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Analysis of progressive technologies for reducing aircraft emissions

The paper is focused on the analysis of technologies for reducing global and local emissions from aircraft to achieve the strategic goals of ACARE and ICAO/CAEP

Strategic goals

Today ICAO is concerned with international aviation GHG emissions as of highest priority. Ambitious goals, unveiled by the European Commission with the Strategic Research Innovation Agenda (SRIA) – Flightpath 2050 challenges and goals, are confronting the aviation community with new challenges in aircraft design and operation due to new technologies implementation (Table 1). Those goals are targeting significant power efficiency, emission and noise reductions for future aircraft, so the aviation sector is likewise under governmental and international pressure to reduce further the impact on environment significantly.

Table 1. Comparison of long-term goals for environmental impact factors of aviation between the Policy of ICAO and EU on Research and Development

Environmental impact factor from aviation	**ICAO Policy Goals** [1]	**EU ACARE Goals** (*FP2050* till 2050) [2]
Noise	***Limit or reduce the number of people affected*** *by significant aircraft noise*	***Perceived noise*** emission of flying aircraft ***is reduced by 65%***
NO_x emissions	***Limit or reduce the impact of aviation emissions*** *on local air quality*	***90% reduction in NO_x emissions***
Greenhouse gas emissions and fuel/energy consumption	***Limit or reduce the impact of aviation greenhouse gas emissions*** *on the global climate***:** a ***reduction in net aviation CO_2 emissions of 50%*** by 2050, relative to 2005 levels	***75% reduction in CO_2 emissions*** per passenger kilometer

Strategy development to achieve environmental targets in aviation sector by evolutionary and revolutionary technology solutions highlighted on a necessity to formulate midterm and long-term goals, especially in part of climate change impact of aviation.

Thus, additionally to ACARE goals, CAEP within the standard-setting process established the technology goals for NOx regulation [3, 4]:

• The medium-term goal (2016) was agreed at 45%±2,5% below CAEP/6 at OPR 30;

• The long-term goal (2026) was agreed at 60%±5% below CAEP/6 at OPR 30.

The mentioned goals determine a design space for engine combustion technologies to reduce both NOx emissions and fuel flow rate.

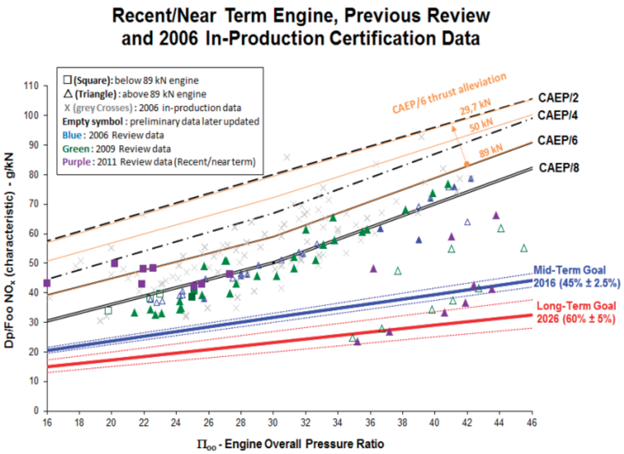

Fig.1. Historical ICAO certification Standards together with 2006 medium-term and long-term goals

Fig. 1 demonstrates a large gap between the goals and last regulatory limits. Also, it was found, that long-term aims to achieve NOx reduction should be based on the implementation of progressive technologies, while standards, on the other hand, are based on already certificated technology. It is important to note, that some engines certificated since 2008 are already close to mid-term and long-term technology goals.

The aircraft designed to provide high cruise efficiency and low global emissions involves the implementation of progressive technological solutions, both in the design of the aircraft (sweptback wing) and in the design of the engine (high gas speed from a jet engine) to provide high cruise speed, small fuel consumption and emission reduction. Long-terms programs are concentrating on the improvement of engine efficiency via application new combustion chamber technologies, sensor and cooling technologies that permit the engines and auxiliary power units to save 15% of fuel [4].

Advances in engine combustion design

Last advances in engine combustor design lead to significant reduction of NOx emission and subdivided on the 2 categories:

• RQL (rich burn, quick quench, learn-burn) combustor, which controls NOx emission by regulation of air to fuel ratio;

• Staged -DLI (direct learn injection) combustor, which control NOx emissions by switching (staging) between the pilot and main burner zones arranged in concrete circle.

Application of the reached Single Annular Combustors with rich burn (air blast) injection, Double Annular Combustors/Axially Staged Combustors and Lean Burn Combustors lead to progress up to 70-75% reduction of NOx emissions at TRL3 relative to the CAEP/2 certification standard ICAO CAEP has encouraged the research initiatives to further improvements in part of 70-85% reduction at higher TRL[3].

The level of emissions of nitrogen oxides depends on the rate of their formation, which in turn exponentially depends on the gas temperature and the presence of free oxygen. The key to reducing nitrogen oxide emissions is uniform and rapid mixing of fuel with air. The use of ceramic composite materials and heat-protective coating allow to with stand higher temperatures than traditional ones, and also ensure the use of additional air in the fuel injector to increase the mixing of fuel and oil, which guarantees a more homogeneous mixture with fewer local hot spots. In addition, the application of a heat-protective coating protects the surface of ceramic composite parts from oxidation, reduces the temperature regime of the flame tube and extends the engine life.

NASA project "Environmentally Responsible Aviation" (ERA) [5] with industry involvement was focused on the development the progressive technologies of fuel combustion particularly for low emission combustion chambers to meet CAEP 6 regulatory requirement at target levels for the engine N+2 generation.

The considered above combustion technologies were realized within technological programs of Gens for the traditional design of Twin Annular Premixing Swirler (TAPs). TAPS design allow to combine two combustion areas in a single volume of the flame tube: one implements the diffusion combustion pattern and weak one -with the combustion of the well-premixed practically homogeneous fuel-air mix. Such innovation allow to decrease combustion product temperature (approximately by 50%), to improve combustion efficiency and reduce NOx emissions.[4].

The radical changes are expected in the engine architecture in the long-term prospects. For example, engines with two counter-rotating self-sustained fans (*open rotor engines*) that permit to reduce fuel consumption and CO_2 emissions by 30% compared to modern engines of type CFM56. Thus, demonstrator of Open Rotor was developed by SAFRAN [6] with Clean Sky program.

Currently, some researches continue efforts to find the optimum design of the nozzle jet which allow to apply jet-A fuel and alternative fuels to reduce NOx emission level [7].

Electric aircraft

Electrification is not only way to reduce global/local emissions, but also it is the capability unlock the potential for more energy-efficient aircraft and brand new architectures for propulsion systems.

Electrification of aircraft systems has been implemented in following directions:

1.More Electric Aircraft (MEA) is evolutionary trend, which aims to replacement of mechanical, hydraulic and pneumatic systems by equipment that is more electric. Such solution increases the total electric energy consumption and decreases the onboard equipment weight. Electric energy contribution of each successive generation of aircraft has increased with the Boeing 787 (electric loads needs almost 1000 kVa in 5 times higher than conventional A320), fig. 2 [4].

2.More Electric Engine (MEE) assumes electrification of hydraulic and mechanical pumps and actuators in the engine.

3.Another trend aims to switch from constant frequency generation derived from a constant speed gearbox and generator to variable frequency generation with power electronics to convert the electric output to the various frequencies and voltages required by electrical equipment.

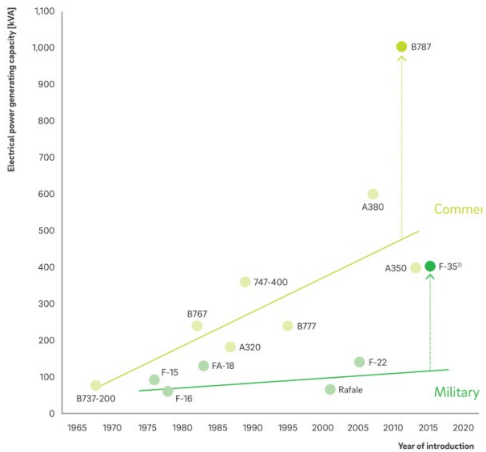

Fig.2. Electric power generating capacity by introduction year (kVa) [4]

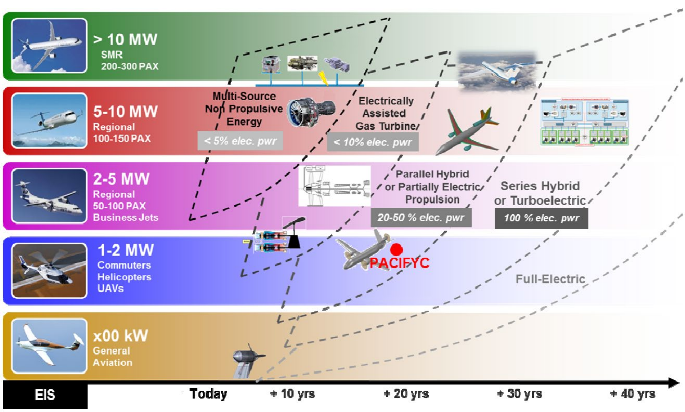

Fig.3. Trends of possible aircraft hybrid architectures at different installed power plants, used from [9]

Up to date a number of new applications were launched worldwide for the four aircraft groups – General Aviation (or Recreational) Aircraft (GA) for 1-10 passengers/pilots, Urban Air Taxis (UAT, aircraft with vertical take-off and landing – VTOL - the groundbreaking eVTOL technology has become a major focus of urban air mobility solutions and promises to become a reality in the near future, as it offers several advantages over conventional helicopters [8]) with similar number of people on board, Regional/Business Aircraft (RA/BA) for 10-50 passengers and Large Commercial Aircraft (LCA) for 100-150 passengers on board. All of them are the starting points in existing roadmap for electrification of the aircraft, as shown in Fig.3, most of them are planned to entry in service in nearest decade 2020-2030, but some of them are already commercially available even now.

Developing more electric, hybrid, and full electric aircraft became one of the most important research directions today [10]. This will include the benefits of changes to technology embedded onto aircraft, including the coming revolution in full electric (use batteries and generators as the only power source on the aircraft, including for the propulsion) or hybrid electric power for aircraft and other offenders like the possibilities of urban air mobility vehicles. In this way, an electrification of the aircraft has the potential to revolutionize the aviation industry as a whole, providing its less impact on environment.

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