Review and analysis of integration properties of an aircraft with a hybrid power plant

Vasyl Loginov[1], Oleksii Pushylin[2], and Oleksandr Tsaglov[1]

Abstract: A review of scientific and technical research in the field of aviation to achieve the goals of ACARE and Flightpath 2050 is made. It is emphasized that today's environmental protection in conditions of a large number of impact factors is and will continue to be a key driver in the development of aviation industry as a whole. Achieving the adopted development programs can be realized only with comprehensive improvement of the airframe and power plant, including on the basis of research into new breakthrough design and schematic solutions. They include the physical principles of power plant operation, in particular, the new scheme of hybrid turbo-electric power plant (HTEPP).

An overview and analysis of integration properties of the aircraft with HTEPP were carried out. The introduction of hybrid-electric technology expands significantly the design space of modern aircraft. The full potential of electric technologies will be used through the synergistic and systemic integration of subsystems of the regional aircraft. Ways of development of electrical technologies at enterprises in Ukraine are shown.

Keywords: integration subsystems, hybrid power plant, parametric shape, life cycle cost, operating efficiency

Nomenclature

ACARE	:	Advisory Council for Aviation Research and Innovation
EFACA	:	Environmentally Friendly Aviation for all Classes of Aircraft
EM	:	Electric Motor
HTEPP	:	Hybrid Turbo-Electric Power Plant
GE	:	General Electric
IATA	:	International Air Transport Association
ICAO	:	International Civil Aviation Organisation
MCU	:	Motor Control Unit

V. Loginov[1] (login_w@ukr.net), O. Pushylin[2], and O. Tsaglov[1]
[1]FED JSC, Programs and Projects Department, Kharkiv, Ukraine
[2]Ivchenko-Progress SE, Ground Application Installations Department, Zaporizhzhia, Ukraine
e-mail: login_w@ukr.net; pushilinae@ivchenko-progress.com; aitsaglov@fed.com.ua

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1. Introduction

The perspective of increasing efficiency through evolutionary approaches is already reaching the limits of development. This means that radical changes in conceptual and technological thinking are needed when creating new models of aviation technology, taking into account the lack of environmental impact. One of these methods is the use of electric power plant in an airplane, helicopter or UAV. Many aviation companies and organisations in the world have new development programs regarding electric on-board units (SAFRAN Press Kit, 2019; IATA, 2021). Most of the aircraft engine companies (e.g. SAFRAN, GE, P&W) have already started new programs to develop new components and units for engines (e.g. CFM RISE) powered by alternative fuels (biofuel, synthetic fuel, electric fuel), synthetic fuel mixed with kerosene, hydrogen gas or hydrogen liquids. The results of hydrogen technology applications are expected by 2030 on board aircrafts.

To achieve the Flightpath 2050 goal (Flightpath 2050, 2011), most aviation companies are combining for collaborative research and integral implementation of promising technologies. For example, complex scientific and technical task was jointly solved with some organisations or companies during the implementation of Horizon Europe programs (Horizon, 2023; Clean Sky 2, 2020) together. An analysis of modern research on the development of aircraft has shown that the use of hybrid technology when creating a power plant as part of an aircraft is the main method for achieving better performance (Kiruba, 2021).

2. Problem Analysis and Research Methods

It is known, two main subsystems are distinguished in a modern aircraft: the airframe and the hybrid power plant. These subsystems have the greatest influence on the flight-technical and economic characteristics of the aircraft.

The hybrid power plant is a separate complex technical subsystem in terms of the complexity of physical processes occurring in flight, which determines the main flight and technical characteristics of the "flying vehicle" system. In order to reduce the impact of aviation on the environment, new methods and ways of creating hybrid power plants based on:

- application of battery and turboelectric schemes (hybrid technologies),

- direct combustion of hydrogen or hydrogen mixes in the combustion chamber,

- application of hydrogen fuel cells powering electric motors.

In this case, the choice of the main indicator or criterion for the integration of a hybrid power plant as part of an aircraft is a complex task. The analysis of methods and approaches shows that the integration of a hybrid power plant as part of an aircraft is a multi-criteria and multi-disciplinary task (Shmyrov, 2020). Therefore, the problems of system analysis of the hybrid power plant as part of an aircraft are closely related to each other. The authors developed special mathematical methods, algorithms and models, providing the use of a wide database, the ability to analyse the influence of a large number of factors, as well as optimization of parameters, taking into account alternative criteria and many limitations.

As is known, the creation of the airframe is currently carried out separately from the creation of a hybrid power plant. However, the creation of a single airframe with high technical characteristics is not a guarantee of high flight and technical characteristics with the intended hybrid power plant, since the flight data of the aircraft always differ from the calculated ones. This is due to the appearance of new integrative properties of mutually influencing two subsystems - airframe and hybrid power plant. The combination of subsystems characteristics in their interconnection at the level of work processes determines the properties of the aircraft as a whole.

In order to obtain the characteristics of a hybrid power plant as part of an aircraft, the stages of integration are investigated: parametric, criterion, designing and technology. The complexity and importance of technical decisions regarding the definition of integration properties can be seen in the example of the life cycle of an aircraft (Fig. 1). We see interconnected processes from the conception phase of an aircraft to the end of its operation.

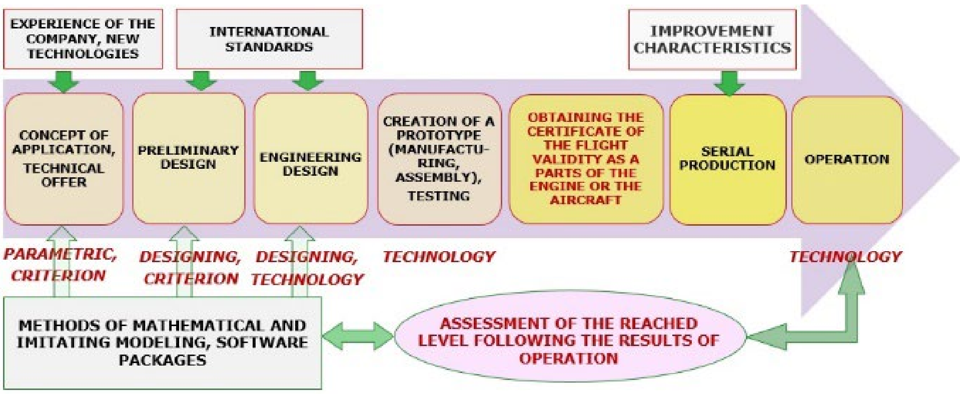

Fig.1. The stages of integration of the airframe and hybrid power plant in the life cycle an aircraft.

Analysis results of modern technical solutions regarding the creation of a hybrid power plant (Schmuck, 2019; Palladino, 2021) show that characteristics of electric motor (EM) is important part of electric aircraft. Therefore, research and obtaining effective technical and economic characteristics of EM is an important part of the creation of HTEPP (Moebs, 2022; Marciello, 2023).

3. Study of EM design characteristics

To evaluate the level of technical implementation of the future design, the characteristics of EM from different manufacturers were analysed. Preliminary research was carried out to develop an advanced electric motor for a hybrid power plant. Issues on the key characteristics of electric motor, its control system and software/hardware were considered. As a result of research, the possible configurations of an advanced EM and its characteristics are received (Fig. 2).

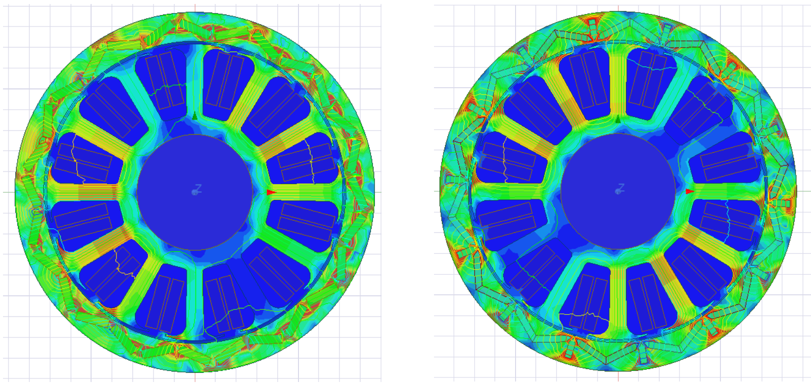

Fig.2. Study of specific rotor configuration of EM
(magnetic inductance and field line distribution in electric motor section)

The features of proposed EM are outrunner architecture, NbFeB permanent magnets, specific rotor configuration with inner magnets location, which are obtained during multidisciplinary development (electromagnetic, thermal and strength analysis in Ansys Electronics, Ansys Workbench and custom programs).

EM control systems (separate and integrated configurations) have state of the art IGBTs and SiC MOSSFETs, redundant fault tolerant design with high specific power ratio, multidisciplinary development (Altium Designer, Simulink, Ansys Electronics, etc). Hardware and software are based on model-based development for airborne application (ARP4754, DO178, DO254, DO331 complies).

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4. Conclusion

Based on the study of two prototypes of electric motors with different initial configuration, the results for them are obtained. When evaluating a prototype with output power - 120 kW, operation speed - 20,000 rpm, supply voltage - 540 V DC, specific power rate >8 kW/kg, with rotor position sensor, the estimated weight is about 15 kg (EM + microcontroller). When evaluating a prototype with output power - 150 kW, operation speed - 20,000 rpm, supply voltage - 800 V DC, specific power rate >12 kW/kg, with integrated sensorless control system, the estimated weight is about 12 kg (EM + MCU).

The volumetric characteristics of EM and the place of installation as part of the hybrid power plant will be specified in the following studies.

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