PARE preliminary analysis of ACARE FlightPath 2050 environmental impact goals

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Abstract

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 European economy is significant and must be sustained. 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 ACARE *FlightPath 2050* Challenge 3 goals, defined in PARE project at mid-term stage.

Keywords ACARE · FlightPath 2050 goals · Environmental protection

Abbreviations

ACARE	Advisory Council for Aeronautics Research in Europe
AN	Aircraft Noise
APU	Auxiliary Power Units
ATS	Air Transportation System
CAEP	Committee on Aviation and Environment Protection
CRL	Commercial Readiness Level
FAA	Federal Aviation Administration
GHG	Green-House Gas
ICAO	International Civil Aviation Organization
LAQ	Local Air Quality
NASA	National Aeronautics and Space Administration
nvPM	Non-volatile Particulate Matter
PM	Particulate Matter
SRIA	Strategic Research and Innovation Agenda
TRL	Technology Readiness Level
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UTM	Unmanned Aircraft System Traffic Management

1 Introduction

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. It provides close to 12 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.

EU aerospace research towards ACARE (Advisory Council for Aeronautics Research in Europe) goals faces several challenges, predefined in five specific groups in Strategic Research and Innovation Agenda (SRIA) *Flightpath 2050* (FP2050) [2]. Environmental protection in conditions of big number of impacting factors 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 impact on the global and local environment in the face of continuing expansion in demand for air transportation. This expansion today is covering not only the Air Transportation System (ATS) as a whole, but the Unmanned Aircraft System (UAS) operations within UTM (Unmanned Aircraft System Traffic Management) and Urban Air Mobility (UAM), it will also put pressure on existing energy supplies. In 2050 aircraft technologies and operational procedures available allow a sufficient reduction in ATS contribution to global and local emissions into atmosphere, and the reduction of

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perceived noise of flying aircraft. These are relative to the design and operational 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 [2]. As an example, in 2015 the ACARE working group on energy and environment estimated that the EU aviation sector had secured an overall 38% reduction in CO₂ per passenger-kilometer 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. While this represents significant progress, effort must be further strengthened to meet the even more challenging goals for noise, global and local emissions set for 2050 [1].

2 Air traffic and correspondent impact on environment forecasting

There is evident basic assumption that the impact on environment from aviation sector is fully dependent on the traffic volume in air transportation. Second point is a structure of the aircraft fleet used for air transportation with their specific environmental performances. Concerning the air traffic in Europe it is little bit less growing than the a world as a whole, but differences between the regions exists in Europe also—the same as the differences between ICAO predefined regions around the world. European regional air traffic in 2019 was rising at the end of the second decade of the XXI century ~6% annually. In 2017, 1 043 million people in the EU traveled 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 (Fig. 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. European airlines saw traffic rise 5.6% in June 2019 compared to June 2018, with overall estimated flight growth for 2019 at 1.1% [3]. Capacity climbed 4.5% and load factor rose 1% percentage point to 87.9%. The growth was certainly supported by strong demand and has brought traffic back to the most-likely scenario from the 2013 forecast (after double-dip decline in 2008—Fig. 1). Current COVID-19 crisis impact sufficiently reduced air traffic (on ~60% in Europe at 2020) and slowed down the development of the aviation sector including the aircraft production around the world. This impact is not considered in an article definitely.

All such forecasts in flight traffic, and accordingly—airport operational capacity limitations, enroute congestion

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

Environmental impact factor from aviation	ICAO policy goals [4]	EU ACARE goals (FP2050 till 2050) [2]	US FAA and NASA goals (NSTC2010 [5] and CLEEN II [6] till 2035)
Aircraft 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)
Green-house 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, relative to typical new aircraft in 2000	60% reduction in Aircraft Fuel/Energy Consumption (CO ₂ emissions per passenger kilometre?) relative to 2000 best in class

Fig. 1 In 2017–2019, strong growth saw traffic back on the most-likely scenario from the 2013 forecast, modified from [7]

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 with a four-pillar strategy:

- *Improved technology*, including the deployment of sustainable low-carbon fuels;
- *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 aircraft noise (AN) exposure of EU population by 2035–2040, but it will continue

to be a key challenge in aviation sector. AN exposure, if to be more truthful, has stabilized over the past decade by the implementation of ICAO Balance Approach to AN management and first of all by sufficient improvements in making the aircraft fleet quieter. The total EU 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 in 2014, and 2.58 and 0.98 million people in 2017 respectively (Fig. 2, [8]). In 2020 the number of exposed by noise population will be reduced dramatically because of huge reduction in air traffic.

In latest inventory assessments an aviation sector represented 13% of all transport and 3% of the total EU greenhouse gas (GHG) emissions, representing 22% of global aviation's GHG emissions. Due to fleet renewal, emissions of GHG and NO_x have been relatively stable between 2005 and 2014 (Fig. 3). Similar to noise exposure the **reduction** in GHG and LAQ emission from aviation sector in 2020 will be dramatic also. However, the nvPM emissions are expected to increase over the next 20 years (on 25% till 2040) if engine technology remains as it is today [8].

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,—much more is expected in following decade till 2030 as declared by Europe Green Deal in 2019. This is backed up by a legal commitment and framework at EU level to reduce GHG emissions, increase the use of renewable energy and improve energy efficiency. The climate protection targets for 2020, which the EU is on track to meet (with adequate contribution from aviation sector), and 2030 are shown below [8]:

2020

20% cut in GHG emission (from 1990 levels);

Fig. 2 Fleet renewal could stabilise average noise levels at today's 47 major airports by 2030 [8]

Fig. 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 [8]

20% of EU energy from renewables;
20% improvement in energy efficiency;

2030

~40% cut in GHG 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:

2040

60% cut in GHG emission (from 1990 levels);

2050

80% cut in GHG emission (from 1990 levels), including a 60% reduction in transport emissions.

To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050, as defined in the new EU Green Deal proposal (2019). Automated and connected multimodal mobility will play an increasing role, together with smart traffic management systems—ATS, UTM and UAM enabled by digitalisation, and consequently air transport should become drastically less polluting, especially in cities.

It is clear from available studies that these goals cannot all be achieved using evolutions of currently available technologies in aircraft design and operation. Research and innovation for evolutionary aircraft development will drive progress in environmental performance to be on track towards the FP2050 goals. Fuel efficiency improvement of the aircraft in flight will still being a driver for their future developments, concentrating on further less fuel consumption technologies of the engines, cleaner and smarter aerodynamics for drag reduction and lift forces rise, and on reduction of aircraft empty weight. 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 (Fig. 4).

To achieve the FP2050 goals, step changes in aircraft configuration and operation (including alternative energy sources) will be required—currently envisaged evolutions will not be sufficient [1]. Changes in aircraft configuration may concern as on more traditional Tube-and-Wing (T + W) technology, so as Blended-Wing-Body (BWB) configuration. There are many advantages for long-range flying BWB were found in comparison with T + W aeroplane: Takeoff Gross Weight ~ 15% less (for empty weight 12.3% lower), Lift-to-Drag Ratio ~ 20% higher, Fuel-Burn 27.5% lower, Required Thrust 27% lower, and Operating Cost 13% lower [9]. In addition for BWB a cumulative reduction of certification noise levels up to 40 dB and GHG emission on 80% is possible to expect, which are necessary for reaching the European and US 2050 goals (Table 1). When the BWB is sized with a similar range and payload capacity as the 737–800, NASA's 2005 best in class single-aisle jet, the BWB again achieved NASA's N + 2 goals [10]. Operational changes are expected mostly due to new on-board navigational and air

Fig. 4 The goals and action areas for *Challenge 3* of the ACARE perspectives

traffic management improvements in directions of vertical and lateral flight path optimization as close to the airport so as along the routes. 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-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.

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 FP2050 targets.

Complementarily to TRL a *Commercial Readiness Level (CRL) scale* is considered to serve as a framework for defining the spectrum of commercial maturity, from basic market research to full deployment, which is expected at the end of the project period. Following sections are arranged in accordance to the sequence of environmental objectives in the strategic document ACARE [2].

4 Reduction of noise and emissions

ACARE FP2050 goal 9: “In 2050 technologies and procedures available allow a 75% reduction in CO_2 emissions per passenger-km and a 90% reduction in NO_x emissions. The perceived noise of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000”. This goal covers noise and emissions. The distinction is made between engine and aerodynamic noise and

local (impact on local air quality—LAQ) and global (impact on climate change) emissions.

Unfortunately, aircraft has a large number of noise sources. The major sources of engine noise are the fan and jet, and to a lesser extent, the compressors, combustor, turbine and bleeds (which may actually dominate at certain times during flight, Fig. 5). Airframe noise is generated by the airflow surrounding the moving plane. The main sources are the discontinuities of the aircraft structure, such as high-lift devices, landing gear wheels (when extended), and trailing edges which lead to speed shearing (aircraft speed versus still air). A further source of noise arises from the interaction of the engines exhaust jet with the airframe. As a general rule, engine sources dominate on take-off while airframe noise dominates on approach (Fig. 5b).

There is potential for reducing noise by better component design and incremental improvements in existing technology, but it is not appropriate to detail all the possibilities here (Table 2 is used for illustrative examples). Instead, we highlight where new technological improvement is likely, and cases where an improvement in aircraft efficiency and gaseous emissions creates a new noise risk that will need to be addressed. However, they can be broadly classified as engine noise sources and airframe noise sources.

Fig. 5 Sources of acoustic emission during: **a** takeoff; **b** landing [11]

Table 2 Examples of potential noise reduction through component improvements. (based on data given in (CAEP/9 Meeting, 2013))

Compo-nent	Technology	Estimated dB reduction on component level	Timescale	Notes
Fan	Rotor Sweep Stator Sweep and Lean	2 dB	Near term	Current TRL 5 to 9
	Variable area nozzle	2 dB	Near term	Complexity and weight issues
	Liner improvements	2–4 dB	Near term	Manufacturing & repair technologies need to be developed. Integration with other systems such as deicing
	Active stators	Up to 8 dB	Near/long term	Highly complex weight and structural integrity issues
	Active blade control	Up to 20 dB	Near/long term	
Jet	Chevrans	1–3 dB on TO	Near term	Potential fuel burn penalty
	Fluid injections/microjets/ excitations	1–3 dB	Near/long term	Highly complex
Landing gear	Fairings	Up to 3 db	Near term	Weight penalty. Maintenance access
	Low noise design	Up to 5 db	Near/long term	
	Flow control	1 dB	Near/long term	Weight penalty
High lift devices	Slat track treatment	Up to 5 db	Near term	Potential impact on L/D
	Flap side edge treatment	Up to 5 db	Near term	Potential impact on L/D
	Low noise design	Up to 5 db	Near/long term	Potential impact on L/D
Core	Hot stream acoustic liners	2–4 dB	Near term	

The major contributor to the reduction of engine noise has been the increase in the by-pass ratio (BPR) of turbofan engines, which also decreases fuel consumption, leading both to lower emissions and more favorable economics. The range of liners employed to attenuate noise will be significant in the near term. Specifically, lip liners (where the intake liner is extended around the lip of the nacelle intake) are feasible now that the problem of integrating them with the de-icing system has been overcome. Modern ceramics and improved manufacturing have made core exhaust liners possible, but the problem of high temperatures and a highly curved geometry must still be solved. Equally, ALM allows for varying the depth of nacelle liners to obtain a distribution of acoustic impedance that can be optimized for maximum attenuation or the use of radically new liner design.

Recommended Phased Approach to meet 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. *Goal 9* includes analysis of expected advances on noise reduction with Noise Reduction Technology, as well as the Noise Abatement Procedure contributions.

For example, NYSERDA TRL Calculator results for analysis and assessment of *ACARE Challenge 3 Goal 9* achievements at 2nd stage of the studies on PARE Project are shown in Fig. 6 grounding on the results of the 2nd year PARE report [12]: TRL=8, CRL=7 for midterm 2020 goal;

TRL=3, CRL=1 for midterm 2035 goal. For 2050 goal a new SRIA and new goal definitions are necessary.

Aviation emissions of CO₂ and NO_x are produced by aircraft, support vehicles and ground transportation dominantly. The emissions from these sources fall into two categories: emissions that cause deterioration in LAQ and emissions that cause climate change. Current and future technological developments to achieve the challenging ACARE 2050 CO₂ goal are essential to mitigate substantially the increase of aviation CO₂, with realistic traffic growth assumption (Fig. 7).

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. 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 [3]. ACARE runs three research projects to achieve these goals: *X-Noise EV*, which relates to aviation noise research, *Forum AE*, which relates to emissions research, and *Core-Jet Fuel*, which relates to alternative aviation fuels.

A new assessment was performed against ACARE CO₂ and NO_x goals and is summarized in Table 3. Each new generation of aircraft has substantial fuel efficiency improvements, first of all due to improvements in their engines (~80% of the fuel savings for the last generation of aeroplanes are due to improvements in their propulsion systems),—up to 20% more fuel efficient than the previous one. This is true for new generation aircraft (latest deliveries A220/A320neo/B737MAX for single-aisle category,

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

Fig. 6 NYSDERDA TRL Calculator results for analysis and assessment of ACARE Challenge 3 Goal 9 “Reduction of Noise and Emissions” [12]

Fig. 7 Global aviation CO₂ forecast with ACARE assumption [13]

A330neo/B777X and A350/B787 for twin-aisle category with their entry into service during 2015–2020), which are ~20% more fuel-efficient than their predecessors. The contribution of technology improvements in fuel burn (fuel burn reduction scenarios) is realized through the implementation of a new ICAO aeroplane CO₂ emissions standard, its aim is to implement more fuel-efficient technologies into new manufactured aeroplane designs. The international aviation fuel efficiency, expressed in terms of volume of fuel per RTK, is expected to improve at an average rate between 1.29 and 1.37% per annum to 2045 with extrapolation to 2050. This indicates that ICAO’s aspirational goal of 2%

per annum fuel efficiency improvement [4] is unlikely to be met by 2050 if the evolutionary approach will be considered alone.

As example, CO₂ Road-Map (Fig. 8) demonstrates the potential to accommodate significant aviation growth to 2050 without a substantial increase in CO₂ emissions, through a better than doubling of carbon efficiency, namely in UK [14]. Through the adoption of newer, more efficient aircraft, sustainable fuels and better air traffic management and operational procedures, the aviation industry in the UK and in total EU will be able to accommodate significant growth through to 2050, including the effect of additional

Table 3 FORUM-AE assessment against ACARE emissions goals [13]

	Reference 2000	ACARE 2020 Goals (at TRL6)		ACARE 2050 Goals (at TRL6)	
		High level	Detailed SRA	High level	Detailed SRA
CO ₂	Representative technology of aircraft and engine with 2000 EIS & representative ATM	– 50% per pass km	Aircraft: – 20–25% Engine: – 15–20% ATM: – 5–10%	– 75% per pass km	Aircraft & engine: –68% ATM: – 12% Other: – 12%
NOx (LTO)		– 80%	Engine: – 60% CAEP6 Complement achievement by aircraft + ATM	– 80%	Engine: – 75% CAEP6 Complement achievement by aircraft + ATM
NOx (Cruise)		– 80%	Achieved through – 50% fuel burn and – 60% cruise EINOx reduction	– 80%	Achieved through – 75% fuel burn and further cruise EINOx reduction
Other emissions		Damaging emission reduced	Emissions qualitatively reduced (particles, CO, UHC) and better understanding of impacts	Emissions free taxing + qualitative reduction	Knowledge of emissions (particles, VOC) and better understanding of impacts

runway capacity in the East European States (for EU region), without a substantial increase in CO₂ emissions.

A thorough analysis of the CO₂ Road-Map at Fig. 8 shows its full correspondence with action areas for *Challenge 3* of the ACARE perspectives at Fig. 4, confirming that an ACARE vision is also a basket of measures necessary to reach the Challenge 3 goals. Absent in ACARE document [2] market-base measures (defined by ICAO CORSIA standards [15]) must be considered as the main pusher of the new cleaner (and quieter) aircraft designs, appropriate infrastructure and SAF into the market, not being the economic instruments of management in aviation sector itself.

Although, there is no ACARE objective related to non-volatile particles (nvPM), this is now a key environmental and regulatory concern, which requires appropriate mitigation solutions in technology (engine combustor technology and fuel composition). It is evident gap in current SRIA FP2050, while a new ICAO standard for nvPM engine emission instead of smoke number standard was adopted by ICAO Council in March of 2020.

5 Aircraft electrification nowadays and in future

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Stepwise development to meet environmental targets in aviation sector—evolutionary and revolutionary technology solutions to be researched and implemented complementarily—provides a necessity to formulate mid-term and long-term goals, especially driven by climate change impact of aviation. For example a concept of More Electric Aircraft covers a number of technologies to be introduced in aircraft control in flight during nearest decades (mid-term goals for emission reduction and energy supply). Full Electric Aircraft concept is considered as a subject of deep concern for the last decade (long-term goals) in progress to 2050 achievements. Complexity of the Challenge 3 towards 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

Fig. 8 The goals and action areas for *Challenge 3* of the ACARE perspectives [14]

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 revolutionize the aerospace and aviation industries. Up to date a number of new programs were launched for the four types of aircraft—General Aviation/Recreational Aircraft, Urban Air Taxis (vertical take-off and landing aircraft), Regional/Business Aircraft and Large Commercial Aircraft. Most of them target an entry-in-service date between 2020 and 2030 (if COVID-19 will not impact the progress sufficiently), 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 (Fig. 9).

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 (ATS) or urban air taxi architectures (UAM). 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.

Considering a time span up to 2035, meaning +20 years in Fig. 9, we can see how full electric power could be employed only in general aviation and in some commuter or UAS 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 (A320/B737 category), Fig. 9.

Concerning fuel burn reduction, one can observe a potential trend for commercial aircraft, Fig. 10. Taking year 2000 as a reference, as considered by FP2050 SRJA, 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 (ultrafans with BPR = 15 and higher), while further improvements are subjected to large uncertainties. 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.

5.1 Emissions free taxiing at airports

More than 200 members of ACI Europe (the trade association for European airports) have committed to produce net zero carbon emissions by 2050. The taxiing of aircraft on engine power and the use of auxiliary power units (APU) on the ground can be significant contributors to emissions at airports and also generate noise. UK cross-industry group Sustainable Aviation found that 30% of total CO₂ emissions at Heathrow Airport came from aircraft taxiing and the use of auxiliary power units (APUs) [14].

Fig. 9 Trends of possible aircraft hybrid architectures at different installed power, from [16]

Fig. 10 Fuel burn reduction expectation with respect to year 2000 [17]

Savings of 100,000 tonnes of CO₂ per year have been calculated at Heathrow from reduced engine taxiing and APU substitution.

On a global level, IATA has estimated a CO₂ savings potential in the order of 6 million tonnes annually. The most obvious way to achieve ACARE FP2050 *Goal 10* is to use electric towing vehicles. There are technical aspects like ensuring compatibility of towing brackets and sufficient traction power. Also infrastructure aspects with recharging facilities for a fleet of electric towing vehicles.

Electric landing gear drive equipped with traction motors can provide taxi capability without the use of main engines

or tractor. WheelTug was the first company to demonstrate the operation of an on-board electric taxiing system in 2005. An example of external ground propulsion system is TaxiBot—semi-autonomous hybrid electric tractor, a system developed by Israeli Aerospace Industries. Safran has generated real industry buzz by offering the first electric taxiing solution, with an electric motor in the landing gear, powered by the APU, so that pilots no longer have to use their jet engines for taxiing. This innovative solution is now being developed with Airbus for the A320neo/ceo. The target date for entry into service is 2022. According to a study carried out with airlines, this system makes a lot of sense at

busy airports with long taxiing times, as well as for carriers that operate a number of daily shuttle flights. With this new technology, they can reduce not only their operating costs, but also their environmental footprint.

On-board solutions are the most suitable for narrow-body aircraft, which have many flight cycles during the day with high taxiing time. For wide-body aircraft, the fuel savings during taxiing would be canceled during the flight phase due to having extra on-board weight. Therefore, one possible scenario to be foreseen is a mixture of the two types: on-board for narrow-bodies and external systems for wide-bodies aircraft.

The current preferred battery technologies for ground movements at the airport or on the airfield and in the aircraft itself are the lead—acid and the nickel—cadmium (Ni—Cd) batteries. However, since these batteries are technically exhausted, no significant improvement in terms of energy density, cycle life, calendar life, etc. is expected; there is a shift to lithium—ion (Li—ion) technology in the aviation industry, being that Li—ion chemistry offers a large variety of materials and cell architectures, which enables the possibility to design high-power as well as high-energy systems.

In general, regarding Li—ion batteries, an increase in the energy density, with state-of-the-art chemistry, could be mainly achieved by optimizing the form factor and the cell production process. Nevertheless, even if the current chemistry has proven itself, efforts are still to be made to increase the energy density as well as other key performance parameters to meet future requirements. NYSERDA calculator results for analysis and assessment of *ACARE FP2050 Goal 10* “Emissions Free Taxiing at Airports” achievements: TRL = 3, CRL = 2 [12].

6 Design and manufacture bearing in mind recycling

ACARE FP2050 goal 11: “Air vehicles are designed and manufactured to be recyclable”.

Recycling of aircraft parts depends mostly on the materials used and also on the fabrication process. The choice of materials for an aircraft is subject to a considerable set of constraints related to performance, weight, availability, cost, ease of manufacture and maintenance, durability and resistance to hostile environments. Adding the recycling ability is an additional constraint which can bring benefits in several of other areas; it may require consideration of materials not previously used in the aerospace industry and take advantage of the major progress made synthesizing new substances with tailor-made properties (graphene).

Recycling aircraft parts depends mostly on the materials used and also on the fabrication process. The choice of materials for an aircraft is subject to a considerable set of

constraints related to performance, weight, availability, cost, ease of manufacture and maintenance, durability and resistance to hostile environments. Adding the recycling ability is an additional constraint which can bring benefits in several of other areas; it may require consideration of materials not previously used in the aerospace industry and take advantage of the major progress made synthesizing new substances with tailor-made properties (graphene). There is a need for effective materials extraction and separation technologies, worthwhile end-use applications for the recovered materials as well as an attractive business model for aircraft recyclers. Only when all of these conditions are united can the aircraft recycling industry truly take-off in Europe.

Recent technological advances in the field of power electronics, fault-tolerant architecture, electro-hydrostatic actuators, flight control systems, high density electric motors, power generation and conversion systems have ushered the era of the more electric aircraft. A small size, high-energy density (more than 100 W-hour per kilogram (Wh/kg)) battery is the need of the aircraft industry as a 10 kg decrease in the weight of aircraft will result in the savings of 17,000 tons of fuel and 54,000 tons of carbon dioxide emission per year for all air traffic worldwide. The reduction in battery weight is also profitable in terms of cost. The life duration of an aircraft battery depends on various factors such as number of operating hours, ambient temperature, start frequency and on-board charge. It is therefore difficult to determine in advance how long the expected life of a battery will be in the real situation.

It is recommended that a comprehensive assessment of materials used in aircraft production is made and that recyclable alternatives and related issues of availability, ease of use, certification, maintenance and cost are assessed. NYSERDA calculator results for analysis and assessment of *ACARE FP2050 Goal 11* “[Design and manufacture bearing in mind recycling](#)” achievements: TRL = 8, CRL = 4 [12].

7 Sustainable alternative fuel sources

ACARE FP2050 goal 12: “Europe is established as a center of excellence for sustainable alternative fuels, including those for aviation, based on a strong European energy policy”.

The supply of fuel alternative to kerosene is subject to major efforts by large consumers like the US Air Force. The consumer base is more diversified in the airline industry but it is no less important due to the large number of flight hours. Although airlines have been willing to test new fuels a coordinated effort must be done far upstream to: (i) consider a variety of sources of fuel, that do not interfere with food production and whose environmental impact is neutral or positive (waste disposal); (ii) establish

the technical feasibility to meet all applicable quality and safety standards and certification requirements; (iii) assess the economic and environmental feasibility of large-scale sustained production, distribution and use.

For example hydrogen is a clean fuel that produces only water vapor by combustion; however the quantities produced and altitudes should be considered as for contrails. Hydrogen has a low volume power density and requires cryogenic conditions; water is an abundant source of hydrogen but its separation by hydrolysis is energy-consuming. Hydrogen-powered aircraft are expected feasible and may appear on intra-European routes around 2040. At the opposite extreme some algae have high yields per unit area of culture; the full processing chain up to flight grade fuel needs to be considered. In between other options exist, making multiple sources of aviation fuel all the more desirable.

The use of the biofuel has been tested in two series of flights. The first series of 18 long-haul flights from Amsterdam to Aruba, on an Airbus A330-200 (carrying around 4,500 passengers informed about the project) was performed using biojet fuel blend in one engine to compare the performance of the two engines. No significant performance differences were noted, but that the water accumulated in the tanks during flights can be lowered using the synthetic fuel, reducing the maintenance frequency and costs. The second series of 80 short-haul flights, from Oslo to Amsterdam, on an Embraer E190, carrying about 8,000 passengers, using the camelina biojet blend in both engines, confirmed the no detrimental effects on operation with similar or slightly better fuel consumption and, no variation in fuel gauging systems.

The flight series were complemented with a series of lab-based emission measurements using a testbed APU. APU emissions tests were completed for the two ITAKA fuel batches and baselined against a standard fossil Jet fuel: performance parameters were as expected quite similar, fuel consumption decrease up to 1% (saving fuel and CO₂ emissions), and the emitted particulate matter (PM) was decreased up to a 50% for a 50:50 fuel blend. PM emissions are the major air quality concern that are linked with a significant number of premature deaths across Europe. High paraffinic fuels such as HEFA biojet could significantly help to reduce the impact of this pollutant in the vicinity of airports. The information obtained has been supplied to the ICAO for the development of future standards for aircraft engines. At present, using biofuel in aviation is not of economic benefit because it is more expensive than the conventional aviation kerosene. As predicted by the experts, the oil prices can fall in already in the near future. This being the situation, one of the measures can be the legislative obligations to use in one or another proportion the purer, but simultaneously the more expensive alternative types of fuels.

ACARE also runs the research project entitled Coordinating research and innovation of Jet and other sustainable aviation Fuel (*Core—JetFuel*). European aviation specifically must guarantee that, in 2050. It is recommended that a comparative study of potential alternative fuels, their availability in the required large quantities and the feasibility and cost of large—scale production, distribution and use is performed. NYSERDA calculator results for analysis and assessment of ACARE FP2050 Goal 12 “Sustainable Alternative Fuel Sources” achievements: TRL = 7, CRL = 3 [12].

8 Atmospheric research, weather and the environment

ACARE FP2050 goal 13: “Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritized environmental protection plan and the establishment of global environmental standards”.

Atmospheric hazards have been a safety concern throughout the history of aviation and are addressed in the ACARE goal 15. A better modelling and understanding of atmospheric phenomena can reduce disturbances of air traffic management (ACARE goal 5) and allow an increase of runway capacity at airports (ACARE goal 1). As major users of the airspace aviation can contribute to the monitoring of the atmosphere and to the establishment and implementation of global environmental standards. The monitoring of the atmosphere is performed by a vast array of earth and satellite sensors, plus specialized weather aircraft like those used by National Oceanographic and Atmospheric Administration in the USA to fly through tropical storms and collect in-situ atmospheric data. The data transmission capabilities of airliners in modern ATM systems could be used not only for traffic proposes but also to collect atmospheric data in support of environmental standards and policies. It is in the interest of airlines to preserve their flight environment and if appropriate some of the millions of flight around the world could be a source of in-situ measurement and monitoring.

There are several methods to monitor the atmosphere, such as: routine ground—based measurements (made by ground—based sensors—land-based and buoys); systematic aircraft measurements (made by aircraft and balloons); and satellite measurements (made by space—borne sensors).

Changes to temperature, precipitation, and storm patterns are all expected in the near-term, certainly by 2030. The impacts of sea-level rise are more gradual and not expected until later in the century. However, more frequent and intense storm surges will have an earlier impact on European aviation, reducing capacity and increasing delay.

Currently, there are several European initiatives and projects that have as main objective monitoring the atmosphere through satellite and airborne instrumentation, which are:

- Copernicus project, previously known as the Global Monitoring for Environment and Security;
- Constellation Observing System for Meteorology, Ionosphere and Climate project;
- Advanced Satellite Aviation Weather Products initiative;
- European Organisation for the Exploitation of Meteorological Satellites; In-service Aircraft for a Global Observing System project.

It is recommended that regular airliner flights are used to collect in-situ atmospheric data, which should further be processed to have near real-time knowledge of conditions along flight routes. NYSERDA calculator results for analysis and assessment of *ACARE FP2050 Goal 13* “Atmospheric Research, Weather and the Environment” achievements: TRL = 3, CRL = 3 [12].

9 Conclusion

In conclusions there are few current recommendations formulated for ACARE FP2050 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 its psychoacoustic effects and other kinds of impact; 2) Besides struggling with short term solutions to an increasingly pressing *noise problem* a modest effort should be made towards a long-term definitive solution: aircraft in audible outside airport boundaries; 3) To formulate a set of *trade-offs* between different types of emissions (CO₂, NO_x, PM and water vapor) in *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 (and associated supporting airport infrastructure). Additional to them expected drastic improvement in aircraft configuration in direction to reduce operational weights and to rise lift-to-drag performances intended to all classes of the aircraft including BWB implementation for basic aeroplane design [9, 10].

Evident gaps were found also concerning the absence of the strategic targets for nvPM emission reduction in aviation sector, necessity for reformulation of global impact from the inventory assessment to real climate change value like the ICAO currently reconsider this strategic goal in CAEP work [4]. The elaboration of CORSIA documents still continue in ICAO/CAEP and the voluntary stages of the States involvement into this global program is very close [15]. The successful solutions for Europe will be dependent of how Europe Green Deal (2019) directive will co-inside with ICAO environmental policy. For noise subject it will be important to formulate the goal for supersonic aircraft, which is returning to operation during next decade, and for

UAS, which are attractive expansion of air transportation in UTM and UAM systems in near future.

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Declarations

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