ACARE environmental goals need for change

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Abstract. Climate change is the megatrend that will have the biggest impact on the development of sustainable air transportation in near future. Aviation is expected to triple its proportional share of a Paris compatible 1.5°C budget, declared by UNFCCC Agreement for global temperature through 2050 under current international policies. Basket of measures proposed by ICAO to keep the temperature change under this limit, including aircraft technology (up to 25%) and operation improvement (up to 9%) for fuel burn reduction by engines and new revolutionary architectures of the aircraft, deployment of sustainable alternative fuels (over 40% of fuel burn reduction), market based measures (ICAO CORSIA) as pushing system for more quick and efficient implementation of the first three, etc. Pioneering sustainable technology is allowing the civil aviation sector to embrace the next generation of aviation through electrification and alternative fuel sources. More than 90% of GHG emissions from global commercial aircraft operations are generated by Large Commercial Aircraft, so research to reduce commercial aircraft emissions will be most useful if it focuses on technology applicable to them.

1. Introduction

Besides safety, environmental protection is a major issue to be considered in air traffic management and aircraft operation. Among the environmental problems there are global and local problems exist, that is why ICAO Environmental Policy during last decade consists of the two separate parts at least – “General provisions, noise and local air quality” and “Climate Change” [1]. The image of Air Transport in the public mind has been tarnished by its perceived impact on the environment. The main levy to reduce aviation emissions will be to reduce travel demand through taxes and/or individual emissions quotas. Hardly any technical solution is able to reduce both types of impact. Trade-off decisions have to be made by all industry actors. The potentially negative impact of any drastic “green” approach on the supply industry is a concern. There is a need for global agreements on such measure to maintain fair competition.

In recent years the aviation sector has initiated a comprehensive range of measures to mitigate its impact on the environment. To achieve the ACARE Flightpath-2050 goals, step changes in aircraft configuration and operation (including alternative energy sources) will be required (Figure 1) – currently envisaged evolutions will not be sufficient, there is a need a real basket of measures! Such disruptive change will have consequences for all stakeholders: manufacturers, airlines, airports, ANSPs and energy suppliers. 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 pre-final term stage.

In 2050 technologies and procedures available allow a ***75% reduction in CO_2*** emissions per passenger kilometre and a ***90% reduction in NOx emissions***. The ***perceived noise emission of flying aircraft is***

reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000. Besides a***ircraft movements is expected to be emission-free when taxiing***. ***Air vehicles should be designed and manufactured being recyclable***. ***Europe is established as a centre of excellence on sustainable alternative fuels***, including those for aviation, based on a strong European energy policy. ***Europe is at the forefront of atmospheric research*** and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

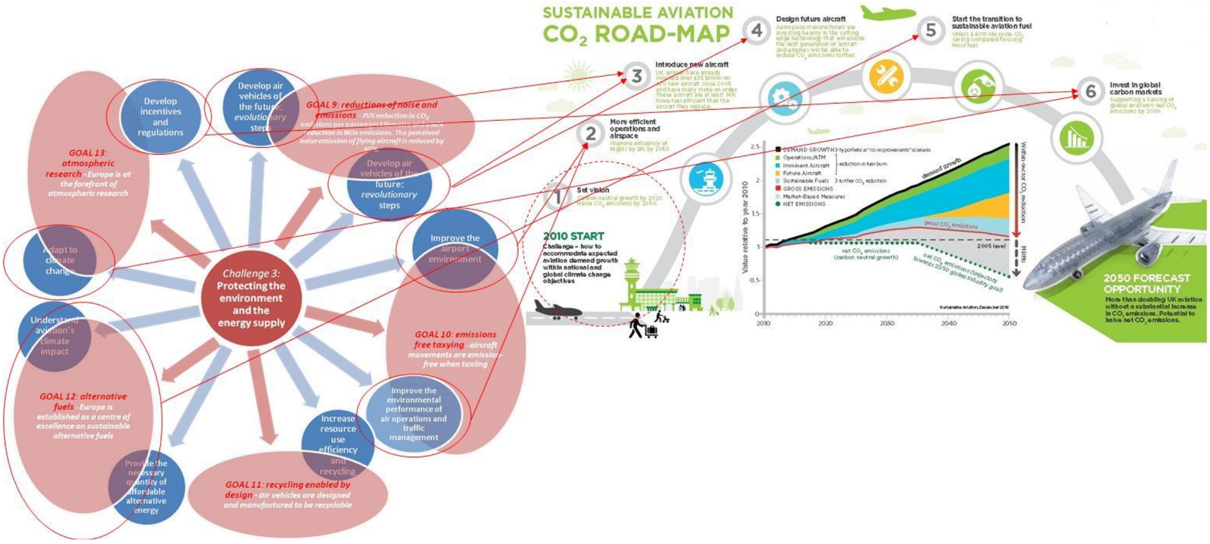


Figure 1. The goals and action areas for *ACARE Challenge 3* in relation to fuel/energy consumption & GHG reduction along Sustainable Aviation Roadmap 2050

2. Assessment of necessary reductions of aviation impact on environment

In subject of climate change control the recorded total CO_2 aviation emissions are approximately 2% of the global greenhouse gas (GHG) emissions (international aviation accounts for about 1.3% of total global CO_2 emissions, rest – domestic aviation), which is rising on 3-4% annually due to traffic and appropriate fuel consumption growth. Accordingly the international aviation is expected to triple its proportional share of a Paris-compatible (declared by UNFCCC Agreement in Paris, 2015) 1.5°C budget for global temperature rise through 2050 under current international policies and “doing nothing” in technology development of the aviation sector. Paris Agreement calls upon all the States to maintain global warming at 2°C in the middle of this century, compared with pre-industrial levels, and perform maximum efforts to keep the temperature rise even within 1.5°C. Results of all last researches show the impossibility to reach these goals with *evolutionary* approach for aircraft design development – mostly concentrated on improvement of fuel consumption by engines, improvements in aerodynamics and weight reduction of the aircraft. A very new ICAO Standard on CO_2 emission of the aircraft – both “being in production” and “new designs” – must contribute essentially to global aviation GHG emission reduction (it is realized in vol. III “Aeroplane CO_2 Emissions” to Annex 16 “Environment Protection” to ICAO Convention [2] – the world’s first global design certification standard governing CO_2 emissions for any industry sector), but concerning only the evolutionary path of the technologies in new aircraft designs and operation. Among the *revolutionary* expected changes in aircraft design are the concepts of full electric (FEA) and hybrid electric (HEA) aircraft, both concepts are relative to aircraft engine thrust production. These FEA and HEA concepts will compete with sustainable aviation fuels (SAFs) implementation in aviation sector, including biofuels and hydrogen. Hydrogen and fuel cell technology has undergone significant development in the last decades, industry technology outlook and expert interviews consider an optimistic and achievable forecast of the performance of H_2 powerplant components for aircraft over the next decade. Other pathways to reach this aspirational goal – aviation sector development within 1.5°C of global temperature rise – are still not foreseen today completely, a number of possibilities are under investigation and assessment. In real consideration the availability of SAFs are expected between 5-10 Mt annually, due to their production prognosis in following decade, but to solve the climate task completely in 2050 – its production should be around 300 Mt to cover the needs of aviation sector only. In this article the competitiveness of electric aircraft (with so called e-fuels) with imminent designs is considered, SAFs and hydrogen fuels are mentioned as possible future scenarios only.

To keep the climate change within Paris requirements to global temperature all the states and responsible economic sectors should begin their radical reduction of the GHG emissions now – during the current and following decades – and in a second half of XXI century to achieve a global balance between man-made emissions and natural and again man-made carbon sinks that accumulate and store these gases (such as the oceans, forests and soil in natural environment, and new technologies to utilize these emissions). In fact, this means the need to completely phase out fossil fuels by 2050 in any sector, including energy and transportation sectors first of all, and the transition to 100% usage of renewable energy sources, with aviation sector in the list of key players. As part of that global authority decision, the ICAO, as a responsible international board in management of aviation sector, set a sector-specific target that CO_2 emissions from civil aviation in 2050 should be at or below 2020 level [3] (Figure 2, the data compiled from [2]). Looking on a number of possible scenarios [6], the mostly optimistic long-term aircraft fuel efficiency of 1.37% is significantly lower of ICAO's desired goal of 2% [1] – it means that evolutionary technology improvements may cover only around two-thirds of the necessary fuel consumption reduction per annum. ICAO (by its Committee on Aviation and Environment Protection – CAEP) even has identified the number of technology, operational and organizational measures that can contribute to reductions of CO_2 emissions (so called ICAO's basket of measures – the Figure 1 shows a basket of measures from ACARE vision [15]) more effectively: aircraft related technologies and standards to stimulate their implementation; improved air traffic management and aircraft operation (first of all fuel burn reduction per flight will be reached due to more direct cruise flights and more efficient vertical profiles in air traffic management); development and deployment of SAFs [4]; market-based measures (MBM) – global and regional [5]. First two – aircraft technology and operation – will contribute to fuel burn reduction as a primary goal and to CO_2 emission reduction consequently only on one-third necessary volume in relation to aviation GHG emissions 2020 range (Figure 2).

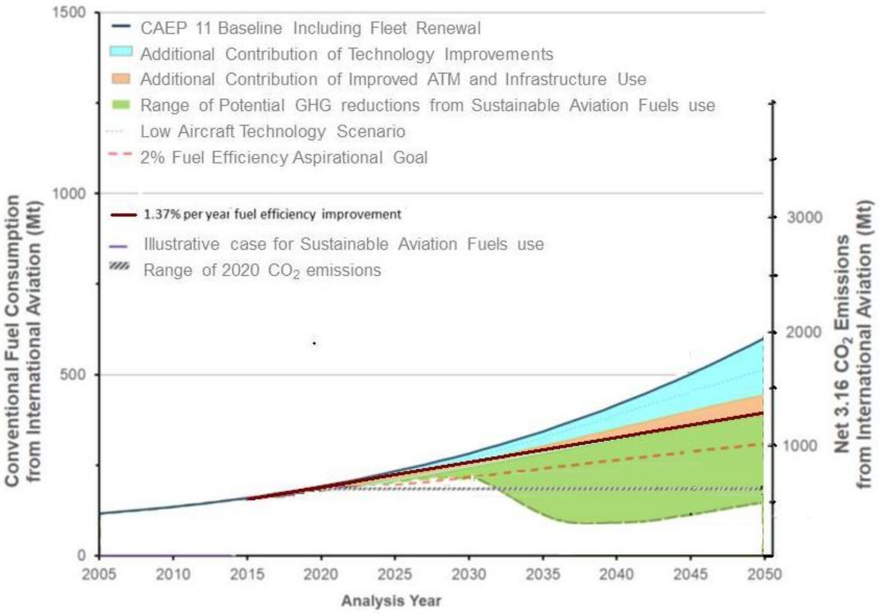


Figure 2. ICAO CAEP trends in fuel burn (left axis of ordinate) and net CO_2 emissions (right axis of ordinate) from international aviation

A currently predefined by UNFCCC Agreement 1.5°C pathway in ICAO environment protection policy (coordinated by the CAEP and realized by the member states) would expect global emissions of CO_2 and its equivalents to peak by around 2020 and decline thereafter, and necessitate negative emissions by around the mid part of the 21st century. Global MBM implementation in accordance with ICAO Standard requirements [5] must intensify aircraft technology and operation improvements, including revolutionary approach to them from one side, it must intensify SAFs development and deployment from other side, including their higher regional specification in accordance with natural possibilities around the world (scenarios assessment in Figure 2 are grounded on and would require for high availability of bioenergy feedstocks around the world with a substantial expansion of the agricultural sector, complementarily a complete shift in aviation from petroleum refining to SAF production).

Global fuel consumption and CO_2 emission projections in Figure 2, so as air traffic and aircraft fleet as the basic values for the forecasting, can be affected substantially by a wide range of factors such as fluctuations in fuel prices and global economic conditions – every crisis not only put down the operational and economic data in aviation sector (Figure 3), but shifted the prognostic curves from pre-crisis trends. The impact of COVID-19 crisis is still under the development, its recovery path is not understanding completely to today's situation. In further text the COVID-19 impact is not considered.

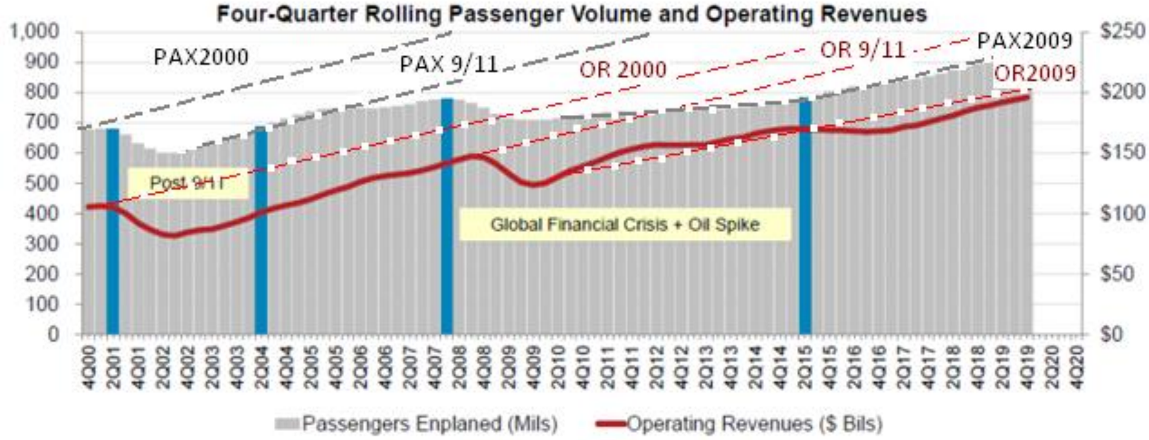


Figure 3. 9/11 and global financial crisis had a U/L-shaped impact on air transport (the data for USA only)

As with the fuel burn analyses in Figure 2, a current analysis considers the contribution of: new aircraft technology, improved air traffic management, and infrastructure use. While in the near term (2010 to 2020), fuel efficiency improvements from aircraft design and operational improvements are expected at level of the predefined 2020 targets (Table 2 shows the reached fuel efficiency by new aeroplanes implemented in operation during last years), they are projected to accelerate in the medium term (i.e., 2020 to 2030, see in Figure 4). In the wide-body segment (Twin Aisles – TA), three new aircraft types have been launched last few years: the Airbus A330neo, Boeing 777X and Boeing 787-10. As such the fuel-efficiency characteristics of these aircraft are well-defined and lead us to have a high degree of confidence in their impact, over time, upon fleet efficiency.

Table 1: New aeroplane types recently entered the market

Aeroplane category	Previous Generation (reference)	New generation (latest deliveries)	Entry into service	Fuel saving to reference
Regional Jets	ATR/CRJ, E-Jet	MRJ, E-Jet E2	2020	20–24%
Single Aisles	A320/B737	A220/A320neo/B737 MAX	2016/2017	20%
Twin Aisles	B767	A350/B787	2015/2011	20–25%
	A330/A380/B777/B747-8	A330neo/B777X	2018/2019	14–20%

The ACARE 2020 Goal for aircraft fuel efficiency is looking reached first of all in Technology/Operation domain, consequently the goal for CO_2 reduction also. Overall fleet efficiency improvement associated with replacing baseline fleet with "*imminent*" aircraft is 22.0%. Potential reductions in CO_2 emissions due to anticipated improvements in ATM efficiency and operational practices – assumed aircraft CO_2 emission saving in three main categories: ATM on 6.3%, APU substitution on 0.3%, Aircraft Operations on 2.1%. Total CO_2 emission reduction ATM and operational practices may be reached on 8-9%.

Under the most optimistic Scenario "Optimistic Aircraft Technology and CAEP/9 IE Operational Improvements" (initially considered as 1.5% fuel efficiency improvement per annum for all aircraft entering the fleet out to 2050) 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…1.37% per annum to 2045 with extrapolation to 2050 (Figure 4). This indicates that ICAO's aspirational goal of 2% per annum fuel efficiency improvement is unlikely to be met by 2050 if the evolutionary approach for future aircraft designs will be considered alone.

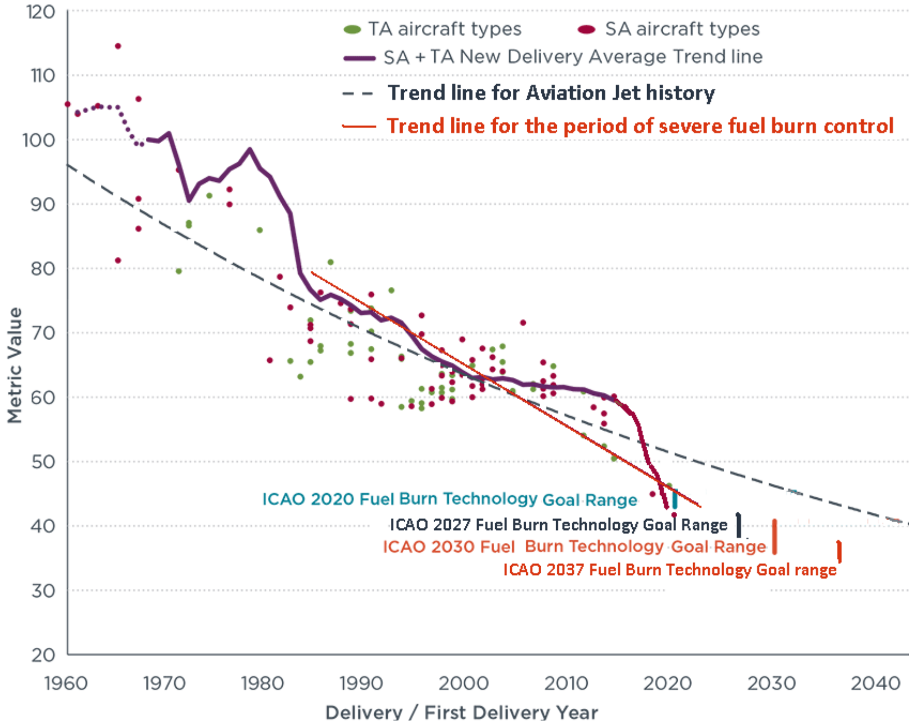


Figure 4. Fuel burn metrics for aircraft in operation and the ICAO/CAEP IE technology goals: CAEP/9 – for midterm at 2020 and long-term at 2030; CAEP/11 – for midterm at 2027 and long-term at 2037 (metric value is equal to 100 to the point when new age SA and TA – Boeng-737 and Boeing-747 – were delivered to the market)

In the narrow-body segment (Single Aisles – SA), the extent to which the Airbus A320neo family and the Boeing 737 MAX will improve upon the fuel efficiency of their respective predecessors is now significantly greater than was understood in 2012. An additional member of the Airbus A320neo family, the A321LR, has been launched. 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 last generation of aeroplanes are due to improvements in their propulsion systems), – up to 20% more fuel efficient than the previous one. For example, if to look on most popular aircraft in operation for passenger transportation the Boeing 737, it took to the skies for the first time in 1967 (it was Boeing 737-100), carrying on board 124 passengers over the distance 2775 km with a total payload around 13 tones. A current most popular version the Boeing 737-800 is carrying on 48 % more passengers, flying 119 % farther with a 67% increase in payload, while burning 23% less fuel—or 48% less fuel on a per-seat basis. Boeing 737 MAX is ~20% more fuel efficient than its predecessor – it is usual for new generation of RJ and SA aeroplanes, TA designs even reached 25% of fuel efficiency improvement (for example in comparison of Airbus 350 or Boeing 787 to Boeing 767). It is a kind of evolutionary technologies' improvement, which is still character for current and next decade of aircraft design development.

By 2050, the contribution of cumulative GHG emissions from international aviation is forecasted between 2.8…5.3% against the 2.0°C budget scenario, and the projected annual emissions in 2050 could lie between 1.8 and 6.6% of global GHG emissions under the RCP4.5 scenario prepared and assessed by IPCC (global mean surface temperature change at the end of the 21st century projected within 1.8°C [9]). Scenario RCP4.5 (Figure 5) is an intermediate IPCC forecasting between a stringent mitigation scenario RCP2.6 and a scenario allowing for very high GHG emissions RCP8.5 among all 4 Representative Concentration Pathways (RCPs) in the latest IPCC's 5th Assessment Report [9].

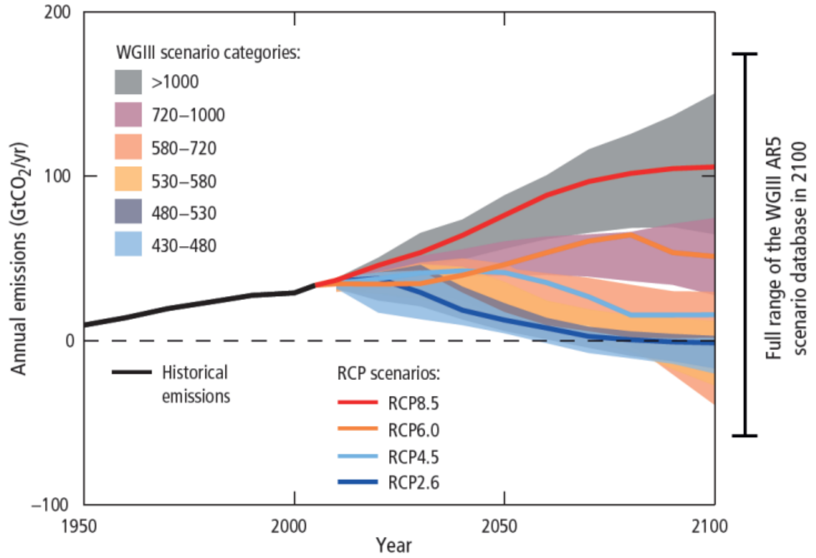


Figure 5. Annual anthropogenic CO_2 emissions, used from [8]

Contribution from international aviation into global CO_2 emission for the scenario RCP4.5 during the period of 2010 – 2050 is presented in Table 2. CO_2 is considered as the main GHG emitted from international aviation, but there is a number of other significant non-CO_2 climate forcing factors arising from emissions of PM, NO_x and H_2O, including the formation of contrails by aircraft during cruise flights. However, because of their much larger uncertainties in comparison with CO_2 emission these forcing factors are not included in consideration in latest IPCC report [9].

Table 2. International aviation's contribution in CO_2 global emission for ICAO and IPCC scenarios

Scenario	Basic description	Contribution in the given year, %				
		2010	2020	2030	2040	2050
CAEP 2019 [7]	ICAO/CAEP Optimistic scenario	1.00	1.29	1.37	1.37	1.37
ICAO current goal [1]	ICAO Policy, long term goal – global temperature rise 2ºC		2.00	2.00	2.00	2.00
ICAO aspirational goal [1]	ICAO Policy, long term goal – global temperature rise 1.5ºC		>2.00	>2.00	>2.00	>2.00
RCP4.5 [9]	Baseline including fleet renewal	1.28	2.02	2.89	4.18	6.58
	Carbon neutral growth from 2020	1.28	1.97	1.80	1.74	1.78

The Paris Agreement objective of pursuing efforts to limit a temperature increase to 1.5℃ is more stringent than the target, which was the basis of the current emission reductions strategy (Figures 1 and 5, Table 2), which also left the 2050 ambition open, setting a range of 80-95% cuts, but in practice mostly working towards the lower end of that range. Considering that global temperatures have already risen at least 0.8℃ and GHG concentrations are increasing rapidly aviation (international and domestic) must decarbonise itself by 2050, so as all the impacting sectors in general. Meeting the goals of the Paris Agreement will require rapid near-term emissions reductions.

Substantial reduction of CO_2 in aviation sector may be achieved with SAFs implementation (Figure 1 and 5, Tables 2 and 3) [4], in combination with market-based measures [5], which are considered as an important instrument for pushing SAFs into the air transportation market. The values for RCP4.5 in Table 2 are higher than the same values for expected aircraft flight fuel efficiency put in forecasting by CAEP, but once again they are not enough to reach the 2% annual reduction technology goal defined by ICAO Policy [1].

Table 3. Ongoing and potential future mitigation measures

Measures	CO_2	Change in non-CO_2	Assumption considered
Market-based measures, ICAO CORSIA [5]	✔	✘	
Technology improvements [6] and CO_2 Airplane Standard [10]	✔ up to 25% reduction in 2050	✔(if fuel ↓; small ↓ NO_x), potentially small ↑ in contrails	1.5% efficiency improvement per year for new aircraft entering the fleet
Operational improvements [6]	✔ up to **9% reduction**	✔(if fuel↓; small↓NO_x)	• Electric taxiing systems • Removing constraints on vertical and horizontal profiles flight • optimized descent profiles • RNAV routes, dynamic airspace configurations, ADS-B use
Lower carbon footprint SAF [4]	✔up to **41% reduction**	✔ reduced aromatics and sulphur in fuel: decreased contrails, decreased direct negative RF from S aerosol, unknown changes in aerosol – cloud interactions	• 100% replacement with SAF. • Scenario would require a substantial expansion of the agricultural sector. • approximately 170 new large bio-refineries to be built every year from 2020 to 2050, at an approximate capital cost of US$15 to 60 billion per year
Carbon neutral synthetic fuels	✔		***?***

The modeling assessment shows that up to 100% of jet fuel demand in international aviation sector could be met using SAFs in 2050, providing neutral carbon growth of aviation during the period 2020-2050. SAFs are considered as biofuels first of all, since 2008 six types of biofuel for aviation production pathways have been certified up-to-date, and other pathways are in the qualification process, utilising a variety of feedstocks worldwide including non-crop sources such as waste oils, waste gases and municipal wastes. Projects to produce SAF providing at least a 70% life cycle carbon savings compared to fossil fuel are presently under development elsewhere in the world. They will be able to reduce net global life-cycle CO_2 emissions from commercial aviation immediately because they are drop-in fuels, so they are compatible with existing aircraft and system infrastructure – therefore they can be used without any modification to present aircraft. They are qualified for use in up to a 50% blend with fossil fuel, with the potential for higher blends in future. In comparison with conventional jet fuel the combustion of equivalent amounts of the SAFs is also producing lesser amounts of other harmful emissions, such as sulphur oxides and particulate matter.

3. New technology requirements for next aircraft generation

The world aerospace industry is a big success story and now again an air transportation system is in a period of great change and generational shift. During last decades the importance of aircraft efficiency has increased with the rise in jet fuel prices first of all [11] – due to high fuel prices different aircraft concepts have been taken into consideration, including the usage of varied fuel types [12, 13], but also the usage of more electricity.

Today ICAO is concerned with international aviation GHG emissions mostly – Volumes III [3] and IY [5] to Annex 16 are the latest ICAO standards for Environment Protection from civil aviation impact. Ambitious goals, unveiled by US NASA [14] with its N+3 goals or the European Commission with the Strategic Research Innovation Agenda (SRIA) – *Flightpath 2050* [15] challenges and goals, are confronting the aviation community with new challenges in aircraft design and operation due to new technologies implementation (Table 4). Those goals are targeting significant power efficiency, emission and noise reductions for future aircraft designs, so the aviation sector is likewise under governmental and international pressure to reduce further the impact on environment significantly.

Table 4. Comparison of long-term goals for environmental impact factors of aviation between the Policy of ICAO, EU and USA on Research and Development

Environmental impact factor from aviation	**ICAO** Policy Goals [1]	**EU ACARE Goals** (FP2050 till 2050) [15]	**US FAA and NASA Goals** (NSTC2010 [14] and CLEEN II [16] 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)
NOx emissions	***Limit or reduce the impact of aviation emissions*** on local air quality	***90% reduction in NOx 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 CO2 emissions*** per passenger kilometre	***60% reduction in Aircraft Fuel/Energy Consumption*** (CO$_2$ emissions per passenger kilometre) relative to 2000 best in class

Technologies currently at Technology Readiness Level (TRL) 3-5 cannot achieve the EU goal on 75% reduction in energy consumption and carbon dioxide emissions in 2050. It is estimated that around a 30% reduction must come from radical innovations now being at lower TRL. The EU ULTIMATE project elaborated two aircraft concept designs at TRL1. For a shortrange (RJ and SA) aircraft mission, the project estimated a 55% reduction in CO$_2$ whereas for the TA aircraft a 46% reduction was achieved, both relative to year 2000 in-service baseline aircraft.

The same EU ULTIMATE project explored the capability for local air quality emission to demonstrate:

- 15-20% reduction in NO$_x$ emission and a 10% reduced core engine weight over a year 2050 reference configuration;
- Globally by 87% relative to year 2000 state-of-the-art.

There is expected 75% of the Landing-Take-Off (LTO) cycle nitrogen oxide relative to CAEP/6 even till 2035. Good progress has been shown on state-of-the-art Single Annular Combustors with rich burn (air blast) injection, Double Annular Combustors/Axially Staged Combustors (rich pilot / rich main) and Lean Burn Combustors. The latest state-of-the-art lean burn fuel injection systems with centrally integrated pilot fuel injection for flame stabilisation have achieved up to 70 to 75% of NO$_x$ reduction at TRL3 (demonstrated in a high-pressure single sector combustor test rig) relative to the CAEP/2 certification standard. A technology deterioration factor, which describes the transition from TRL3 to TRL6 needs to be considered, leading to likely technological progress by the end of Framework 7 of a range of approximately 60 to 65% NO$_x$ reduction. It is most likely that in Horison-

2020 research initiatives will need to focus on further improvements towards 70 to 85% NO_x reduction, which may lead to another 50% relative NO_x reduction [17].

During the combustion of hydrocarbon-based fuels, aircraft engines generate gaseous and particulate matter (PM) emissions. At the engine exhaust, particulate emissions consist mainly of ultrafine soot or black carbon emissions. These particles, referred to as “non-volatile” PM (nvPM), are present at high temperatures, in the engine exhaust. Compared to conventional diesel engines, gas turbine engines emit non-volatile particles of smaller mean diameter. These particles are invisible to the human eye and are ultrafine. The CAEP/11 meeting in 2019 recommended a new nvPM mass and number standard for aircraft engines and this will be considered by the ICAO Council for adoption in the early part of 2020. The new nvPM standard will apply to new type and in-production engines with rated thrust greater than 26.7kN from 1 January 2023. The limit lines for nvPM mass and number provide some alleviation for engines with rated thrusts below 150kN. This standard is less stringent for in-production engines and a supplementary “no-backsliding” measure was introduced. The new nvPM standard is the first of its kind, and it includes a full standardized certification procedure for the measurement of nvPM, and the regulatory limit for the nvPM mass concentration set at the current ICAO smoke visibility limit. The new nvPM standard is recommended as a new Chapter to Annex 16, Volume II.

CAEP will also continue to monitor and review technology developments, including combustion technologies and advances in engine combustor design, with a view to understanding how these technologies may impact the production of gaseous emissions and PM in the future. The recommendation on the new nvPM mass and number Standard was accompanied by an agreement by CAEP to conduct an early review of the relevant regulatory levels. This will involve the collation and analysis of the certified and certification-like nvPM mass and number emissions data that will become available for all in-production engines during the period 2019 to 2022. The margins to the agreed CAEP/11 nvPM SARPs will be reviewed to assess possible technological advancements to reduce nvPM emissions. With this new Standard, ICAO will have completed the main environmental Standards for the certification of aircraft and engines, namely for noise, local air quality (NO_x, HC, CO, nvPM) and climate change (CO_2), making the aviation industry the only sector with mandatory environmental certification requirements at the global level for the operation of its equipment. Once applicable, all new aircraft will need to be certified to these ICAO standards before operating. *Among the Challenge 3 goals from ACARE any targets for nvPM emission reduction is absent.*

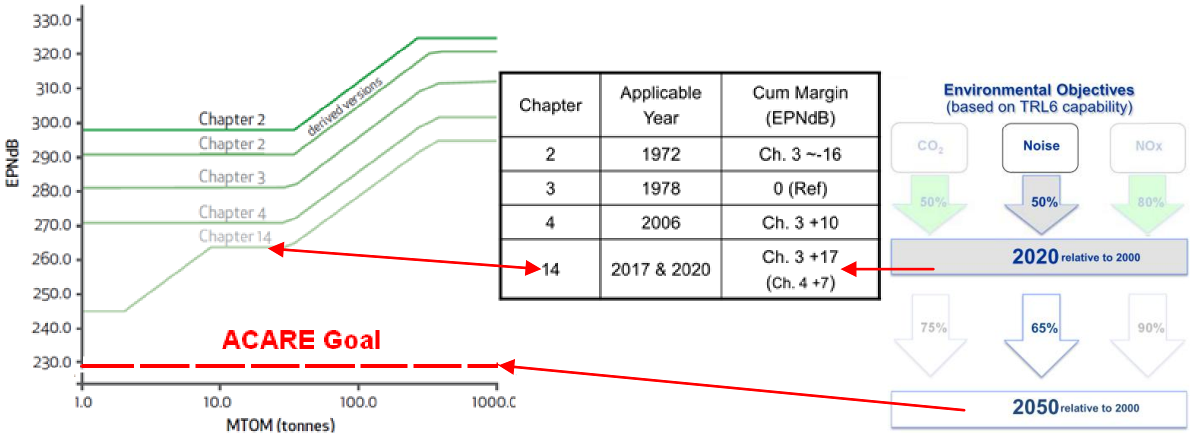
During the current CAEP/12 cycle (2019-2022) it is also planned to conduct a scoping study for NOx for in-production engines to investigate the feasibility for further NOx stringency analysis. ICAO continues to monitor developments in aeroplane and engine applications, and concepts to develop methodologies for emissions certification. In addition, advancements in supersonic technologies are being monitored to assess possible consequences for aeroplane and engine based emissions and an exploratory study to provide a better understanding of airport noise impacts resulting from the introduction of supersonic aircraft is ongoing.

The ULTIMATE propulsion concepts will reduce aircraft noise per operation:

- by 3 dB stemming from newish propulsion technologies alone;
- Globally by 15 dB relative to year 2000 state-of-the-art.

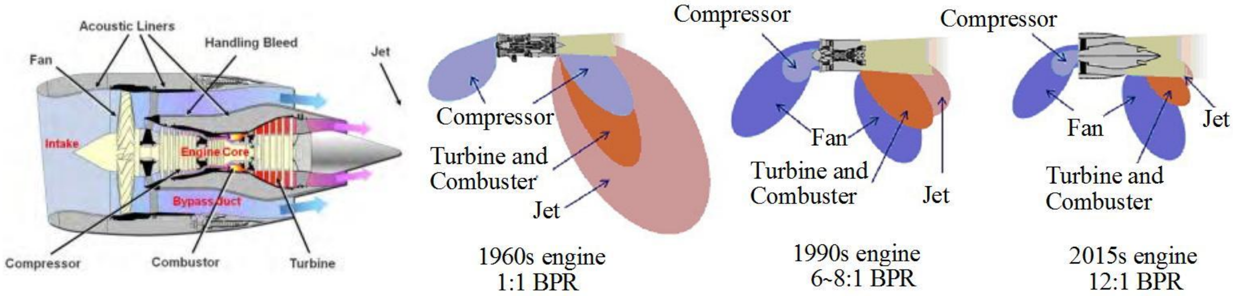
Since the start of the jet age, enormous progress has been made in lowering noise levels (Figure 6) and reducing the noise footprint per aircraft movement. Only in the last 15 years alone Rolls Royce and other engine manufacturers have continued to improve aircraft engine design, resulting in a sustained reduction in noise each time a new aircraft engine is introduced, first of all due to increasing their by-pass ratio (BPR), and, of course, supporting new standard influence on aircraft noise exposure reduction around the airports as illustrated in Figure 6. In by-pass engines, the main sources of noise are the fan, jet and gas generator. Figure 7 shows a typical directivity pattern and qualitative distribution of noise power between the main noise sources of turbojet with varying of their bypass ratio. Thus, in current turbofans with a large bypass ratio the fan is the main source of broadband and discrete noise in upstream and downstream directions, and the jet and gas generator make a significantly smaller contribution to the overall noise level of the engine. During the 50 years of aircraft noise standardization from ICAO (1st Edition of Annex 16 – Aircraft Noise was in 1969)

Chapter 2 to 14 the cumulative decrease was reached up to ~35 dB, close to this value is necessary to be reached till the ACARE noise goal at 2050. In 2014, ICAO adopted a new (latest) standard that will result in a reduction of 7 EPNdB compared to the Chapter 4 Standard, so in-production aircraft are prohibited to be manufactured with noise higher than Chapter 14 requirements (Figure 6).



Chapter	Applicable Year	Cum Margin (EPNdB)
2	1972	Ch. 3 ~-16
3	1978	0 (Ref)
4	2006	Ch. 3 +10
14	2017 & 2020	Ch. 3 +17 (Ch. 4 +7)

Figure 6. ICAO requirement to aircraft noise and ACARE 2050goal



a) b)

Figure 7. Typical directivity patterns and qualitative distribution of noise power between the main sources (a) in dependence with varying by-pass ratio (BPR) (b) of the turbofan engines

For higher BPR the size and weight of the engine nacelle and the limited space for acoustic liners and other noise reduction measures point towards the open rotor. The propfan promises reductions in fuel consumption up to 20% corresponding to a BPR of 30-40 not feasible with engine nacelles. The reductions in fuel consumption have direct benefits in lower emissions and better economics. However, increasing the BPR further, whilst delivering additional jet noise reductions, would not deliver such significant reductions in aircraft noise due to other noise sources (especially fan noise) becoming dominant. Such ultra-high-bypass-ratios introduce additional design challenges including the increased engine installation drag and weight, the mechanical design of the fan, and the aerodynamic performance of the fan, compressor and low-pressure turbine.

In conclusion relative to the ACARE noise target of -10dB per operation, the aircraft noise research effort can be considered as globally on track to meet its objective but will require significant support in the few years remaining before 2020. Midterm EU ACARE noise goal in 2020 will be reached by improvements up to current models A-320neo and Boeing-737MAX. Midterm EU ACARE goal in 2030-35 are expected to be reached by improvements in TA sector in aircraft fleet up to current models A-330neo, A-350XWB and Boeing-777X, B-787-9. Noise exposure footprints of the new aircraft (data provided by Airbus [18]):

- The design noise footprint of the A320neo (MTO=68.3t) is nearly a square kilometre smaller than older A320-214 aircraft (MTO=68t), Figure 8a;
- The Boeing 737 MAX noise footprint is more than 1.7 square kilometres smaller than the 737 NextGen (737 MAX 8 with LEAP-1B compared to 737-800 with CFM56-7B);

- The A350-900 (MTO=252t) noise footprint is to be over 2.5 square kilometres smaller than the A340-300 (258t);
- The Boeing 787-8 with Trent1000 noise footprint is more than 2.4 square kilometres smaller than the aircraft it replaces - 767-300ER with CF6-80C2, Figure 8b.

Figure 8. Noise footprint for 85 dBA SEL for new generation aircraft: a) A320neo; b) Boeing 787-8

The goals indicated in Table 5 for 2020 and 2030 provide a reference for potential future developments and are combined with existing aircraft data for the same weight categories (namely Regional Jets **RJ**, Short/Medium Range two-engine aircraft **SMR2**, Long Range two-engine aircraft **LR2** and Long Range four-engine aircraft **LR4**) over the period 1960 to 2020.

Table 5. CAEP IEP2 Aircraft Noise Goals for short-medium (2020) and long (2030) term [19]

Aircraft type	Reference		Mid Term Goal (2020) TRL6			Long term goal (2030) TRL6		
	cumulative margin (EPNdB) v chapter 4	Bypass ratio	cumulative margin (EPNdB) v chapter 4	reduction EPNdB: Total (BPR,NRT)	Bypass ratio	cumulative margin (EPNdB) v chapter 4	reduction EPNdB: Total (BPR,NRT)	Bypass ratio
Regional jet	4	5.0	14	10.0 (6.0 ,4.0)	7 ± 1	21.5±4.0	17.5 (12.0, 5.5)	9 ± 1
Small-medium range (turbofan)	5	5.0	22.5	17.5(12.0, 5.5)	9 ± 1	30.0 ±4.0	25.0(18.0 , 7.0)	13 ± 1
Small-medium range (CROR)	5	–	–	–	–	7.5 → 15.5	8.5	–
Long range twin (Turbofan)	6	6.0	22	16.0 (10.5, 5.5)	10 ± 1	28.0 ±4.0	22.0 (15.0, 7.0)	13 ± 1
Long range quad (Turbofan)	5	5.0	22.5	17.5 (12.0, 5.5)	9 ± 1	27.0 ±4.0	22.0 (15.0, 7.0)	11 ± 1

Over the last decades, the increasing globalization and the associated need for substantially shortened travel times has led to public and privately-funded development of supersonic aircraft. Supersonic transportation (SST) is focused on making the planet dramatically more accessible through supersonic flight. At the beginning a small number of SST aeroplanes is expected to be flying a limited number of business jet airport-pairs and a limited number of commercial air transport airport city-pairs. Dubai and London Heathrow are expected to be the two busiest airports, accounting for 7% and 6%, respectively, of daily SST movements. The environmental impact of civil supersonic aeroplane projects remains a major concern. The adoption of certification standards that would allow higher noise levels than those for current and future subsonic aeroplanes does not guarantee the public acceptability of supersonic aeroplane projects in Europe. The authors of the paper [20] consider that the environmental impact must be addressed holistically for noise and emissions before considering the introduction of supersonic aeroplane projects into the global air navigation system.

For sonic boom the level of 65 dBA has been set as technical target for unrestricted operations. For community noise the SST 2.0 targets were considered as mid-term objectives for subsonic aircraft – ICAO Chapter 4 - 10dB. This new noise standard requirement is likely to apply to the future SST aircraft when operating in the subsonic speed regime to ensure some margin for operational flexibility and technological viability, this noise level of the SST will not be higher than current small business jets, as indicated in Figure 9. And for emissions during LTO operations (ground emissions), the targets are considered as ICAO mid-term objective for subsonic aircraft, for cruise emissions, an integrated approach combining aircraft + engine design and ways to operate it, allowed to optimize the emissions during cruise and to demonstrate the very low climate impact of a supersonic fleet. In terms of species quantification, the mid-term objective of EI_{NOx} has been revised to 10-12 g/kg fuel burnt.

Promising technologies have been identified to reach these targets. Among them we can quote: variable confluence engine, innovative noise suppression systems, low boom technologies, challenging architectures and structures. Some of these technologies have links with subsonic aircraft ones (for ex. low NO_x combustion chambers). Links with other relevant projects (concerning sub and supersonic aircraft) have been identified. In most of the cases the TRL of the specific technologies identified in HISAC is rather low.

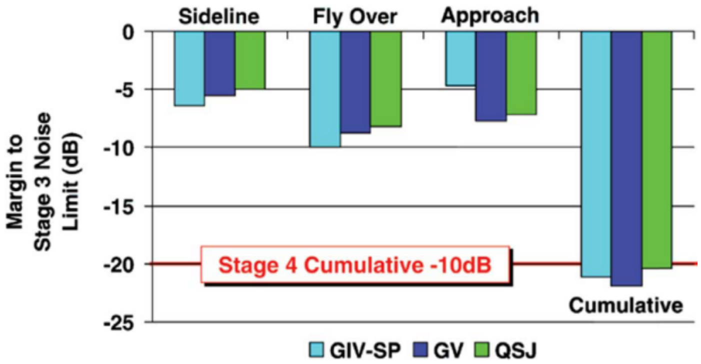


Figure 9. SSBJ community noise requirements (Source: [Henne P.A., 2005])

In 2018, Austria presented to ICAO a working paper [20] on behalf of the European Union, of all EU Member States, of other Member States, of the European Civil Aviation Conference, and of EUROCONTROL. The paper clearly states that less stringent noise limits would jeopardize the public acceptability of supersonic aircraft and that the emission regulations in Chapter 3 are outdated. The European position is to:

1) target the ***same*** noise limits for *supersonic* and *subsonic* aeroplanes;
2) revise Chapter 3 to provide an incentive to fit aeroplanes with best available environmental technology;
3) introduce carbon dioxide emission regulations, and
4) investigate the climate impact of the supersonic fleet especially with regard to the higher altitudes at which these aircraft would operate.

The authors of this paper [20] are of the opinion that internationally agreed environmental certification standards are essential for the sustainable development of the aviation sector. Past development of subsonic noise standards has been effective at ensuring public acceptability of subsonic aircraft operations as one element contributing to the balanced approach to noise management. Therefore, the adoption of standards that would allow higher noise levels than subsonic aircraft does not guarantee the public acceptability of supersonic aeroplane projects in Europe. Such a situation would inevitably call into question the purpose of ICAO Standards. Early evidence available indicates that supersonic aeroplane projects will not be able to meet current noise limits of subsonic aeroplanes due to criteria that designers have set themselves while detailed information on HISAC preliminary study indicate that it could be possible to design a supersonic aeroplane that meets maximum permitted noise levels for subsonic aeroplanes, even with conventional engines [20].

Looking on enormous progress reached in aircraft noise levels (Figures 6-8) and the noise exposure footprint (aircraft produced today are 75% quieter than those of 50 years ago) reduction per aircraft movement, for example like only Rolls Royce (alone or with other engine manufacturers) has continued to improve aircraft engine design for fuel consumption, noise and engine emission in the last 15-20 years, as illustrated in Figure 7b by growing BPR, and, of course, supporting new standard influence on aircraft noise exposure reduction around the airports, these new quiet aircraft typically output half the noise of the aircraft they are replacing, so air traffic movements can double without increasing the total noise output. In more detail, airport [21] predicts that as current aircraft are replaced by '*Imminent*' and '*Future*' aircraft, the noise exposure from EU aviation reduces by around

20%, which is close to current EU Eurocontrol forecasting. In 2014, ICAO adopted a standard Chapter 14 of ICAO Annex 16, 2019 that will result in a reduction of 7 EPNdB compared to the Chapter 4 Standard (Figure 6), so in-production aircraft are prohibited to be manufactured with noise higher than requirements. But introduction of new supersonic aircraft (SST 2.0) may misbalance reached progress for subconic aircraft transportation, if their requirements to noise will not be in accordance with Chapter 14 (as it is expected now – only Chapter 4 standard is looking achievable with existing technologies nowadays). So for particular airports in EU (around 10 in following decade), where the SST 2.0 will contribute to their noise exposure, and the expected overall aviation noise exposure reductions (by around 20% in forecasted period) will be much less. For community noise the SST 2.0 targets were considered as mid-term objectives for subsonic aircraft – *ICAO Chapter 4 - 10dB*. This new noise standard requirement is likely to apply to the future SST aircraft when operating in the subsonic speed regime to ensure some margin for operational flexibility and technological viability, this noise level of the SST will not be higher than current small business jets, as indicated in Figure 9.

As populations in megacities continue to grow, the increased urbanization and traffic situation is pushing ground transport systems to their limits. Bringing urban mobility to the third dimension offers the potential to create a faster, cleaner, safer, and *more integrated transportation system*. Urban Air Mobility (UAM) refers to a range of vehicle concepts and missions operating in a community, from small Unmanned Aerial Systems (sUAS) to vehicles large enough for several passengers. Setting up a suitable UAM infrastructure is a major challenge for any city. *Airbus* predicts that, by 2030, the UAM market will be worth an accumulated $50 billion, less than half of which will go to vehicle makers. Electric propulsion is seen as a key technology that could enable these kinds of systems, across the range of vehicle types and sizes. The embracement of mostly electric or hybrid UAM will contribute to *low carbon and resilient cites*, in line with EU policies, conducting in different tasks dedicated to energy and environmental impact. New aircraft technologies for increased mobility are likely to lead to new sources of community noise – *unfortunately even the latest version of* [15] *is not looking on this subject at all*, though there are already over 200 sUAS concepts currently in development [22]. *It is an evident gap* in [15] and not only concerning to noise reduction.

Many of these sUAS are harnessing electrical power in a bid to be more environmentally and economically sustainable, with multiple electric vertical takeoff and landing (eVTOL) aircraft taking shape. The market of eVTOL concepts is broadly diversified, with a common set of technologies such as electric propulsion. Other programs are looking beyond electricity to alternative energy sources such as hydrogen fuel cells. Compared to a traditional single main rotor helicopter with combustion engine, an eVTOL should be significantly quieter, more reliable and safer and significantly less expensive. At flying altitude, noise from advanced eVTOLs will be barely audible. Even during take-off and landing, the noise will be comparable to existing background noise. Preliminary first order noise analysis showed that noise exposure is expected to be more severe near the take-off and landing areas – noise level comparisons were shown for Robinson R22 and it's quieter versions. Size of noise 65 dBA L_{Amax} footprint in observed scenario, where the new helicopter is 30 dBA quieter than original helicopter (R22-30), is smaller for arrival area and larger for departure area around the heliport.

The vision for 2030+ is to demonstrate innovative and disruptive technologies, enabling new aircraft performance levels, and opening up new business models. By mid-2030, the mobility of people and goods is expected to undergo progressive changes, especially over distances of less than 500 km (inter-urban regional connections). Innovations and technologies related to propulsion, optimisation of different fuel types and airframe characteristics will reach higher levels of maturity, becoming available for regional air transport as well as other present and future air vehicles operating in that distance frame. Air vehicles operating in this range and operational environment (including regional aircraft with a capacity of up to 80 seats) are considered the first application in the scheduled air transport system that will adopt hybrid-electric propulsion technologies for reducing the environmental footprint, toward climate-neutral aviation. Air vehicles operating at smaller distances or on thinner routes will also benefit from electric propulsion solutions tested on regional aircraft testbeds, by sharing the development of power modules and making use of different approaches to air vehicle integration.

It is clear that dealing with global warming and climate change issue is holistic and should be analysed with a systemic perspective. A European Strategic Research Agenda for climate-friendly transport' project, which was co-financed by the European Commission, in their study presented the main results based on their findings, that technology alone would not be sufficient to achieve the necessary reductions in carbon emissions and they proposed that integrated solutions should be necessary. For instance, technological improvements might offer significant GHG reduction potential, but strong interventions in policy schemes would be needed. In addition, they asserted that long-term technological solutions could not be treated independently from the short-term behavioural change and behavioural and social changes should be recognized as paramount. Therefore, they concluded that there was a number of vital reasons why significant climate policy for the transport sector was not being effectively developed at the EU supranational level and implemented in member states.

The typical time between aircraft generations replacing each other is in the order of 20 years, sometimes longer. With new aircraft models currently being introduced in almost all seat categories, it is uncertain if the next generation of aircraft will arrive before the 2030s except in the 211 – 300 seat category, as seen in Figure 10.

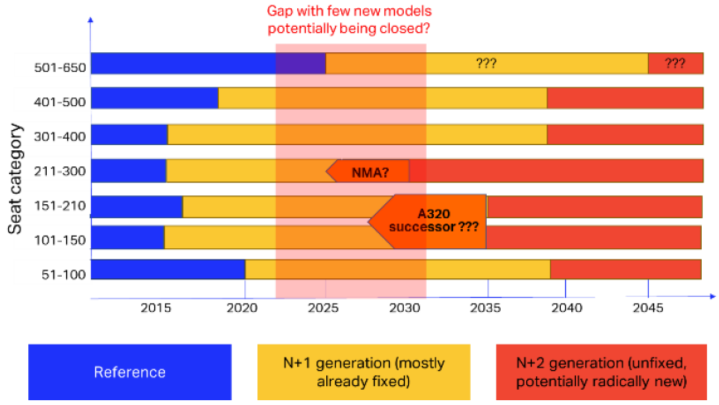


Figure 10. Expected sequence of future aircraft generations in different seat categories, including recent indications on new developments

The international standards for the implementation of CORSIA have in the meantime been adopted as an Annex to the Chicago Convention [5]. CORSIA is the first Global MBM for any sector and represents a cooperative approach that moves away from a "patchwork" of national or regional regulatory initiatives through the implementation of a global scheme that has been developed through global consensus among governments, industry, and international organizations. CORSIA aims to stabilize net CO_2 emissions from international civil aviation at 2020 levels. In 2010, ICAO adopted two Global Aspirational Goals Carbon neutral growth from 2020 onwards (CNG2020) 2% annual fuel efficiency improvement through 2050. Resolution A40-18, paragraph 9: "The Assembly… Requests the Council to continue to explore the feasibility of a long-term global aspirational goal for international aviation, through conducting detailed studies assessing the attainability and impacts of any goals proposed, including the impact on growth as well as costs in all countries, especially developing countries, for the progress of the work to be presented to the 41st Session of the ICAO Assembly. Assessment of long-term goals should include information from Member States on their experiences working towards the medium term goal". Main reason for new LTAG is a latest Paris Agreement [9]: "… emission pathways consistent with holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C". The aviation sector is committed to advances in technology, operations and infrastructure to continue to reduce the sector's carbon emissions. Offsetting is not intended to replace these efforts. Nor would CORSIA make fuel efficiency any less of a day-to-day priority. Continued aviation CO_2 emissions to 2050 will be inconsistent with 1.5 degree emission, Table 3. Rather, CORSIA can help the sector achieve its climate targets in the short and medium term by complementing emissions reduction initiatives within the sector. The aviation sector is also committed to reduce its net CO_2 emissions to half of what they were in 2005, by 2050. Achieving this ambitious goal will require continued investment in new technologies and strong support mechanisms for the deployment of SAFs. Offsetting required and provided by CORSIA will allow an airline to compensate for its emissions by financing a reduction in emissions elsewhere. While carbon offsetting does not require them to reduce their emissions "in-house", it provides an environmentally effective option for sectors where the potential for further emissions reductions is limited. There are many ways to achieve CO_2 reductions that can be used as offsets, many of which bring other social, environmental or economic benefits relevant to sustainable development.

Conclusions

The need and challenge of tackling climate change is an unrelenting priority. The European Commission issued the report "A Clean Planet for All", where highlights the pressing need for deep decarbonisation. It shows the scale of the contributions from various sectors, including transport, towards the required level of decarbonisation in the EU by 2050. The key challenge facing the aviation sector in this and the next decades is to develop and introduce safe, reliable, and affordable low- to zero-emission air transport for citizens and to concurrently ensure Europe's industrial leadership is maintained and strengthened throughout the transition to a climate-neutral Europe. Today's aircraft are 75% more fuel (and CO_2) efficient than aircraft from the early jet age, but by 2050, the contribution of cumulative GHG emissions from aviation sector is forecasted between 2.8…5.3% against the 2.0°C budget scenario, and the projected annual emissions in 2050 could lie between 1.8 and 6.6% of global GHG emissions under the RCP4.5 scenario prepared and assessed by IPCC. It is clear that dealing with global warming and climate change issue is holistic and should be analysed with a systemic perspective. In 2010, ICAO adopted two Global Aspirational Goals adding to 2.0°C budget scenario a Carbon neutral growth from 2020 onwards (CNG2020) 2% annual fuel efficiency improvement through 2050. Ambitious zero- and low-emission technologies will drive these transformations in aviation sector. These include hybrid-electric solutions for regional and short-range flights and ultra-efficient aircraft designs utilising thermal engines suited for the adoption of SAFs covering the larger and more energy intense medium and long-range sectors. GMBM CORSIA must help the aviation sector achieve its climate targets in the short and medium term by complementing emissions reduction initiatives within the sector, but ***GMBM principles are not included in current ACARE Flightpath 2050 vision – evident gap that must be covered first of all.***

Among the Challenge 3 goals from ACARE perspectives [15] ***any target for nvPM emission reduction is absent*** also. nvPM is considered currently as the most impacting emission on air quality in urbanized locations, this is valid for airport LAQ assessments and the first ICAO mass and number standard for new types and in-operation aircraft is considered as a first step to control the nvPM aircraft engine emission efficiently.

In 2014 ICAO adopted a standard Chapter 14 of ICAO Annex 16, 2019 that will result in further reduction (on 7 EPNdB compared to the previous Chapter 4, as shown in Figure 6), so in-production aircraft are prohibited to be manufactured with noise higher than requirements. Latest assessments predict that as current aircraft are replaced by '*Imminent*' and '*Future*' aircraft, the noise exposure from EU aviation reduces by around 20%, which is close to current EU Eurocontrol forecasting.

But introduction of new supersonic aircraft SST 2.0 may misbalance reached progress for noise exposure from subconic aircraft transportation, if their requirements to noise will not be in accordance with Chapter 14. In following decade the SST 2.0 will contribute to their noise exposure in around 10 EU airports, and the expected overall aviation noise exposure reductions (by around 20% in forecasted period) will be much less. ***The targets for SST 2.0 noise should be considered in ACARE vision as mid-term and long-term objectives like for subsonic aircraft.***

New aircraft technologies for increasing from day-to-day urban mobility are likely to lead to new sources of community noise – ***unfortunately even the latest version of*** **ACARE vision till 2050** ***is not looking on this subject at all***, though there are already over 200 sUAS concepts currently in development. *It is an evident gap* and not only concerning to noise reduction.

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