia. Thus, it is preferable to focus on the development of turbo-electric and hybrid schemes.

The turbo-electric scheme involves using a distributed propulsion system, allowing to implement the powered high-lift system. One of the possible aircraft configurations for this type of a plane is a set of fans mounted along flaps and a deflected horizontal stabilizer. Fans are driven by electric motors, which are powered by a turbine generator. During takeoff, the fan-mounted flaps deflect creating lift. This arrangement allows for ultra-STOL implementation. After take-off, the flaps and the horizontal stabilizer are returned to a horizontal position to create thrust. In this case, the fans along the trailing edge remove the boundary layer from the wing, thereby reducing the aerodynamic drag. As a result, both ultra-STOL and high lift-to-drag cruise ratio are provided. The disadvantage of this scheme is its efficiency’s high dependency on the critical technologies’ performance level.

Another alternative is a parallel HPS with propellers located on the leading edge of the wing, which provides an additional wing blowing during takeoff and landing. This type of system not only allows to implement STOL, but also makes it possible to reduce the wing area and, thus, increase cruise efficiency. The disadvantage of this scheme is a significant increase in the mass of the system compared to the traditional one.

Another type of parallel HPS can be based on so-called hybrid turboprop engines (HTE). In this case, the hybridity of the engine means that an electric machine is integrated into the reduction gear, allowing to add power to rotate the propeller or, conversely, to use some of the free turbine mechanical power, operating in generator mode. Using electric batteries allows to adjust HTE power in a wide range with the same heat part, and, therefore, allows to significantly vary engine characteristics without changes in the hot section and in the power turbine. In this scheme, it is possible to turn off the gas generator of one engine, but continue to rotate its propeller by the electric machine integrated into the reduction gear, the energy to which will be supplied from the electric machine of the rest of HTE operating as a generator. The core of the second HTE will simultaneously be working in the maximum continuous mode and will provide rotation of both its own propeller, and the propeller of the other HTE with a turned off gas generator. Operating in the maximum continuous mode, HTE will have minimum specific fuel consumption in comparison to the cruise throttled mode of the traditional propulsion system based on two turboprop engines. Also, in this case the service period of the hot section will be increased.

The fourth possible scheme is a series HPS, which consists of a single turboshift engine rotating an electric generator, the energy from which is distributed to electric motors rotating propellers. There is enough engine and generator power to sustain a cruise flight with some reserve. Additional power necessary during takeoff and climb is provided by batteries. Such a scheme will have significantly lower fuel consumption and lower operational costs due to the use of a single heat engine, which will constantly work in its optimal mode.

4. Critical technologies required for the HPS concepts’ implementation

The main indicators of aircraft HPS components and systems’ excellence are their specifics (specific energy, specific power, etc.), weight and dimensions indicators. This paper highlights the most important technologies for each HPS component. Their development will lead to improvement in these indicators:

a) Batteries:
- developing new chemistry (mixed oxide and based on LiS technologies);
- mass production technologies for cells with advanced chemistry;
- technologies for creating fire-safe battery assemblies with thermostating systems;
• intelligent control and monitoring systems;
• developing preliminary power elements for emergency power supply.

b) Gas turbine engines:
• technologies for creating high-pressure single-stage compressors with a compression ratio of over 10:1 and two-stage centrifugal compressors with a compression ratio of over 14:1;
• high-temperature uncooled turbine blades made of advanced single-crystal alloys and composite materials (including ceramic and metal);
• using compact recuperators and developing design solutions for placing them in a gas turbine engine;
• non-traditional rotor bearings (hybrid, gas-dynamic, non-metallic composite, electromagnetic), providing rotational speeds of up to 100,000 rpm without oil cooling;
• resource-saving technologies for units and parts manufacturing (additive technologies, precision casting, electrochemical methods, friction welding, hardening methods);
• engine components made of composite materials (elements of hot and cold sections);
• "electrification" of a gas turbine engine (oil and fuel systems electric drives; starter generator built into the engine without a gearbox);

c) Power control, transmission and distribution systems:
• aircraft electrical devices (contactors, connectors, insulation, cables), designed for voltages exceeding 1000 V with the possibility of safe operation at altitudes from 0 to 10,000 m;
• power semiconductor switches (transistors, diodes) based on SiC with an operating voltage of more than 1500 V;
• compact thin-film capacitors with an operating voltage of more than 1000 V, a capacity of more than 500 μF and operating temperature of ± 60°C;

d) Electrical machines:
• new design and layout solutions for electrical machines, including those providing effective cooling and minimal weight;
• new soft magnetic materials with a saturation induction of more than 2.2 T and technologies for manufacturing stators of electrical machines using those materials;
• new materials for permanent magnets with a remanence of more than 1.3 T at a temperature of more than 100°C;
• technologies of waste-free production of magnetic assemblies with inhomogeneous magnetization;
• winding materials, including those based on carbon nanotubes, with an operating temperature of at least 300°C.

5. Conclusion

Electrical components’ characteristics currently achieved in Russia do not allow to create an HPS aircraft at the moment. However, in contrast to traditional propulsion systems, HPS technologies have a high potential of improving. In order to realize the potential of HPS and EPS and preserve Russia's competence in creating advanced civil airplanes, it is advisable to implement an aviation science comprehensive plan – a roadmap that will ensure the development of HPS technologies in Russia to the level required for their implementation.

6. References
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