DOI: 10.13009/EUCASS2019-847

PARE preliminary analysis of ACARE Challenge 3 environmental impact goals (towards quieter and cleaner environment in aviation sector)

Oleksandr Zaporozhhets, Volodymyr Isaienko, Kateryna Synylo, Sergiy Dmytriyev***
**National Aviation University,*
1, avenue Cosmonaut Komarov, Kyiv, 03058, Ukraine
zap@nau.edu.ua
***StateEnterprise "Ivchenko-Progress", Ukraine*

Abstract
Aviation is recognized as one of the top advanced technology sectors in Europe and generates innovation that benefits society at large far beyond its direct operational sphere. Environmental protection is and will continue to be a key driver for the aviation industry as a whole. Meeting community expectations on aircraft noise, engine emission and fuel/energy consumption has always presented a challenge to aircraft and engine manufacturers and to those involved in airport planning and air traffic management. The paper describes the current points of the EU civil aviation on a way to FlightPath 2050 Challenge 3 goals, defined in PARE project at initial stage.

1. Introduction

Aviation is recognised as one of the top advanced technology sectors in Europe and generates innovation that benefits society at large far beyond its direct operational sphere. It provides close to twelve million skilled jobs, directly and indirectly, and contributes over 700 billion euros to Europe's gross domestic product [1]. Home to some 400 airlines and nearly 700 airports, European aviation plays a key role in serving society's needs for safe, secure and sustainable mobility in Europe and all over the world. Its impact on the wider European economy is significant and must be sustained.

EU aerospace research towards *Flightpath 2050* goals [2] faces several challenges. Environmental protection is and will continue to be a key driver for the aviation industry as a whole. The challenge with respect to the environment is to reduce continuously the environmental impact in the face of continuing expansion in demand for aviation. This expansion will also put pressure on existing energy supplies. In 2050 technologies and procedures available allow a ***75% reduction in CO_2*** emissions per passenger kilometre and a ***90% reduction in NO_x emissions***. The ***perceived noise emission of flying aircraft is reduced by 65%.*** These are relative to the capabilities of typical new aircraft in 2000 (Table 1).

ACARE will continue to foster the need to monitor achievements and progress on the SRIA objectives. As an example, in 2015 the ACARE working group on energy and environment estimated that EU aviation sector had secured an overall 38% reduction in CO_2 per passenger-kilometre against a goal of 50% reduction goal for 2020. Similarly, technical solutions showed a potential reduction of 37% in perceived noise has been achieved against a goal of 50%, also by 2020. Whilst this represents significant progress, effort must be further strengthened to meet the even more challenging goals for CO_2, noise and NO_x emissions set for 2050 [1].

2. Air traffic and correspondent impact on environment forecasting

In 2017, 1 043 million people in the EU travelled by air, an increase of 7.3 % compared with 2016, and 6,7 % increase in 2018 (6,4 % increase globally) – air travel growth has eased in comparison to the strong upward trend seen in 2017, but still continue to go along Regulation and Growth Forecast (Figure 1). Strong and broad-based traffic growth in 2017 across all market segments finally took European flight totals over the 2008 peak, to 10.6 million. Indeed, even 4% growth in flights in 2017 looks modest compared to almost twice that reported for passengers or passenger-km. Current growth is certainly supported by strong demand. This growth has brought traffic back to the most-likely scenario from the 2013 forecast (after double-dip decline in 2008 – Figure 1).

DOI: 10.13009/EUCASS2019-847

Table 1: Comparison of long-term goals for environmental impact factors of aviation between ICAO Policy, EU and USA Research and Development agenda

Environmental impact factor from aviation	**ICAO Policy Goals** [3]	**EU ACARE Goals** (*FP2050* till 2050)	**US FAA and NASA Goals** (*NSTC2010* [4] and *CLEEN II* [5] till 2035)
Noise	***Limit or reduce the number of people affected*** *by significant aircraft noise*	perceived noise emission of flying aircraft ***is reduced by 65%***	***52 dB reduction*** relative to cumulative margin of ICAO/FAA Stage 4 noise limit (a 25-year goal, by enabling N+3 aircraft and engines)
NO_x emissions	***Limit or reduce the impact of aviation emissions*** *on local air quality*	***90% reduction*** in NO_x emissions	***80% reduction*** in NO_x emissions (for cruise relative to 2005 best in class and for LTO relative to ICAO CAEP/6 standard)
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 kilometre	***60% reduction in Aircraft Fuel/Energy Consumption*** (*CO_2 emissions per passenger kilometre?)* relative to 2000 best in class

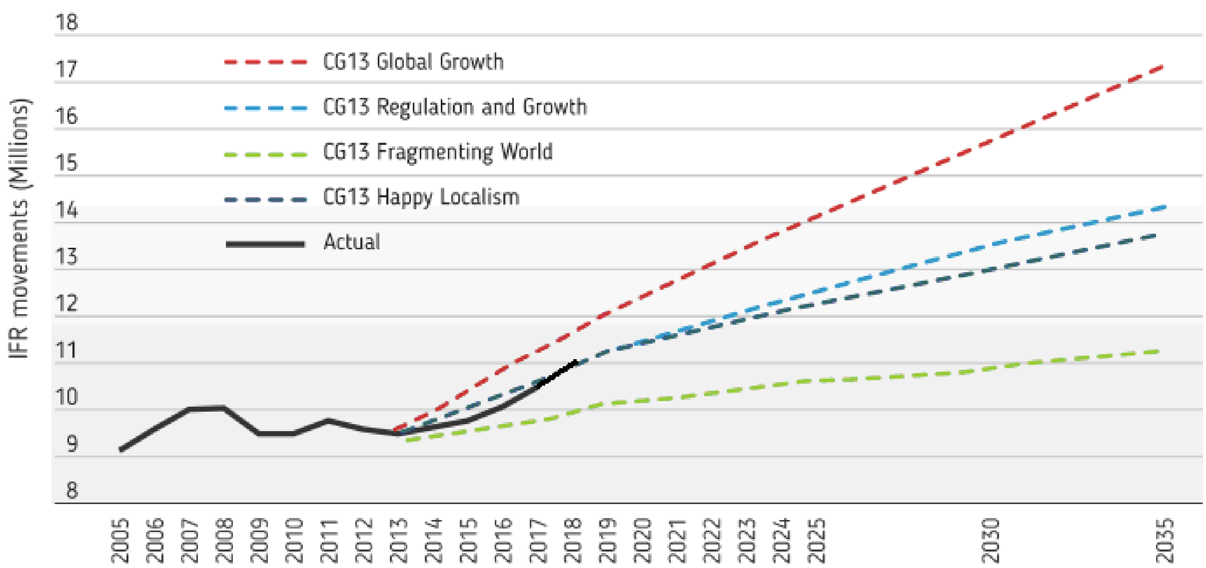


Figure 1: In 2017-2018, strong growth saw traffic back on the most-likely scenario from the 2013 forecast, modified from [6]

All such forecasts in flight traffic, and accordingly - airport operational capacity limitations, enroute congestion provide the conditions for a growth of impact of aviation on environment. The Challenges of Growth 2018 environment report [6] describes the background and impact in more detail. It also begins to address some of the adaptation measures that are available.

The local environment agenda for aviation is driven largely by noise and occasionally by local air quality impacts, whereas the national and international agenda is primarily focussed on climate change and carbon dioxide emissions. In carrying out its responsibilities, ICAO and its Member States will strive to limit or reduce these dominant and prioritised impact factors (Table 1). Meeting community expectations on aircraft noise, engine emission and fuel/energy consumption has always presented a challenge to aircraft and engine manufacturers and to those involved in airport planning and air traffic management. To achieve these targets, all (governmental and industrial) stakeholders agreed to closely work together along a four-pillar strategy:

- *Improved technology*, including the deployment of sustainable low-carbon fuels;

DOI: 10.13009/EUCASS2019-847

- More *efficient aircraft operations*;
- *Infrastructure improvements*, including modernized air traffic management systems;
- *Actions* within the aviation sector *to adapt and develop resilience* to the current and future impacts of climate change
- A *single global market-based measure*, to fill the remaining emissions gap.

Continued efforts may stabilize noise exposure by 2035-2040, but it will continue to be a key challenge. Noise exposure has stabilized over the past ten years. The total population inside the L_{den} and L_{night} contours decreased by only 2% (L_{den}) and 1% (L_{night}) between 2005 and 2014, to reach 2.52 and 1.18 million people respectively in 2014 (EUER 2016), and 2.58 and 0.98 million people respectively in 2017 (Figure 2, [7]).

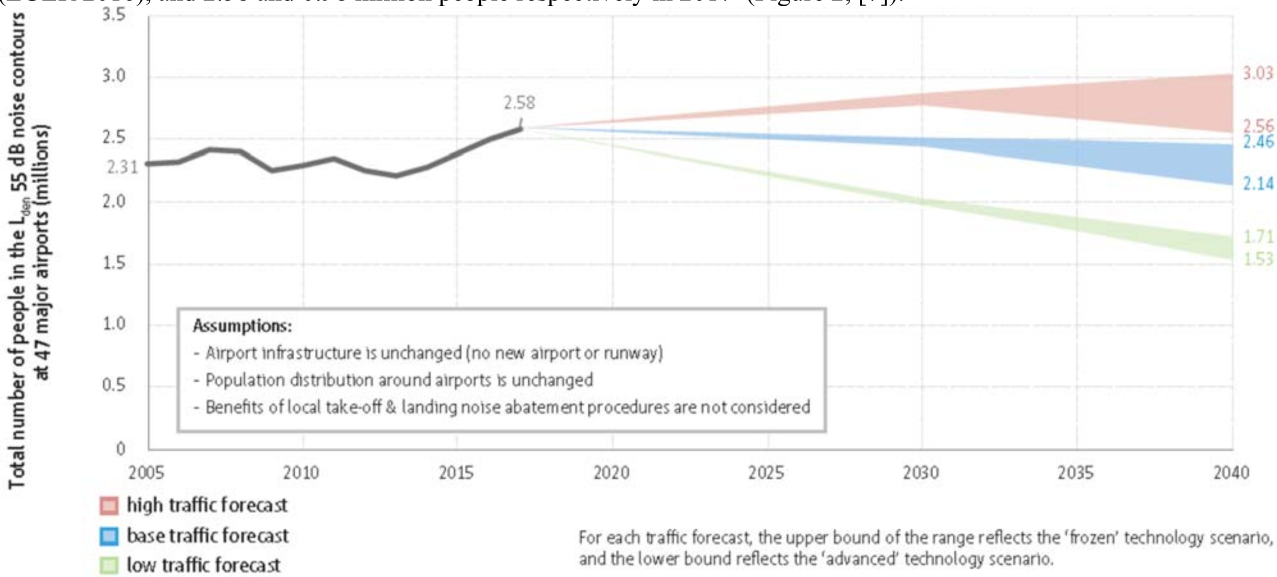


Figure 2: Fleet renewal could stabilise average noise levels at today's 47 major airports by 2030[7]

The EU plays a leading role in international efforts to limit climate change, and increased its climate finance contributions to €20.2 billion in 2016. This is backed up by a legally binding commitment and legal framework at EU level to reduce greenhouse gas emissions, increase the use of renewable energy and improve energy efficiency [7]. Due to fleet renewal, emissions of CO_2, NO_x, HC, CO and PM have been relatively stable between 2005 and 2014 (Figure 3). However, nvPM emissions are expected to increase over the next twenty years if engine technology remains as it is today (it is expected *(+25% growth till 2040*). The 'climate and energy' targets for 2020, which the EU is on track to meet, and 2030 are shown below [7]:

2020

20% cut in greenhouse gas emission (from 1990 levels)
20% of EU energy from renewables
20% improvement in energy efficiency

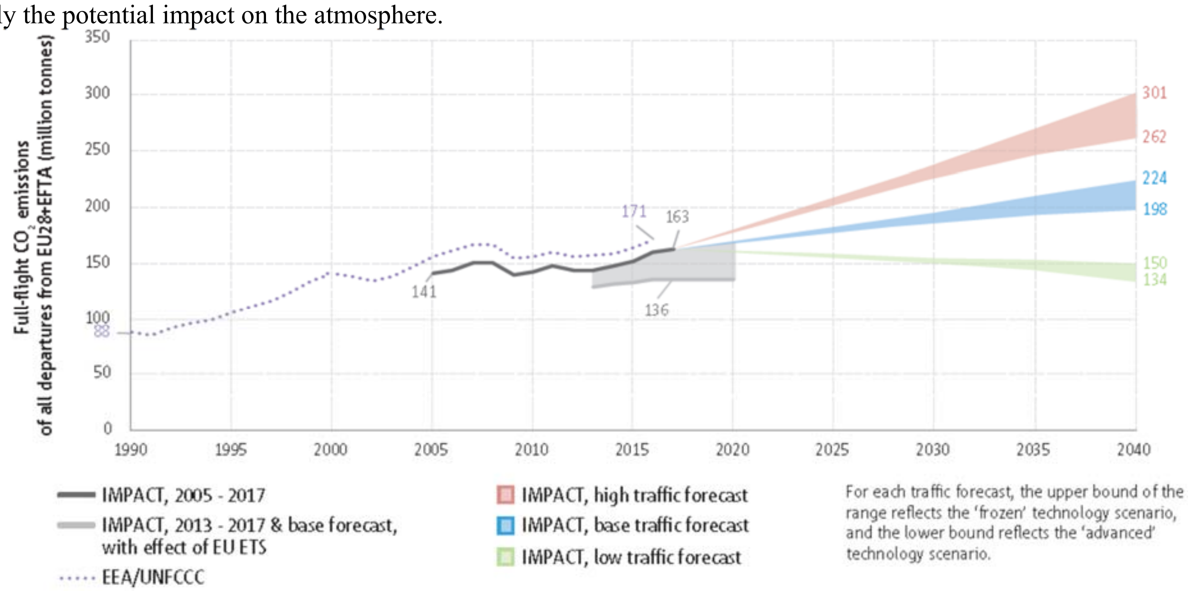
2030

At least 40% cut in greenhouse gas emission (from 1990 levels)
32% of EU energy from renewables, with an upwards revision clause by 2023
32.5% improvement in energy efficiency, with an upwards revision clause by 2023
The EU has also agreed on a '2050 low carbon economy' roadmap that suggests the following targets:
60% cut in greenhouse gas emission by **2040** (from 1990 levels)
80% cut in greenhouse gas emission by **2050** (from 1990 levels), including a 60% reduction in transport emissions.

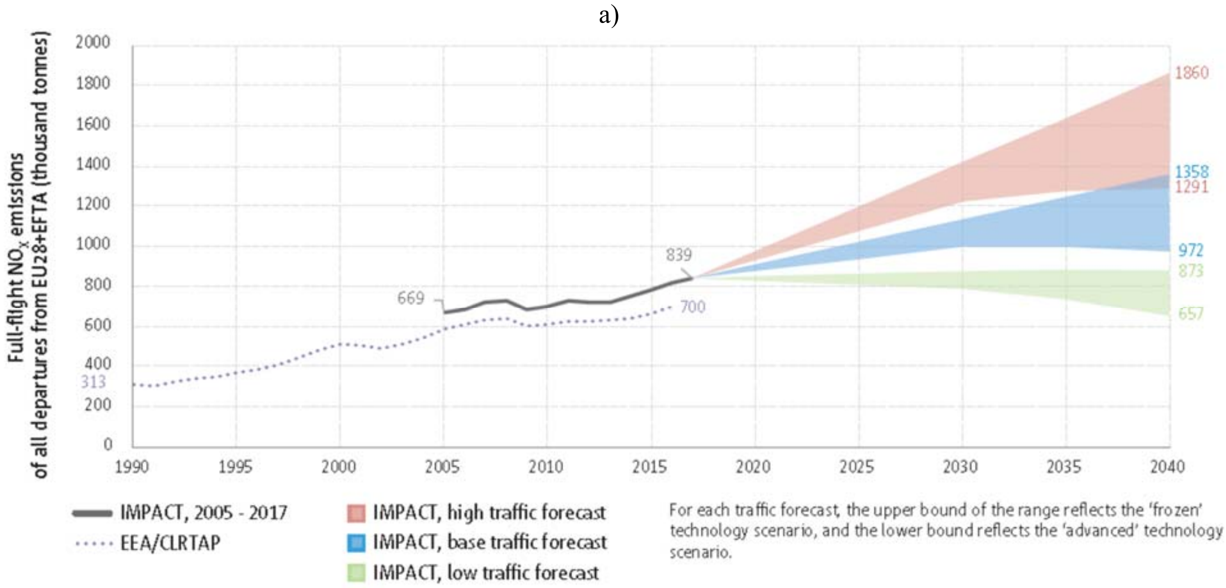
It is clear from available studies that these goals cannot all be achieved using evolutions of currently available technologies. Research and innovation for evolutionary aircraft development will drive progress in environmental performance to be on track towards the FP2050 goals. Changes will be introduced in new aircraft or by retrofit into the growing civil aerospace fleet. It is also essential that such technology roadmap and its implementation must continue to receive support through government policy and that it remains a priority for European society (Figure 4). To achieve the 2050 goals, step changes in aircraft configuration and operation (including alternative energy sources) will be required - currently envisaged evolutions will not be sufficient [1]. For example, noise and emissions reductions can be achieved only if sufficient efforts are made for new technologies to mature; the transition from technology availability to technology uptake in a product or system is influenced by many factors; besides technology maturation, certification, sustainability and cost-effectiveness. There are also factors of a non-

DOI: 10.13009/EUCASS2019-847

technological nature such as market expectations, new products or improvements being developed. Towards 2050, the forecast growth in the aviation industry will drive the need to deliver revolutionary technology solutions at an increasing rate and secure the path to sustainable energy supplies that can displace today's fossil fuels to mitigate fully the potential impact on the atmosphere.



a)



b)

Figure 3: emissions are steadily increasing again since 2013: a) CO_2, b) NO_x will increase further, but advanced engine combustor technology could help curb their growth after 2030 [7]

3. Technology Readiness Level assessment

One of the biggest challenges in managing technology is to properly choose which technologies to invest in and to know when technologies are ready or mature enough to be considered for a particular system/product. There are not plenty of metrics and tools developed to measure how ready a technology is. The most universally accepted methodology for assessing the upward slope of this curve is the *Technology Readiness Level* (TRL) *scale* - a systematic, metric-based assessment of how far technology development has progressed. TRLs are used to quantify the technology maturity status of an element intended to be used in a mission in accordance with Standard ISO 16290, 2013. The timeframe to 2050 leaves scope to mature what is now low TRL basic research to promising high TRL demonstrations and feasible solutions to meet aviation targets.

DOI: 10.13009/EUCASS2019-847

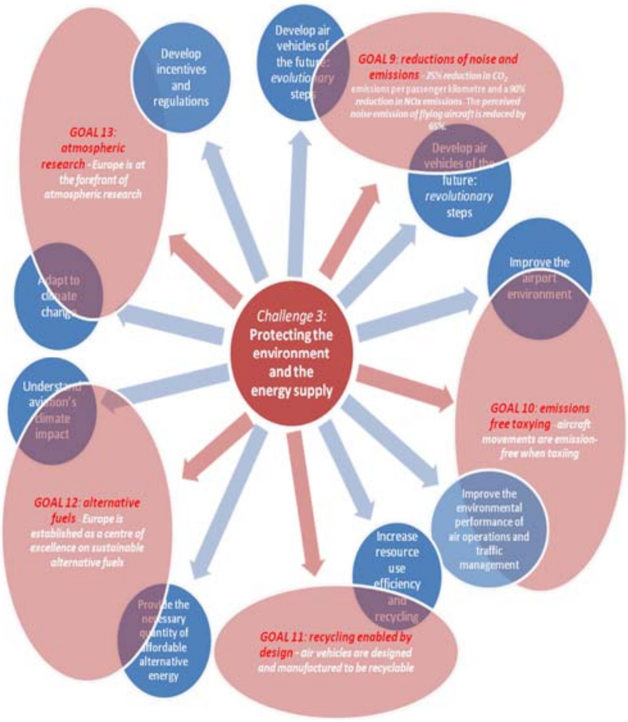


Figure 4: The goals and action areas for *Challenge 3* of the ACARE perspectives

An approach by consensus based on expert's judgement, assessment of the TRL situation and results from the technology evaluation exercises has then been used to perform the 2015 progress assessment, coming up with updated progress achievement figures and formulating associated recommendations for future research. Recommended Phased Approach to meet ACARE Noise Goal #9 includes analysis of expected advances on noise reduction with Noise Reduction Technology 1 (NRT1) and NRT2, as well as the Noise Abatement Procedure. For example, NYSERDA TRL Calculator results for analysis and assessment of ***ACARE Challenge 3 Goal 9*** "Reduction of Noise and Emissions" achievements at 1st stage of the researches on PARE Project are shown in Figure 5 grounding on the results of the 1st year PARE report.

Category	Answer
Technology	Preliminary testing of technology components has begun, and technical feasibility has been established in a laboratory environment
Product Development	Demonstration of a full scale product/system prototype has been completed in the intended application(s)
Product Definition/Design	The product/system has been scaled from laboratory to pilot scale and issues that may affect achieving full scale have been identified
Competitive Landscape	Competitive analysis to illustrate unique features and advantages of the product/system compared to competitive products/systems has been completed
Team	Balanced team with technical and business development/commercialization experience running the company with assistance from outside advisors/mentors
Go-To-Market	Market and customer/partner needs and how those translate to product requirements have been defined, and initial relationships have been developed with key stakeholders across the value chain
Manufacturing/Supply Chain	Manufacturing process qualifications (e.g. QC/QA) have been defined and are in progress

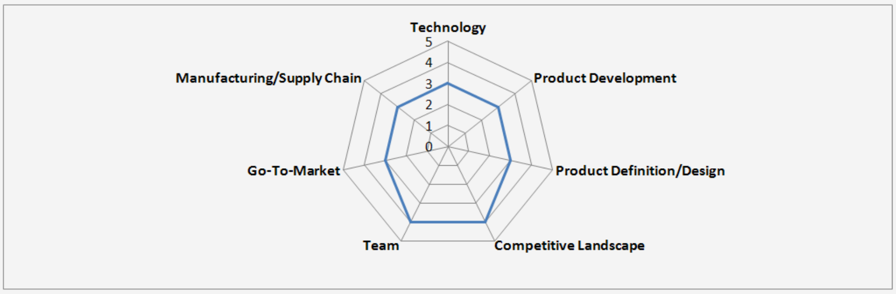


Figure 5: NYSERDA TRL Calculator results for analysis and assessment of ACARE Challenge 3 Goal 9 "Reduction of Noise and Emissions"

DOI: 10.13009/EUCASS2019-847

Current and future technological developments to achieve the challenging ACARE 2050 CO_2 goal are essential to mitigate substantially the increase of aviation CO_2, with realistic traffic growth assumption (Figure 6). A large part of the effort of the last decade was supported within EU Clean Sky, and within other European projects like LEMCOTEC, ENOVAL and E-BREAK.

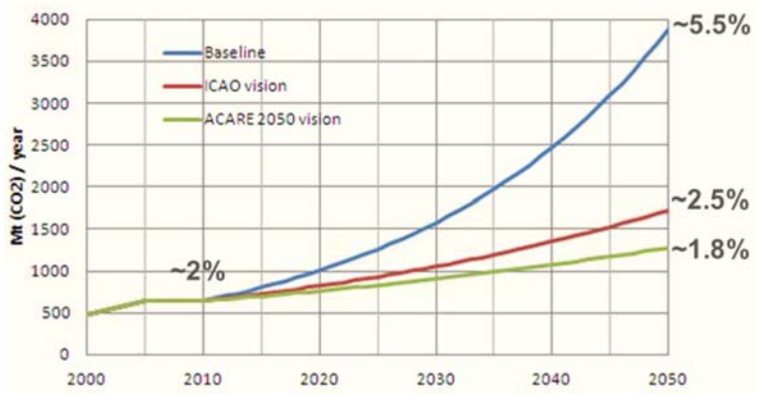


Figure 6: Global aviation CO_2 forecast with ACARE assumption [8]

A new assessment was performed against ACARE CO_2 and NOx goals and is summarized in the following Table 2. Although, there is no ACARE objective related to ultrafine particles, this is now a key environmental and regulatory concern, which requires appropriate mitigation solutions (combustor technology and fuel composition).

Table 2: FORUM-AE assessment against ACARE emissions goals [9]

	Reference 2000	ACARE 2020 Goals (at TRL6)		ACARE 2050 Goals (at TRL6)	
		High Level	detailed (SRA)	High Level	detailed (SRIA)
CO2	*Representative technology of aircraft & engine with 2000 EIS, & representative 2000 ATM*	"-50% per pass km"	aircraft: -20% to -25% engine: -15% to -20% ATM: -5% to -10%	"-75% per pass km"	aircraft & engine: -68% ATM: -12% Other: -12%
NOx (LTO)		"-80%"	engine: -60% CAEP6 ; complement achieved by aircraft + ATM	"-90%"	engine: -75% CAEP6 ; complement achieved by aircraft + ATM
NOx (Cruise)		"-80%"	Achieved through -50% Fuel Burn & -60% cruise EINOx reduction	"-90%"	Achieved through -75% Fuel Burn & further cruise EINOx reduction
Other emissions		"damaging emissions reduced"	emissions qualitatively reduced (particles, CO, UHC) and better understanding of impacts	"emissions-free taxiing" + qualitative reduction	knowlegde of emissions (particles, VOC) and better understanding of impacts

4. Aircraft electrification nowadays and in future

Stepwise development to meet environmental targets in aviation sector – evolutionary and revolutionary technology solutions to be researched and implemented – provides a necessity to formulate midterm and long term goals, especially driven by climate change impact of aviation. For example a concept of More Electric Aircraft (MEA) covers a number of technologies to be introduced in aircraft control in flight during nearest decades (midterm goals for emission reduction and energy supply). Full Electric Aircraft (EA) concept is considered like a subject of deep concern for the last decade (long term goals) in progress to 2050 achievements. Complexity of the Challenge 3 towards *FlightPath 2050* creates the conditions when/where new evolutionary and revolutionary technology achievements are expected in all spheres of aviation sector – aircraft design and manufacturing, their operation and maintenance, including airport and ATC infrastructure and procedures.

New technologies will bring change, challenge and opportunity, too. This will comprise harnessing the benefits of changes to technology embedded onto aircraft, including the coming revolution in full-electric (use batteries as the only source of propulsion power on the aircraft) or hybrid electric power for aircraft and other disruptors like the possibilities of urban air mobility vehicles. Electrification of aircraft has the potential to

DOI: 10.13009/EUCASS2019-847

revolutionize the aerospace and aviation industries. Up to date a number of new programmes were launched for the four types of aircraft – General Aviation (GA)/Recreational Aircraft, Urban Air Taxis (vertical take-off and landing aircraft), Regional/Business Aircraft and Large Commercial Aircraft (LCA). Most of them target an entry-in-service date between 2020-2030, although some are already commercially available. The design and usage optimization of electric propulsion architectures over a range of aircraft designs and series of missions is complex (Figure 7). Electrical propulsion is finally on the map: almost 100 electrically propelled aircraft are already in development globally. Most developments are currently working on general aviation or urban air taxi architectures. Given the current state of technological advancement, this is unsurprising as these smaller architectures require less total power and are less limited by constraints such as battery and motor gravimetric densities.

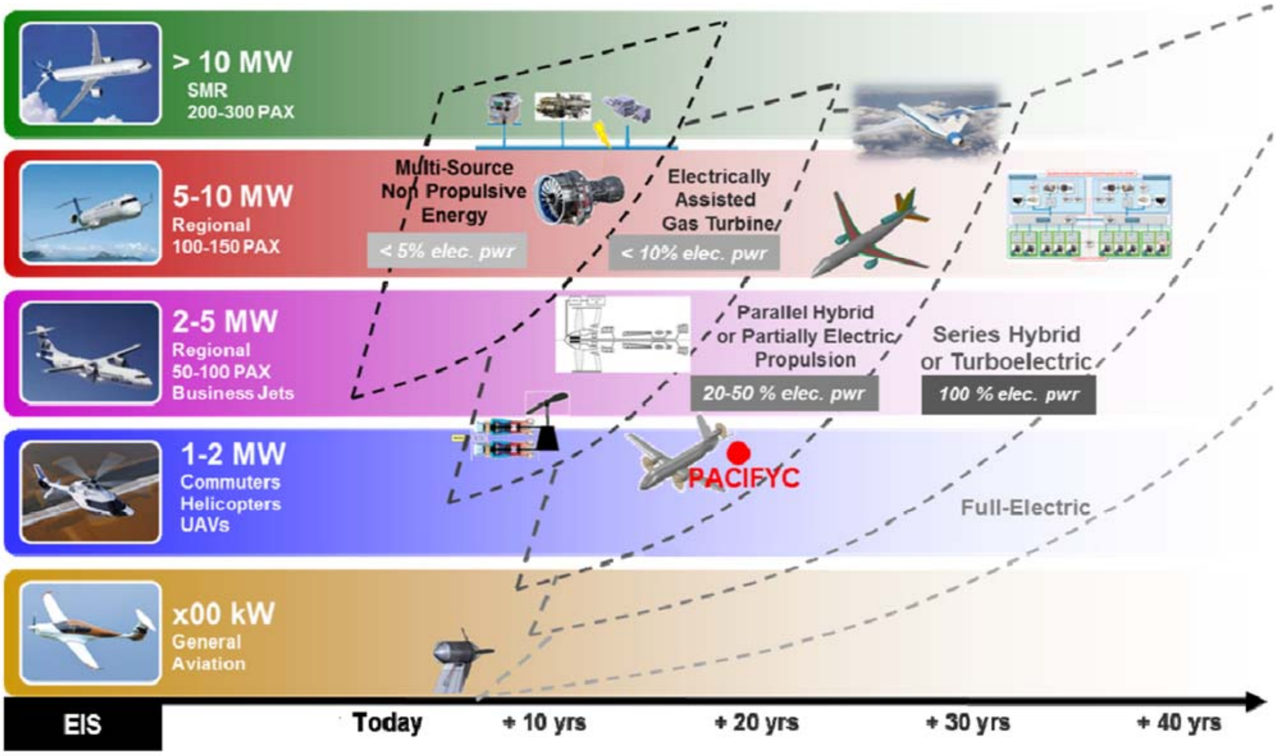


Figure 7: Trends of possible aircraft hybrid architectures at different installed power, from [10]

Considering a time span up to 2035, meaning +20 years in Figure 7, we can see how full electric power could be employed only in general aviation and in some commuter or UAV applications, while partially electric propulsion would be needed to power commuters and regional propeller-driven airplanes. Turbofan aircraft would at most benefit from assisted electric power, provided that a trade-off could be made between engine mass increase and fuel consumption, noise and pollutant emissions decrease; only more electric aircraft tendency is thus expected.

Moving to a larger time span, up to 2050 (+35 years), we can expect to have advanced enough batteries to grant high performance to enable full electric power sources even to standard 200-300 PAX airliners, Figure 7. This possibility to extend this technology to large aircraft by 2050 is affected by heavy uncertainty and requires large improvements in terms of power-to-weight ratio of electric motors and electro-mechanical conversion, cooling systems, wiring and, of course, on batteries.

Concerning fuel burn reduction, one can observe a potential trend for commercial aircraft, Figure 8. Taking year 2000 as a reference, as considered by Flightpath 2050 program, it can be expected an improvement due to hybrid electro-mobility starting around 2025, with fuel saving around 25-30% due to advanced turbofan studies, while further improvements are subjected to large uncertainties.

Conclusion

In conclusions there are few current recommendations are formulated for *FlightPath 2050* Challenge 3 Goals: 1) Support a broad research *effort to reduce aircraft noise* (a) at the source (b) through operating procedures and (c) taking into account psychoacoustic effects; 2) Besides struggling with short term solutions to an increasingly pressing *noise problem* a modest effort should be made towards along-term definitive solution: aircraft in audible outside airport boundaries; 3) To formulate a set of *trade-offs* between (a) different types of emissions (CO_2, NO_x,

DOI: 10.13009/EUCASS2019-847

PM and water vapor) in (b) *local airports and global cruise flights*; 4) Besides struggling with short-term emissions problems put a modest effort towards a long-term definitive solution: the hydrogen powered and *electric powered aircraft* are among the possible solutions.

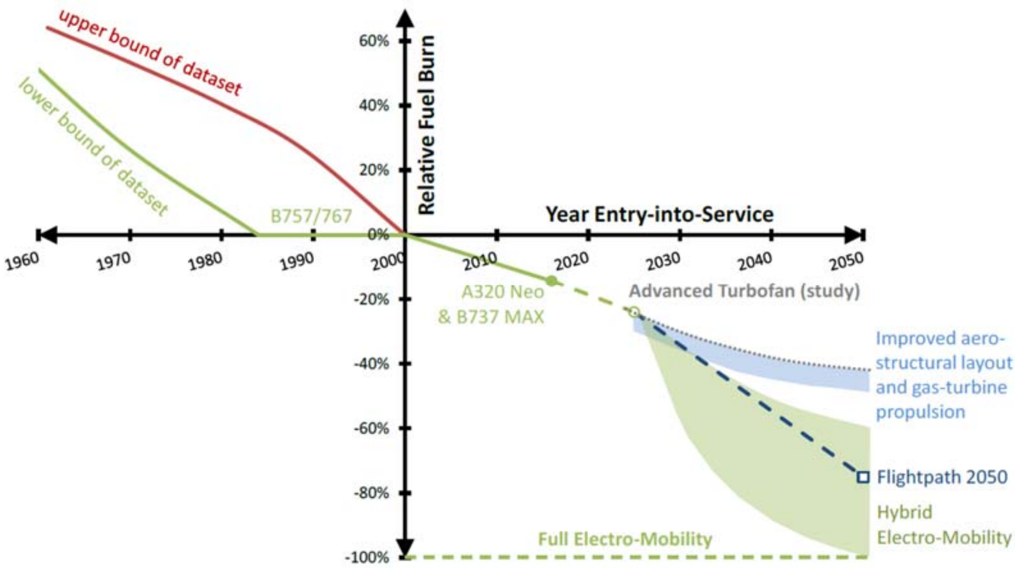


Figure 8: Fuel burn reduction expectation with respect to year 2000 [11]

References

[1] Strategic Research and Innovation Agenda – 2017 update. Vol. 1. Delivering Europe's Vision for Aviation. Advisory Council for Aviation Research and Innovation in Europe (ACARE), DLR, 2017.

[2] Flightpath 2050. Europe's Vision for Aviation Report of the High Level Group. Policy. EU Directorate-General for Research and Innovation, Directorate General for Mobility and Transport on Aviation Research

[3] ICAO Resolution A39-1. Consolidated statement of continuing ICAO policies and practices related to environmental protection – General provisions, noise and local air quality. Resolutions Adopted By The Assembly 39th SESSION, Montréal, 27 September—6 October 2016, provisional edition, October 2016.

[4] National Aeronautics Research and Development Plan. NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, WASHINGTON, D.C. 20502, February 2, 2010

[5] ASCENT Project 037 CLEEN II Technology Modeling and Assessment. Continuous Lower Energy, Emissions, and Noise (CLEEN) Program. Georgia Institute of Technology, 2015.

[6] EUROPEAN AVIATION IN 2040. Challenges of Growth, 2018. Summary Report. European Organisation for the Safety of Air Navigation (EUROCONTROL), June 2018.

[7] European Aviation Environmental Report 2019 [www.easa.europa.eu/eaer]

[8] European Aviation Environmental Report 2016. [www.easa.europa.eu/eaer]

[9] FORUM-AE, 2015. Mid-Term Synthesis. D4.14, Forum-AE Coordination & Support Action, FP7 – 605506.

[10] Isikveren A.T., Fefermann Y., Maury C. Long-term Hybrid-Electric propulsion architecture options for transport aircraft, Conference: Greener Aviation, Brussels 2016.

[11] A.T. Isikveren, A. Sizmann, M. Hornung, Realising Flightpath 2050: Initial Investigation of Potential Technological Solutions, SAE 2011 AeroTech Congress and Exhibition, Toulouse, France, 2011.