



# **Clean Sky 2**

## **Technology Evaluator**



**First Global Assessment**  
**2020**

-

**Technical Report**

**May 2021**



Page intentionally blank



**Legal disclaimer / Copyright Note**

The copyright for this document belongs to the Clean Sky 2 Joint Undertaking.  
It contains proprietary information not to be distributed/reproduced/disclosed  
without prior written authorisation of the CS2JU.  
Any unauthorised use of the information contained in this document is prohibited.

TE\_1<sup>st</sup>\_GA\_2020\_Tech\_Rep\_v6.pdf



## Table of Contents

List of Acronyms .....	6
List of Figures.....	9
List of Tables.....	12
Executive Summary .....	13
1 Introduction.....	21
2 Technology Evaluator .....	23
2.1. Overall Assessment Timeline .....	24
2.2. First Assessment – Interim Results.....	24
2.3. Key Indicators and Metrics.....	24
2.3. Preliminary Note on COVID Impact.....	26
3 A Vision for the Future .....	27
3.1 Concept Aircraft .....	29
3.2 Reference Aircraft .....	31
4 Methodology .....	32
4.1 Assessment at three Levels: Mission, Airport and Global Fleet.....	32
4.2 Forecast and Scenarios.....	32
4.2.1 Overall Assumptions and Airport Capacity Constraints .....	33
4.2.2 Passenger and Flight Volumes.....	36
4.2.1 Aircraft In Service .....	37
4.2.2 Aircraft Size.....	38
5 Environmental Impact .....	40
5.1 Mission Level .....	40
5.1.1 Fixed-Wing Aircraft.....	41
5.1.2 Fast Rotorcraft.....	77
5.1.3 Synthesis of Interim Results at Mission Level .....	94
5.2 Airport Level .....	96
5.3 Fleet Level (ATS) .....	98
5.3.1 Fleet Replacement.....	98
5.3.2 Towards Larger Aircraft.....	99
5.3.3 Towards Shorter Range .....	102
5.3.4 CO <sub>2</sub> and NO <sub>x</sub> impact at fleet level.....	107
6 Societal Impact .....	109
6.1 Connectivity and Mobility .....	109
6.2 Macroeconomic Effect .....	111
6.3 Competitiveness and Societal Impact .....	113



7	Impact of COVID-19.....	116
8	Outlook towards the Second Assessment.....	118
9	Conclusions.....	122



## List of Acronyms

Acronym	Definition
a/c	aircraft
AEO	All Engine Operative
AHF	Airport Hub Feeder
AIR	Clean Sky 2 Airframe ITD
ATAG	Air Transport Action Group
BPR	By-Pass Ratio
CDR	Critical Design Review
CfP	Call for Proposals
CFRP	Carbon Fibre Reinforced Plastic
CGT	Cargo Transport
CIT	Commercial Intercity Transportation
CO <sub>2</sub>	Carbon Dioxide
CP	Core Partner
CS2	Clean Sky 2
CS2JU	Clean Sky 2 Joint Undertaking
dB	decibel
dB(A)	decibels on the A Scale
EIS	Entry Into Service
ENG	Clean Sky 2 Engine ITD
EPNL	Effective Perceived Noise Level in decibels (EPNdB)
ECO	Clean Sky 2 Eco-Design Transversal Activity
EMS	Emergency Medical Services
fpm	feet per minute
ft	feet
FL	Flight Level
FRC	Clean Sky 2 Fast RotorCraft IADP
FSW	Friction Stir Welding
FTB	Flying Test Bed
GAM	Grant Agreement for Members
GAP	Grant Agreement for Partners
HLD	High Lift Device
IADP	Innovative Aircraft Demonstration Platform
ICAO CAEP	International Civil Aviation Organization – Civil Aviation Environmental Protection
IFR	Instrument Flight Rules
IPPS	Integrated Power Plant System
ISA	International Standard Atmosphere
ITD	Integrated Technology Demonstrator
kft	kilo-feet
kg	kilogram
km	kilometer
KPI	Key Performance Indicator

Acronym	Definition
KTAS	Knots True Air Speed
LA <sub>MAX</sub>	A-weighted maximum sound Level
Lden	Day-evening-night acoustic level
Lnight	Night acoustic level
LMD	Laser Metal Deposition
LFL	Landing Field Length
LPA	Clean Sky 2 Large Passenger Aircraft IADP
LR	Long Range
LRI	Liquid Resin Infusion
m	meter
Ma	Mach number
MLW	Maximum Landing Weight
MTOW	Maximum Take-Off Weight
MZFW	Maximum Zero Fuel Weight
n/a	not available
nm	nautical miles
nvPM	non volatile Particulate Matter
NGCTR	Next Generation Civil Tilt Rotor
NO <sub>x</sub>	Nitrogen Oxides
OAG	Oil And Gas
OoA	Out of Autoclave
OEI	One Engine Inoperative
OEW	Operative Empty Weight
Pax	Passenger
PAT	Passenger Air Transport
RACER	Rapid And Cost Effective Rotorcraft
REG	Clean Sky 2 Regional IADP
SAR	Search And Rescue
SAT	Clean Sky 2 Small Air Transport Transversal Activity
SEL	Sound Exposure Level
SELA	Sound Exposure Level dB(A)
SFWA	Clean Sky 1 Smart Fixed Wing Aircraft IADP
SL	Sea Level
SMR	Small Medium Range
SoA	State-of-the-Art
SO <sub>x</sub>	Sulfur Oxides
SPD	Clean Sky 2 Strategic Platform Demonstrator
STOL	Short Take-Off and Landing
SYS	Clean Sky 2 Systems ITD
TA	Clean Sky 2 Transversal Activity (SAT – ECO – TE)
TE	Clean Sky 2 Technology Evaluator
TLAR	Top Level Aircraft Requirements



<b>Acronym</b>	<b>Definition</b>
TOFL	Take-Off Field Length
TP	TurboProp engine
USF	Unducted Single Fan engine
VOC	Volatile Organic Compound
VPF	Variable Pitch Fan engine
VTOL	Vertical Take-Off and Landing



## List of Figures

Figure 1 - Schematic Structure of the Clean Sky 2 Programme. ....	21
Figure 2 – Clean Sky 2 Key Demonstrators.....	22
Figure 3 – Information flow from the SPDs through the Technology Evaluator to the Clean Sky 2 JU.	23
Figure 4 - Metrics, levels and dimensions of the TE assessment. ....	24
Figure 5 – Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers. Source: European Aviation Environmental Report 2019. ....	25
Figure 6 - Illustrations of the main Clean Sky 2 aircraft concepts.....	28
Figure 7 - Assessment levels.....	32
Figure 8 - Comparison of Forecast and Scenarios to other available air traffic predictions.....	33
Figure 9 – Aircraft retirement curves.....	34
Figure 10 - 2035 DLR Forecast vs. ICAO CAEP/11 Forecast in terms of number of flights.....	37
Figure 11 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of number of flights. ....	37
Figure 12 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of in-service passenger aircraft by seat classes. ....	38
Figure 13 – Technology insertion and expected engine performance improvements for LR+ before aircraft integration (Rolls-Royce Ultrafan®). ....	42
Figure 14 – Rolls-Royce Ultrafan® engine concept (left), and comparison of fan diameter with A320 fuselage diameter (right), courtesy Rolls-Royce & Airbus. ....	42
Figure 15 - Emissions and noise performance evolution vs year 2000 and ACARE 2050 targets (courtesy Rolls-Royce). ....	43
Figure 16 - Noise levels in “certification ICAO annex 16 conditions”.....	43
Figure 17 – Advanced Long Range Concept LR+. ....	45
Figure 18 - Technology insertion and expected engine performance improvements for SMR+ before aircraft integration (Safran Aircraft Engines UHPE). ....	47
Figure 19 – Advanced Short-Medium Range Concept SMR+v2. ....	48
Figure 20 – Key enabling technologies for UHPE concept (Safran Aircraft Engines). ....	49
Figure 21 - Noise reduction technologies for UHPE concept (Safran Aircraft Engines). ....	49
Figure 22 – Contra-Rotating Open Rotor demonstrator, Clean Sky 1, SAGE2, Safran Aircraft Engines.	50
Figure 23 – Technology insertion and expected engine (CROR) performance improvements for SMR++ before aircraft integration (Safran Aircraft Engines). ....	50
Figure 24 – CROR ground test demonstrator at Safran Aero Engines’ ground testing facility for Open Rotors and Ultra High By-Pass Ratio engines (Istres, France) – Courtesy SAFRAN.....	51
Figure 25 – Ultra-Advanced Small-Medium Range SMR++ Concept.....	53
Figure 26 - Expected qualitative engine performance improvements for the Advanced TP 90 pax (EIS 2025) before aircraft integration (Avio Aero). Total impacts vs Ref 2014 are for the overall aircraft concept.....	55
Figure 27 – Advanced Regional Turboprop 90 pax Aircraft Concept. ....	56
Figure 28 – Velocity field around wing profile (left) and details of droop nose and Fowler flap (right). .....	58
Figure 29 - Expected qualitative engine performance improvements for the Innovative TP 130 pax (EIS 2035) before aircraft integration (GE Avio) – IRON USF engine (REG – CS2 IRON WP1.1.2). Total impacts vs Ref 2014 are for the overall aircraft concept. ....	58
Figure 30 – Innovative Regional Turboprop 130 pax Aircraft Concept.....	59
Figure 31 – C-295 landing on a grass strip in Kenya, courtesy Airbus Defense & Space.....	61



Figure 32 - Airbus C295, purchased by the Government of Canada for the Royal Canadian Air Force's (RCAF) Fixed Wing Search and Rescue Aircraft Replacement (FWSAR) programme, October 2019, courtesy Airbus Defense & Space. .... 62

Figure 33 – Technology lines integrated in the Regional Multi-Mission TP 70 pax aircraft concept.... 63

Figure 34 – Advanced Regional Multi-Mission TP 70 pax concept. .... 64

Figure 35 – Advanced 19 pax Commuter concept. .... 66

Figure 36 – Comparison of overall dimensions and weight of 19 pax reference and concept aircraft. 67

Figure 37 – List of technologies and overall impact at aircraft level for the SAT 19 seat concept. .... 67

Figure 38 – Expected engine performance (MAESTRO) improvements for 19 pax Commuter concept before aircraft integration..... 68

Figure 39 – CO<sub>2</sub> and NO<sub>x</sub> reductions achieved for various mission ranges for the 19-seat Commuter concept (@10kft, 195KTAS, IFR Reserve)..... 68

Figure 40 – Comparison of noise footprint area reduction for reference and concept 19 seat aircraft (green loop 1). .... 69

Figure 41 – Calendar of CDRs (Critical Design Reviews) for the technologies selected within the ENG, AIR, and SYS ITDs for the 19 pax Commuter concept. .... 70

Figure 42 – Schematic view of Serial-Hybrid (SH) and Turbo-Electric (TE) powertrain configurations. 70

Figure 43 – Future E-STOL (Electrical/Hybrid Short Take-Off and Landing) 19 seat commuter concept, EIS 2032. .... 71

Figure 44 - Architectures of the EIS2025 Concept (left) and the EIS2032 E-STOL airplane concept (right)..... 71

Figure 45 - Artistic impression of a 19-seater with liquid hydrogen hybrid propulsion technology (based on preliminary sizing evaluation), courtesy Pipistrel, <https://www.pipistrel-aircraft.com/unifier19-2>..... 72

Figure 46 – Technology insertion and expected overall performance impacts for the business jet concept. SFC performance at engine level only before integration. .... 74

Figure 47 – Engine data and scale factors for BJ2000 (with SN2000) and BJ2035 (with SN2020)..... 74

Figure 48 - Advanced Low Sweep Business Jet concept. .... 75

Figure 49 – The Airbus Helicopters first compound prototype X3. .... 77

Figure 50 – LHD's AW609 Tilt-Rotor development aircraft prototype. .... 78

Figure 51 – The Airbus RACER Concept and its main technology features..... 79

Figure 52 – Airbus Helicopters RACER concept. X-Ray type image of internal components layout. Courtesy Airbus Helicopters. .... 80

Figure 53 – Key design drivers for Hover, RACER, Airbus Helicopters. .... 81

Figure 54 - Key design drivers for Cruise, RACER, Airbus Helicopters..... 82

Figure 55 – Key design drivers for Acoustics, RACER, Airbus Helicopters..... 82

Figure 56 – Key assessment criteria versus mission goals for the RACER..... 84

Figure 57 – Area covered within 1 hour for SAR interventions at 140kts and 220kts. .... 85

Figure 58 – Reduction of the number of heliports required to serve a given area based on the RACER performance..... 85

Figure 59 – The Tilt-Rotor Concept and its main technology features. .... 87

Figure 60 – Impact of technologies on SFC, mass, drag and noise performance for the Tilt-Rotor flight test demonstrator (2023) and the EIS 2030-2035 concept..... 89

Figure 61. Increased coverage area for SAR missions based on NGCTR performance. .... 91



Figure 62. A fleet of three NGCTR vehicles is sufficient to cover the same area guaranteed by eight reference vehicles. ....	92
Figure 63 - Surface area reduction for 60 dB noise level. ....	96
Figure 64 - Evolution of fleet replacement by CS2 aircraft up to 2050.....	98
Figure 65 - Fleet evolution in terms of number of flights by seat class up to 2050.....	100
Figure 66 - Fleet evolution in terms of number of aircraft by seat class up to 2050.....	100
Figure 67 – Comparison of DLR forecasts (constrained and unconstrained) on aircraft deliveries by 2038 to the Airbus GMF (Global Market Forecast) 2019-2038.....	101
Figure 68 – Comparison of Narrowbody (Single-Aisle) and Widebody (Twin-Aisle) aircraft deliveries estimates.....	101
Figure 69 – Cumulative distribution of RPKs versus distance flown (Sabre Market Intelligence). ....	102
Figure 70 – Distribution of flights versus flight distance per aircraft seat classes in 2020. ....	103
Figure 71 - Share of CO <sub>2</sub> emissions per aircraft seat-class and flight distance (range flown) in 2020.....	103
Figure 72 - Distribution of flights versus flight distance per aircraft seat classes in 2050.....	104
Figure 73 – Share of CO <sub>2</sub> emissions, flights and passenger-km per aircraft seat-class and flight distance (range flown) in 2050.....	105
Figure 74 – Evolution of CO <sub>2</sub> emissions by 2050, baseline scenario 0 with T2 Technology Developments - ATAG Waypoint 2050 Report, 2020.....	108
Figure 75 – Evolution of CO <sub>2</sub> emissions by 2050, scenario 2 with T3 Technology Developments - ATAG Waypoint 2050 Report, 2020. ....	108
Figure 76 - Percentage increase of accessible population per country. ....	109
Figure 77 - European cities within a range of 500NM-1000NM (926km-1852km) from BRU (Brussels). ....	110
Figure 78 – Gross Value Added (GVA) and Employment created by aviation in 2014.....	111
Figure 79 – Employment created by aviation between 2014 and 2050. ....	112
Figure 80 – Gross Value Added (GVA) by aviation between 2014 and 2050. ....	112
Figure 81 - Total number of participants and relative share of SMEs, UNIs, RES and IND in the Clean Sky 2 programme (status after CfP11). ....	113
Figure 82 – Number of Clean Sky participating organizations per country. ....	115
Figure 83 – Number of participations and number of members and partners in the Clean Sky 2 programme per country.....	115
Figure 84 – Gantt chart of the Technology Evaluator until programme completion (2024). ....	118
Figure 85 – Evolution of SMR+ concept as a high-wing configuration with VPF engines. ....	119



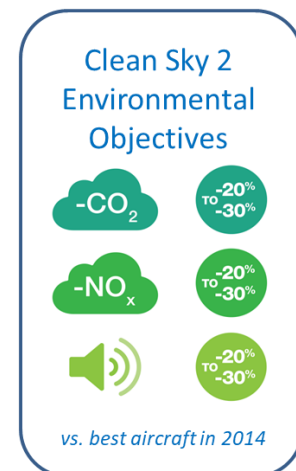
## List of Tables

Table 1 - List of CS2 new aircraft concepts versus reference aircraft, with projected EIS, environmental goals and TRL target at programme close. ....	30
Table 2 - Noise reduction achievements for LR+ Concept. ....	44
Table 3 - Noise reduction achievements for SMR+ Concept. ....	49
Table 4 - Comparison of TLARs for conceptual and reference 90 pax regional aircraft. ....	54
Table 5 – Comparison of TLARs for conceptual and reference 130 pax regional aircraft. ....	57
Table 6 – Characteristics in terms of payload and range for the baseline (C-295) and future multi-mission regional aircraft concept. ....	62
Table 7 – Breakdown of technology contributions to the overall emissions reductions at aircraft level. ....	69
Table 8 – Integrated technologies and expected benefits for the business jet concept. ....	73
Table 9 – Breakdown of technology contributions to the overall gain in performance for the BJ2020. ....	76
Table 10 – Main flight performance characteristics of RACER and TEM-B generic reference helicopter. ....	80
Table 11 – Clean Sky 2 technology streams contributing to the RACER concept. ....	81
Table 12 – Preliminary results for CO <sub>2</sub> and NO <sub>x</sub> emissions reduction for a few typical RACER missions. ....	83
Table 13 – Technology mapping and targets for the NGCTR concept. ....	88
Table 14 - Main flight performance characteristics of NGCTR and AW139 reference helicopter. ....	90
Table 15 - Synthesis results of mission level assessment for the Clean Sky 2 aircraft concepts, by aircraft category and seat class. ....	94

## Executive Summary

Clean Sky 2 is currently the largest European research programme developing innovative, cutting-edge technology aimed at reducing gas emissions and noise levels produced by aircraft. Funded by the EU's Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness by delivering innovative solutions for the aviation sector.

The scope of this document "First Global Assessment" is to report on the state of progress towards the high-level objectives of the Public-Private-Partnership established by the European Commission in 2014<sup>1</sup>. These objectives are to develop ***cleaner air transport technologies for earliest possible deployment***, and in particular, the integration, demonstration and validation of technologies capable of ***reducing CO<sub>2</sub>, NO<sub>x</sub> and Noise emissions by 20 to 30 %*** compared to 'state-of-the-art' aircraft entering into service as from 2014. Besides improving the environmental impact of aeronautical technologies, including those related to small aviation, the objective of Clean Sky 2 is also to develop a strong and globally competitive aeronautical industry and supply chain in Europe.



Therefore, this First Global Assessment of the Clean Sky 2 programme covers two major aspects: ***the environmental impact assessment*** of the technologies developed under CS2 research and ***the socio-economic impact assessment*** of the programme.

This work has been performed by the German Aerospace Center (DLR) based on the inputs from all SPDs within the framework of the Technology Evaluator (TE) as a transversal activity, and the support of several related CfP projects. The role, mandate and interaction mechanisms of the TE, as well as the timeline for first and second assessments are described in [Section 2](#) of this report (pp 23-27). The first assessment is an interim progress status at programme mid-term before the final assessment at programme end, in 2024.

In order to evaluate the environmental benefits of novel aeronautical technologies, a number of concept aircraft have been defined as well as their reference counterpart for comparison. This is presented in [Section 3](#) A Vision for the Future, with a synthesis of all concept vehicles, reference vehicles and objectives in terms of performance improvement, nearest entry-into-service date (EIS) and TRL level at the end of the programme (see Table 1). To date, nine fixed-wing concept aircraft are proposed, addressing each market segment (commuter, regional, small, medium and long range) and two fast rotorcraft concept vehicles. Several concepts are technically ready for an EIS date as early as 2025 for maximum impact (commuter and regional turboprops), whereas for the mainliner concepts (Short-Medium Range and Long Range), 2030 is seen as the nearest target<sup>2</sup> date for introducing an "advanced" concept into the fleet and 2035 for an "ultra-advanced" concept.

<sup>1</sup> Council Regulation (EU) No 558/2014 of 6 May 2014.

<sup>2</sup> The analysis and discussion presented here do not consider COVID effects on air transportation. A dedicated discussion is provided in [Section 7](#) addressing this aspect.

Although the high level objectives of Clean Sky 2 are set at aircraft level, this first assessment goes beyond. This study covers three levels of environmental impact: mission level, airport level (including noise footprint) and fleet level, commonly named "Air Transport System".

The methodology is described in detail in [Section 4](#) including the assumptions which have been taken for the extension to a global fleet assessment in 2050. The predictions are broken down into a "forecast" until 2035 followed by two "scenarios" (high and low) up to 2050.

	<p><b><u>Innovation potential at Mission level</u></b></p> <p>Clean Sky 2 Concept Aircraft are compared with 2014 Reference Aircraft on relevant missions regarding emissions and noise. The results are the basis to quantify the success level versus the CS2 environmental goals.</p>
	<p><b><u>Realistic impact at Airport level</u></b></p> <p>A typical day at representative EU-airports (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>
	<p><b><u>Aviation footprint at Air Transport System (ATS) level</u></b></p> <p>A year with all global flights (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>

**Airport Traffic Congestion**

*Congested airports are already a reality today.*

*An overall reduction of 30% in terms of flight volumes can be expected if airport capacity constraints are taken into account in the forecast model.*

*This is an important novelty of the DLR methodology compared to other models dealing with air transport today.*

The study uses a DLR forecasting model based on various economic growth assumptions, technology diffusion models and fleet replacement rates. It introduces an important novelty, as compared to other models dealing with air transport: **airport capacity constraints**. Here, the model includes the mutual dependence between limited availability of additional airport infrastructure, air passenger demand growth and fleet mix evolution. Comparisons are provided with the results of other models (such as ICAO-CAEP and Airbus/Boeing). To strengthen the credibility of this forecast, DLR has performed the same study without this assumption (i.e. an unconstrained forecast) for comparison. This permitted the consolidation of the conclusions, demonstrating that a constrained forecast is likely to show ***an overall reduction of 30% in terms of flight volumes*** which is to be expected by 2050 versus an unconstrained forecast, with direct consequences on aircraft in service, hence on aircraft deliveries.

For the continuation of the programme, attention will be devoted to further testing the robustness of this model and to extend it to new scenarios, in particular to include the effect of the COVID-19 pandemic on aviation, too recent to be considered in this study.

The results in terms of environmental impact are presented in [Section 5](#) for the three levels of assessment respectively, the main part of this report.



The **mission level assessment** is based on the detailed descriptions of each of the concepts and their technology insertions ([Section 5.1](#)). The technology selection and integration choice has been performed as early as 2018 by each platform owner before running the performance simulation for each model. The definition of each aircraft concept was based on the available technologies with sufficient maturity level in 2018 and the integration at overall aircraft level was performed accordingly, considering mainly weight and volume impact of components and systems, efficiency and weight of the propulsion system and aerodynamic performance of the aircraft (at low speed and high speed). Each SPD has used their own in-house tools, which are proprietary performance simulation tools.

The performance presented for each concept is the result of a complex optimization to balance at best the positive and negative effects of integrating a new technology on-board of the aircraft. This optimisation cycle takes about a year (including trade-off studies and generation of models). It must be noted also, that it is extremely difficult to optimize an aircraft for all environmental objectives simultaneously ( $\text{CO}_2$ ,  $\text{NO}_x$ , and noise) because of the conflicting requirements inherent to each of those objectives individually. A typical example is the substantial improvement in fuel burn reduction provided by a new engine design (e.g. through an increased By-Pass Ratio), which will inevitably introduce penalties in terms of weight and drag because of the increased size of the engine - despite a much better propulsive efficiency. Similarly, noise reduction technologies may be effective and also have a positive effect on drag reduction, but may come at a cost of increased weight of the aircraft. Or, to conclude, reducing fuel burn of the engine, in order to reduce  $\text{CO}_2$ , would require increasing combustion temperature to improve cycle efficiency, which is exactly what must be avoided to reduce  $\text{NO}_x$ .

The difficulty of an appropriate choice for the reference aircraft as “most relevant” or “best in class” deserves a note of caution as well. For mainliners, this reference aircraft is fairly easy to identify as year 2014 state-of-the-art (SoA): A321neo-like for the SMR concept and A350-900-like for the LR concept, although these effectively entered into service respectively in 2016 and 2015. However, in other cases, due to different passenger capacities (e.g. REG-90 or REG-130), or design range, cruise speed, or even maximum ceiling (altitude), there is no exact match in terms of existing aircraft, or no match at all. For the Advanced Regional TP concept, this required to choose the closest aircraft (ATR-72) and up-scale it to 90 pax. For regional turboprop aircraft in general (ATR-72, C-295, etc.), the latest SoA regional aircraft in service in 2014 are based on technology standards of year 2000, whereas regional jets (Bombardier CS-300 or A220-300) are using recent geared turbofan technology (and are approaching the lower end of the SMR market, i.e. A319 (in terms of range (3000nm) and cruise speed ( $\text{Ma}=0.78$ )). In cases where the technologies are intended to be flight-tested on a given aircraft (e.g. the Regional Multi-Mission TP 70 pax, technologies will be flown on a C-295 aircraft within the framework of the REG FTB#2 demonstration), the flying testbed aircraft has been selected naturally as the reference, requiring an appropriate re-scaling methodology, well known by the aircraft manufacturers. For Small Air Transport, all existing aircraft in service have technology standards well prior to year 2000, which required to develop a “generic” 19-seater model with SoA technologies of 2014. Finally, the identification of an appropriate reference for the fast rotorcraft concepts has proven to be most difficult as the cruise speed of the new concepts is almost twice that of any existing



helicopter, closer to an aircraft in terms of cruise speed and altitude, but with VTOL capability. Some of these reference aircraft will be updated in view of the second assessment.

Finally, the overall concept sizing chain used by the Design Offices, enables light scaling and loss model calibration. However, aircraft sizing rules, today kept equivalent to the ones used for the reference aircraft (EIS 2014), are 12-14 years old – (200 pax for SMR, 315 pax for LR) and may no longer be aligned with the market expectations for an EIS 2030. This may lead to consider the modelling of new concept aircraft which may become more relevant in the future, and better meet the demand of the fleet in 2030/2035. We will return to this point when addressing one of the major conclusions of this work, i.e. the need for a large capacity short-range aircraft (>300 seats, <4000km).

The results at mission level underline the fact that ***substantial progress has already been achieved and that the programme is well on track***. Most of the concepts achieve their target or even exceed it (see [Table 15](#)).

Three vehicle concepts have an EIS target date as early as 2025, and all of them achieve or exceed their environmental performance objectives, sometimes well over -30% CO<sub>2</sub> emissions reduction (e.g. the Advanced Regional TP 90 pax with -34% CO<sub>2</sub> and -67% NO<sub>x</sub> reduction).

For the next EIS target date (2030), the Short-Medium Range concept (SMR+) achieves a substantial improvement of -17% CO<sub>2</sub> reduction. The moderate improvement for the LR+ concept (-13% CO<sub>2</sub>) results from the comparison with the A350-900 as a reference, a very recent and already very highly optimized platform, while a substantial reduction in NO<sub>x</sub> emissions is obtained (-38%) thanks to the lean burn technology of the Ultrafan<sup>®</sup> engine.

Finally, for the Ultra-Advanced concepts with EIS 2035 and beyond, even more substantial gains can be expected, with -26% for the SMR++ concept (thanks to the Open Rotor architecture) and -26% for the Innovative Regional TP 130 pax compared to a Regional Jet. The low NO<sub>x</sub> reduction for the SMR++ (-8%) may be disregarded as it results from the core engine model of the Open Rotor not yet including low NO<sub>x</sub> combustor technology (to be updated in the near future). The LR++ (Ultra-Advanced LR concept) has not been modelled as a full aircraft concept but an engineering approach of an additional -7% to -8% improvement versus the LR+ concept has been assumed (-21% CO<sub>2</sub> reduction and -45% NO<sub>x</sub>).

The environmental results for both fast rotorcraft concepts are presented as preliminary and deserve a note of attention. We have addressed the issue related to the difficulty of choosing an appropriate reference vehicle. Although an attempt has been made in a first instance to compare to helicopters, there are still too many design parameters which render the comparison difficult. Both the RACER and the NGCTR have a much higher maximum speed (almost twice that of a normal helicopter) and therefore also a higher power installed for the engines. The range and passenger capacity for the RACER are very similar or equal to the reference helicopter (12 pax), but the maximum ceiling is much higher than a normal helicopter.

The RACER performance results currently show an increase in fuel burn, hence in CO<sub>2</sub> (+2 to 17%), however very encouraging considering the superior characteristics of the new concept. Furthermore,

prospects of adding the “eco-mode<sup>3</sup>” technology as well as the perspective to increase payload without increasing engine power give strong confidence to achieve a decrease of CO<sub>2</sub> of around -15 to -20% for the second assessment.

The NGCTR turns out to be the most difficult to assess, as the passenger capacity is 24 instead of 15 for the reference helicopter, the range has been doubled, and the maximum ceiling is 25,000 ft, that of a pressurized aircraft. The concept vehicles have therefore very different overall weight. Even by using normalized fuel burn by passenger and nautical miles, the comparison has turned out to yield results spanning a very wide range (from +0.5% to -90% CO<sub>2</sub>), very much dependent on the mission selected and mostly on the choice of the reference vehicle.

Work will continue towards the second assessment on adapting the reference vehicles, potentially a ‘generic’ vehicle, similarly to the approach taken for the 19 seat reference commuter, but as a generic compound helicopter and generic tilt-rotor. Relevant work from the Clean Sky 1 GRC programme might be helpful here as well, considering the availability of another generic helicopter model, the Twin Engine Heavy (TEH), more similar in terms of payload-range diagram to the NGCTR.

Still, this is a snapshot of the results at programme mid-term. This means more progress and further improvements of the performance is to be expected over the second part of the programme through further maturation of the technologies and updates of the models as well as inclusion of additional technologies not yet considered today.

The mission level performance results are the basis for the subsequent airport and fleet level calculations.



Thanks to the progress made in noise reduction technologies, the **airport level assessment** also shows substantial improvements (Section 5.2). Noise impacts were estimated by comparing the noise performance of future airport traffic scenarios with and without CS2 technologies in the year 2050 for a set of representative airports (Amsterdam Schiphol, Rome Fiumicino, Stockholm Arlanda, Hamburg, and Toulouse Blagnac). The reductions for 2050 in surface area of Lden contours for relevant noise levels (60-65 dB(A)) are about 10-15% and point out **significant reductions of population exposed and population highly annoyed in the range of 10-25%**.

In 2050, **reductions of CO<sub>2</sub> emissions will amount to about 8-13.5% for the European airports considered, while the associated NO<sub>x</sub> reductions are in the range 6.5-10.5%.**

---

<sup>3</sup> Safran Helicopter Engines’ “eco mode” concept places one engine in standby mode during cruise, reducing fuel consumption up to 15% and increasing range. A smart auxiliary electric motor quickly restarts the engine when additional power is needed. Based on an automatic control system assisting the crew, it has been flight tested by Airbus Helicopters on the Bluecopter demonstrator.



At **fleet level** (Air Traffic System), according to the present forecast (high scenario), approximately **75% of global available seat kilometres (ASK) will be operated with aircraft expected to carry Clean Sky 2 technologies in 2050**, while 25% of global ASKs will still be operated by aircraft with 2014 reference technologies, not yet retired.

#### Air traffic carbon emissions in 2050

*In 2050, more than 55% of CO<sub>2</sub> emissions will come from medium and large aircraft on short-medium haul flights (<4000km). These two aircraft categories will account for about 55% of flights, compared to 15% in 2020.*

By applying the performance improvements obtained for each concept aircraft and by completing the fleet with virtual aircraft based on appropriate technology diffusion models to neighbouring seat classes, **an overall reduction of CO<sub>2</sub> and NO<sub>x</sub> emissions of about 15% and 31% per seat kilometre can be expected for the year 2050** high fleet scenario as compared to a 2050 global traffic scenario incorporating only 2014 reference technology.

For the 2050 low scenario, these values are slightly lower (about 14% CO<sub>2</sub> and 29% NO<sub>x</sub>) as the share of Clean Sky technology aircraft in terms of ASK is slightly smaller at about 70% compared to the high scenario of 75%.

As a comparison, if all new concepts would achieve 20 to 30% performance improvement, and if 100% of the fleet could be replaced within the next 30 years, a maximum of 20 to 30% reduction in CO<sub>2</sub>, NO<sub>x</sub> and noise emissions could be expected. Fleet replacement rate is a key parameter to climate neutral aviation by 2050.

Unfortunately, considering the long development times of a new aircraft as a commercial product (between 5 to 10 years), their extremely long service life (on average 25 years for mainliners, 29 years for turboprops), and the inertia in production rate increase (despite some substantial ramp-up in recent years), the fleet replacement process is slow. **It is therefore crucial to target the earliest entry into service date for the next generation of aircraft.**

Historically, the time between two aircraft generations has been typically 15 to 20 years. This underlines also **the urgent need to accelerate the technology maturation process by promoting and supporting research investments, in order to “skip a generation”**. To this end, not only advanced technologies but possibly also ultra-advanced technologies should be integrated simultaneously onto the next aircraft generation by 2030, if not, by 2035 at the latest.

As to fleet evolution, the model predicts ***a major shift towards larger aircraft (>300seats) mainly to be used to fly short range (< 3000 to 4000km)*** for the mainliner seat class. It is thus expected that the discrepancy between design range and operational use will considerably increase in importance in the future.

Modelling a relevant aircraft concept which would satisfy this fleet prediction will therefore be a major focus towards the second assessment. This trend to larger aircraft at short range has major implications in terms of aircraft design, required runway length, airport capacity, and economics for the airlines. The implications of this result for the environmental impact of CS2 and the implications for policy/regulatory interventions will be further explored as well.

#### A veritable „sky-bus“

Like the famous London double-deckers, high passenger capacity will be the key to respond to air traffic demand in the future, especially on short-haul routes (<4000km).

As a result of airport capacity constraints, a veritable “aerial autobus” of large capacity will be required to move passengers from city to city mostly on intra-continental flights.

Then, the **societal impact** of the Clean Sky 2 programme is addressed in [Section 6](#) considering mobility and connectivity benefits, macro-economic impact at aviation level as well as competitiveness and societal impact.

As to **mobility and connectivity**, the introduction of SAT commuter aircraft (800km range, 300km/h cruise speed), shows that the **percentage of population accessible within 4 hours can be substantially increased up to ~30%**, up to ~37% if cruise speed is increased to 400km/h. Both fast rotorcraft concepts, as well as the multi-mission 70 pax regional turboprop provide substantial improvements for valuable missions such as Search and Rescue (SAR), fast medical evacuation or Emergency Medical Services (EMS), but also simply for passenger transport thanks to their increased flight speed and reduced connecting time. The results of several mission simulations as Airport Hub-Feeder (AHF) or Commercial Intercity Passenger Transportation (CIT) support this conclusion. Flight time is typically reduced by 40% to 50% on longer distance missions, an undeniable progress as well for emergency interventions within the “golden-hour”.

At **macro-economic level**, in the EU28, aviation is responsible for an above-average share of total Gross Value Added (GVA) and total employment compared to the rest of the world. The projection indicates strong positive growth in aviation-related employment in Europe and the world as well as a significant increase in gross value added created by aviation. Based on the movements forecast and an economic input-output model using data from the World Input-Output Database<sup>4</sup>, the economic effects of civil aviation, which are supported by CS2, have been estimated in terms of GVA and employment growth. Although a significant driver is the strong air traffic growth in emerging economies such as China, India, and Indonesia, **the EU28 (and the US) will see both their employment and GVA from aviation roughly double by 2050 versus 2014, maintaining therefore a significant share of the world’s global aviation-related employment and GVA.**

Regarding **competitiveness and societal impact**, as a result of this first assessment, all stakeholders acknowledge that Clean Sky 2 contributes positively to the improvement of the technical know-how, competitiveness and job creation in the EU industry. The structure of Clean Sky 2 enables all actors in the aviation community to collaborate and share ideas easily. Researchers can learn what the industry’s needs are, and SMEs can gain access to much bigger industrial giants and their facilities. In

<sup>4</sup> Cf. <http://www.wiod.org/home>.



turn, industry benefits from the innovative potential of SMEs and the deep specialised knowledge of the research centres and academia.

**Clean Sky has successfully established a robust innovation network and quality supply chain in the aviation sector, motivated to drive cleaner, greener aviation forward.** By the end of 2020, four Calls for Core Partners and eleven Calls for Proposals were launched and evaluated. Through these call mechanisms, the €4 Bn budget / €1.8 Bn funding Public-Private Partnership programme has achieved an unprecedented level of participation in the programme. More than 1850 participants / 940 entities are currently involved in more than 550 granted projects with broad geographical spread and widening of aeronautics sector. Many newcomers from other sectors (e.g. automotive) joined the programme providing key innovation impetus and statistics show a large SME participation with a high percentage of SMEs being first-time EU programme participants as well. **This involves more than 5000 engineers and scientists around Europe working on Clean Sky 2 projects.**

As already briefly mentioned, **the impact of COVID-19 has not been accounted for in the present study.** The work was finalized while the pandemic was in its first outbreak in Europe. Nevertheless, some reflections addressing the potential impacts in the short-, medium- and long term on demand, movements and network, and on global fleet are proposed in [Section 7](#).

The report closes with an outlook towards the second assessment of 2024 in [Section 8](#). This covers a new iteration of technology mapping to include additional technology bricks into the existing concept models and update them. New or updated reference vehicles may be defined to improve performance comparison and new engines as well as new aircraft concepts will be proposed to further reduce the environmental impact by better addressing the needs of the fleet in 2050. The socio-economic impact study will be updated to address not only direct, indirect and induced effects but also catalytic effects. The impact of COVID-19 may play a major role here. The study will be extended to address in further depth the impact on European competitiveness and the “additionality” of Clean Sky 2 as a Public-Private Partnership in the aeronautical landscape.

---

***Funded by the EU’s Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness by delivering innovative solutions for the aviation sector.***

***Clean Sky’s long-term vision is to enable the EU aviation sector to reach complete climate neutrality by 2050. Achieving such an ambitious goal requires sector-wide cooperation, and Clean Sky engages and supports SMEs, universities, research centres and the aviation industry to continue to deliver ground-breaking results.***

# 1 Introduction

Clean Sky is the largest European research programme developing innovative, cutting-edge technology aimed at reducing CO<sub>2</sub>, gas emissions and noise levels produced by aircraft. Funded by the EU’s Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness by delivering innovative solutions for the aviation sector.

The Clean Sky 2 Joint Undertaking was established by Council Regulation (EU) No 558/2014 of 6 May 2014 ***to develop cleaner air transport technologies for earliest possible deployment***, and in particular the integration, demonstration and validation of technologies capable of:

- (i) increasing aircraft fuel efficiency, thus **reducing CO<sub>2</sub> emissions by 20 to 30 %** compared to ‘state-of-the-art’ aircraft entering into service as from 2014.
- (ii) **reducing aircraft NO<sub>x</sub> and noise emissions by 20 to 30 %** compared to ‘state-of-the-art’ aircraft entering into service as from 2014.

**Clean Sky 2  
Environmental  
Objectives**

**-CO<sub>2</sub>**

**-20%  
TO  
-30%**

**-NO<sub>x</sub>**

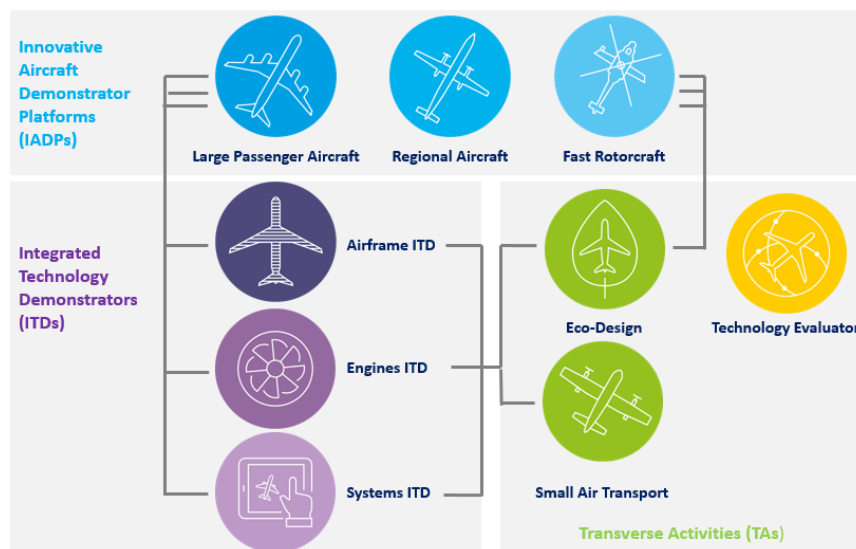
**-20%  
TO  
-30%**

**-20%  
TO  
-30%**

*vs. best aircraft in 2014*

Besides improving the environmental impact of aeronautical technologies, including those related to small aviation, the objective of Clean Sky 2 is also ***to develop a strong and globally competitive aeronautical industry and supply chain in Europe.***

The programme structure is shown in Figure 1. It is composed of three IADPs - Innovative Aircraft Demonstration Platforms - (Large Passenger Aircraft, Regional Aircraft and Fast Rotorcraft), three ITDs - Integrated Technology Demonstrators – (Airframe, Engines and Systems) as well as three ‘Transverse Activities’ or ‘TAs’ (Small Air Transport – SAT, Eco-Design and the Technology Evaluator –TE) with relevance to several ITDs and/or IADPs and requiring coordination and management across the ITDs and/or IADPs.



**Figure 1 - Schematic Structure of the Clean Sky 2 Programme.**

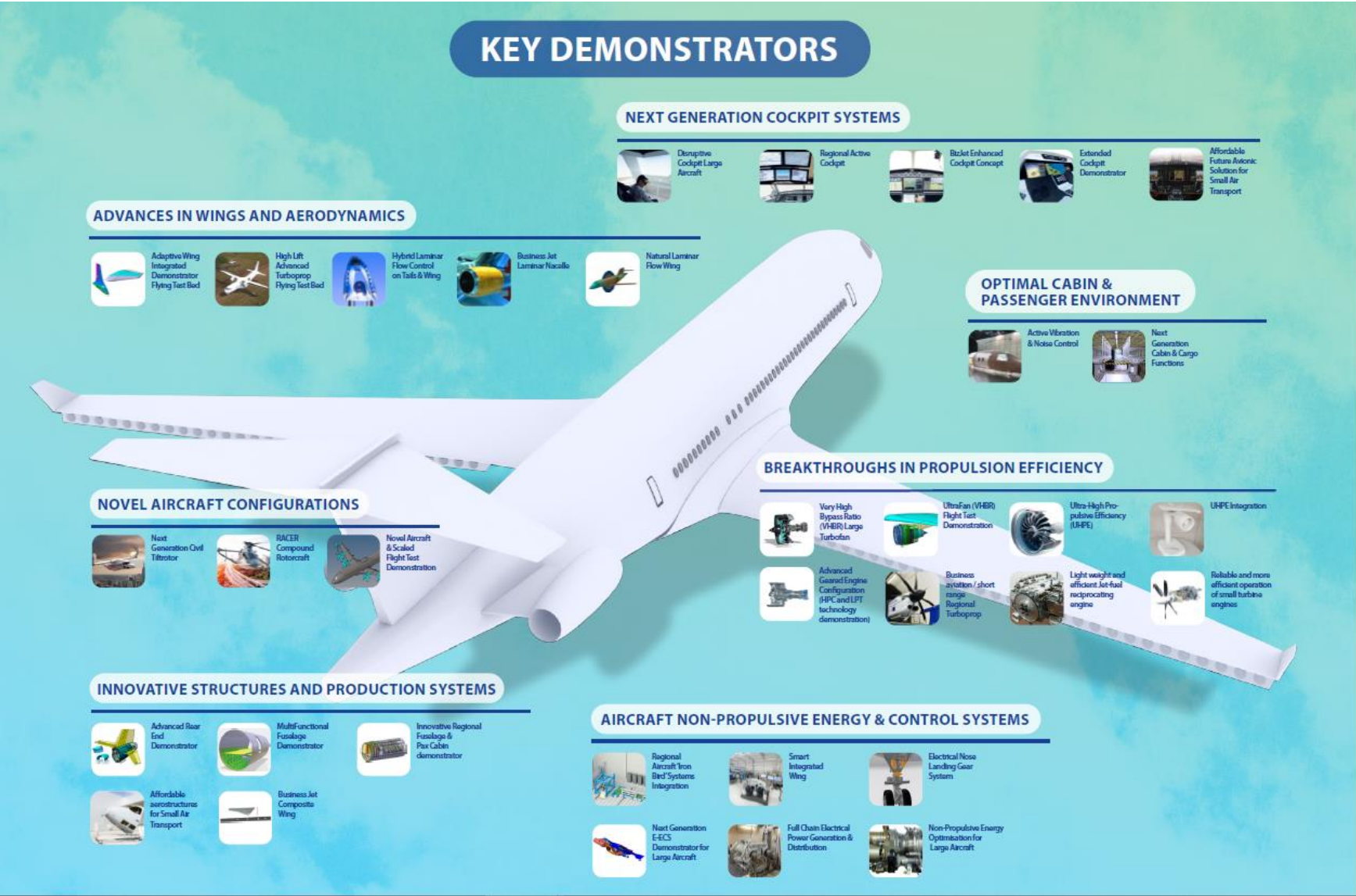


Figure 2 – Clean Sky 2 Key Demonstrators.

## 2 Technology Evaluator

The Technology Evaluator, as a Transverse Activity, has been established as an *independent* Technology Evaluator for the entire duration of the Clean Sky 2 Joint Undertaking, i.e. until 31 December, 2024. It is led by the German Aerospace Center (DLR) and has the following tasks (as per Regulation<sup>5</sup>):

- (i) monitoring and assessing the environmental and societal impact of the technological results arising from individual ITDs and IADPs across all Clean Sky activities, specifically quantifying the expected improvements on the overall noise, greenhouse gas and air pollutants emissions from the aviation sector in future scenarios in comparison to baseline scenarios;
- (ii) providing feedback to ITDs and IADPs in order to enable the optimisation of their performance against their respective goals and objectives;
- (iii) providing input, through the Executive Director, to the Governing Board on environmental and societal impacts across Clean Sky activities to enable the Governing Board to take all actions necessary to optimise benefits across all Clean Sky programmes, against the respective programmes' high-level goals and objectives;
- (iv) providing regular information, through the members, the Executive Director and other bodies of the Joint Undertaking, on the impact of the technological results of the ITDs and IADPs.

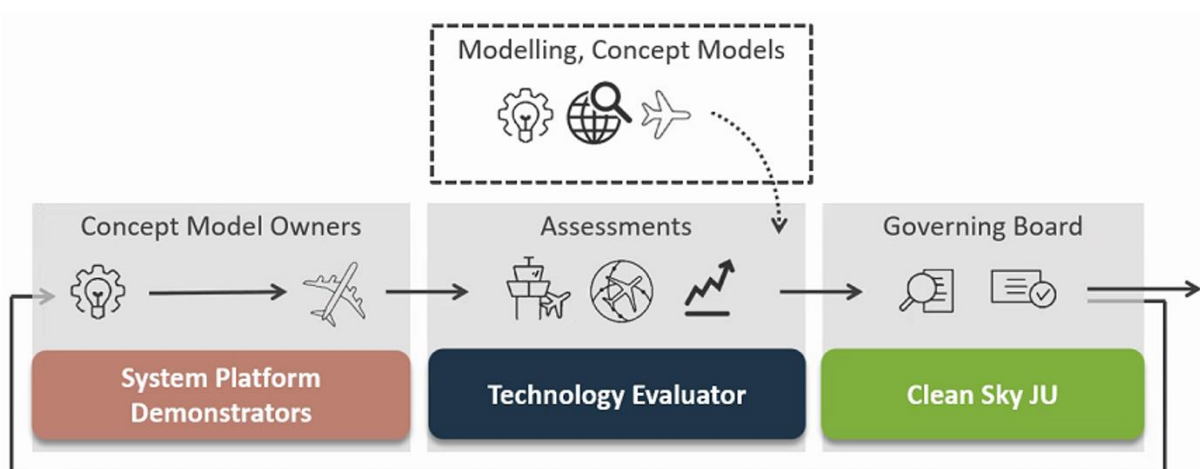


Figure 3 – Information flow from the SPDs through the Technology Evaluator to the Clean Sky 2 JU.

<sup>5</sup> Council Regulation (EU) No 558/2014 of 6 May 2014.

## 2.1. Overall Assessment Timeline

To monitor and assess the progress of the ongoing technology developments across all Clean Sky 2 activities, two major reporting milestones have been set: a **1st Global Assessment by end of 2020**, i.e. approximately at programme mid-term, and the **2nd Final Global Assessment by mid-2024**, at programme closure.

## 2.2. First Assessment – Interim Results

The report reflects the technological achievements of the first five years of the programme which will end in 2024. The report assesses the environmental benefits from CS2 technological achievements, which were considered to have reached, already *before* programme mid-term, a sufficient level of maturity (TRL) to be included in the overall performance models of the new aircraft concepts.

To date, substantial progress has been made in the development of these technology bricks across all platforms. However, additional technologies, still under development, will be integrated by the programme’s end, when mature enough, and will further improve the current results.

## 2.3. Key Indicators and Metrics

The scope of the present assessment covers the environmental (CO<sub>2</sub>, NO<sub>x</sub>, noise) and societal impact (mobility, connectivity and socio-economic impact) while improved air traffic management and infrastructure use or the potential contribution from alternative fuels and impact of offsetting mechanisms have not been considered here.

The key indicators, levels and dimensions of the TE assessment are outlined in Figure 4 .

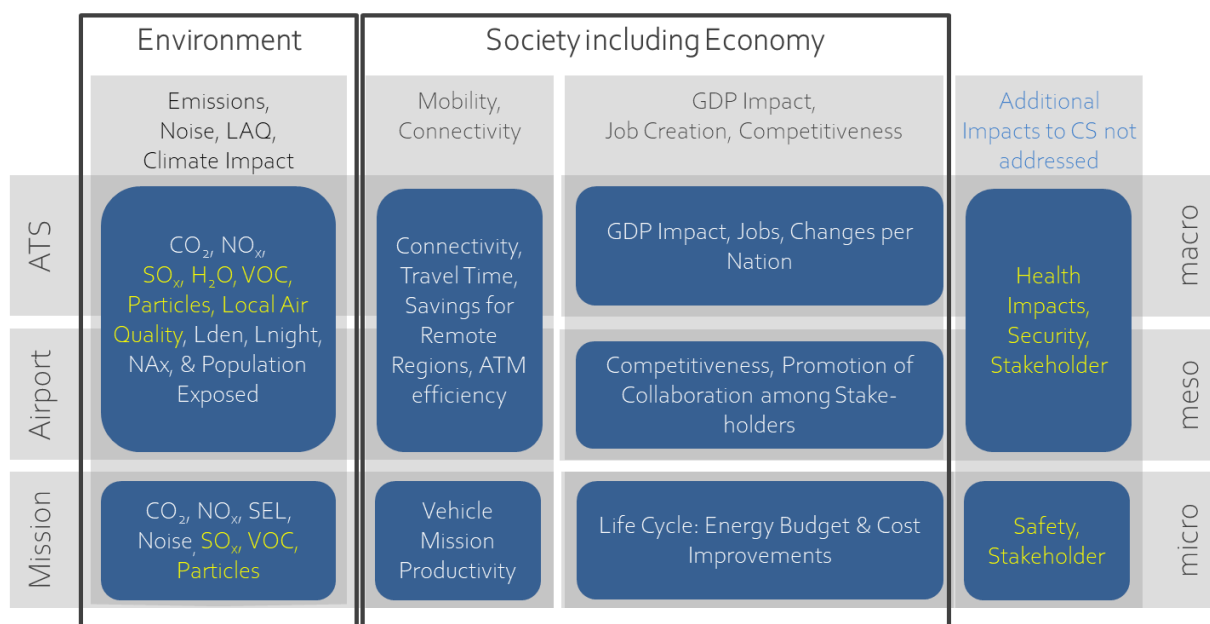


Figure 4 - Metrics, levels and dimensions of the TE assessment.

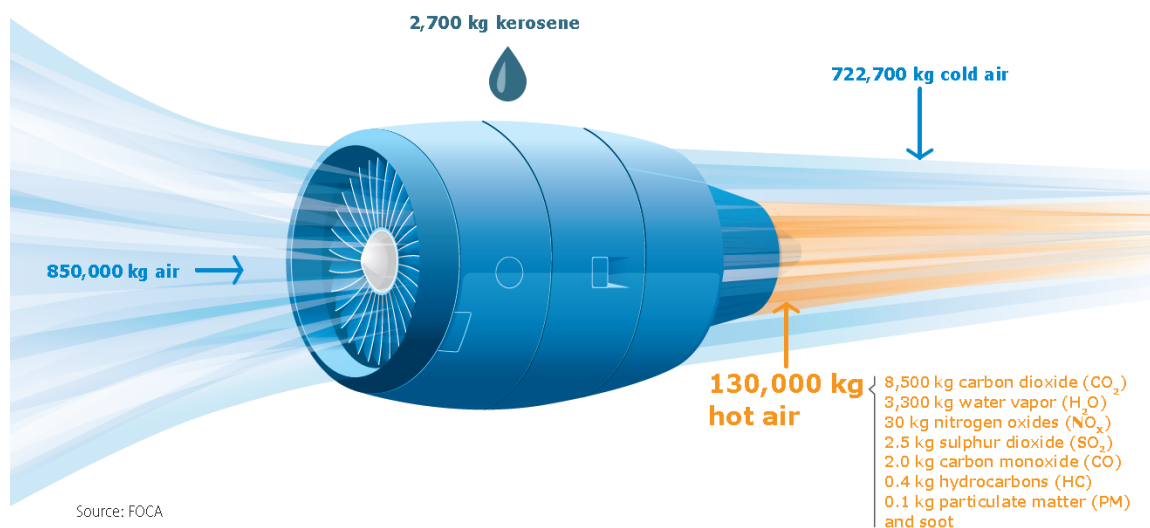
In terms of environment, gaseous emissions are evaluated at the level of CO<sub>2</sub> and NO<sub>x</sub> released during the aircraft mission. Sulfur oxides (SO<sub>x</sub>), water vapour (H<sub>2</sub>O), volatile organic compounds (VOC), nvPM (particles), have not been assessed in the present study. The aircraft (and engine) models are currently not able to provide this level of information about pollutant emissions and will be updated accordingly in the near future, so as to comply also with the evolution of emissions regulations (ICAO/CAEP).

Therefore, local air quality (LAQ) at airport level could also not be assessed. Noise was evaluated through Lden and Lnight levels as well as population exposed (but not population affected).

The corresponding metrics are:

- **Fuel burn:** in kg per mission and normalised to kg per seat-kilometer, correlation with CO<sub>2</sub> emissions.
- **Gaseous emissions:**
  - CO<sub>2</sub> and NO<sub>x</sub> in kg per mission and normalised to kg per seat-kilometer, identical to the fuel burn metrics. At ATS level, this is equivalent to normalise by Revenue-Passenger-Kilometer (RPK\*).

Figure 5 shows emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers. There is a direct relation between fuel burn and CO<sub>2</sub> emitted (1kg of kerosene burnt produces 3.16 kg CO<sub>2</sub> emitted) while NO<sub>x</sub> is depending on thermodynamic cycle temperature and combustion technology.



**Figure 5 – Emissions from a typical two-engine jet aircraft during 1-hour flight with 150 passengers.**  
Source: European Aviation Environmental Report 2019.

- When the reference aircraft has different TLARs, i.e. different passenger capacity or range<sup>6</sup>, or in the case of specific missions, emissions are normalized as follows:
  - Passenger Transport: kg of emissions/pax/nm
  - Freight Transport: kg of emissions/ton/nm
  - SAR missions: kg of emissions/time on station/radius of action

<sup>6</sup> Cruise speed of the reference and concept vehicle may still differ. This is the only parameter which is not taken into account in the current metrics.

- **Noise emissions:**

- for fixed-wing aircraft: cumulated perceived noise levels at the ICAO noise certification points (ICAO annex 16) during take-off and landing, see also Section 5.1.1.1.
- for rotorcraft: noise contour area reduction along defined flightpaths. Noise levels will be compared in terms of area above specific noise thresholds in dB SELA. SELA is an integration of the continuous noise level during the whole duration of the event, it sums the different events over a certain observer giving an indication of the total acoustic energy received, see also Section 5.1.2.

In terms of societal impact, mobility and connectivity benefits are derived at airport and fleet level from the evaluation of aircraft productivity (available seat-kilometres per aircraft – ASK\* per day) at mission level.

Economic impact is evaluated through GDP impact, job creations and competitiveness. A few additional aspects, which are not addressed within the socio-economic study, are health impacts, safety and security and stakeholders (i.e. passengers, airlines, ANSPs<sup>7</sup> and airports).

### 2.3. Preliminary Note on COVID Impact

The present report covers the 1st Global Assessment and addresses the progress status of the above listed tasks. It is a synopsis of the full deliverable report submitted to the CS2JU at the end of June 2020. It comes at a time in which aviation is unfortunately going through one of its most severe crises of all times.

Although some considerations have been given to the impact of COVID-19 in the full report, the bulk of the current work and of this report was written prior to the outbreak of the pandemic in Europe. This may require a re-assessment of the validity of some of the assumptions which have been taken in relation to the forecast and the scenarios of the present work.

An outlook on the potential impact of COVID-19 on the forecast and scenarios for fleet level assessment is given at the end of this report (see Section 7).

#### RPK & ASK

Revenue Passenger Kilometers (RPK) or Revenue Passenger Miles (RPM)\* is an airline industry metric that shows the number of kilometers traveled by paying passengers. It is calculated as the number of revenue passengers multiplied by the total distance traveled. Since it measures the actual demand for air transport, it is often referred to as airline “traffic.”

RPK is often compared to ASK, the available seat kilometers, a measure of the airline’s passenger carrying capacity. It is equal to the number of seats available on a given aircraft multiplied by the number of kilometers flown on a given flight, i.e. the total maximum number of passenger kilometers that could be generated.. An available seat mile is the fundamental unit of production for a passenger-carrying airline.

Comparing RPK and ASK allows to determine the amount of revenue that comes in compared to the maximum amount.

---

<sup>7</sup> ANSP: Air Navigation Service Provider

### 3 A Vision for the Future

The current fleet has been analysed and divided into several market segments: **mainliners** (covering Long Range and Small-Medium Range), **regional aircraft** (addressing different mission targets), **business jets** and **small air transport** (up to 19 seats), and **fast rotorcraft**.

For each of those segments, one or several new aircraft concepts have been defined (Figure 6), with the objective of achieving the High Level Goals of Clean Sky by incorporating, or rather integrating new technologies on board of a new aircraft platform as a concept.



*Advanced Long Range LR+*

LPA IADP



*Advanced Short/Medium Range SMR+*



*Ultra-Advanced Long Range LR++*



*Ultra-Advanced Short/Med. Range SMR++*



*Innovative Turboprop  
130 pax*

REG IADP



*Advanced Turboprop 90 pax*

AIR ITD



*Regional Multi-Mission TP 70 pax*



*Low Sweep BizJet*

TA SAT



*SAT 19-seat Commuter Aircraft*



*Next Gen Civil Tilt-Rotor  
(NGCTR)*

FRC IADP



*High-Speed Compound Helicopter (RACER)*

Figure 6 - Illustrations of the main Clean Sky 2 aircraft concepts.



### 3.1 Concept Aircraft

Each SPD has defined one or several aircraft concepts (see Figure 6) to be accurately modelled in terms of environmental performance based on a set of technology bricks (key enabling technologies) developed within the IADPs or ITDs.

Each aircraft concept or concept vehicle has been attributed a set of specific objectives, as well as a projected Entry-Into-Service date or window (based on all key enabling technologies reaching TRL6 five years before EIS), and an estimated TRL level of the overall concept by the end of the CS2 programme.

The TLARs (Top Level Aircraft Requirements) in terms of range, cruise speed and number of passengers (PAX) are given both for the concept and the reference vehicle.

Most of the aircraft concepts which have been defined contain an “advanced” and an “ultra-advanced” version, the latter with a later entry into service (EIS) but higher environmental performance objective, with a different level of technology maturity expected at the end of the CS2 programme.

For the mainliners, the closest EIS date is generally 2030 for advanced designs, or 2035 and beyond for ultra-advanced designs because of lower technology maturity.

It must be noted however, that several concepts may be ready for a very short-term EIS target date, shortly after closure of the CS2 programme, i.e. 2025. This is the case for the 19-Pax Commuter and the advanced regional airliners (the Multi-Mission TP 70 pax and the Advanced TP 90 pax), with very good performance improvements, as will be seen later.

A number of technologies under development since the programme’s start (2014) have been integrated into these new aircraft concepts. These technologies are stemming from work within the ITDs (Engines, Systems and Airframe) or directly from the IADPs at Platform level (LPA, REG, SAT, FRC).

The technology selection and integration choice was performed as early as 2018 by each platform owner before running the performance simulation for each model. The definition of each aircraft concept was based on the available technologies with sufficient maturity level and the integration at overall aircraft level was performed accordingly, considering mainly weight and volume impact of components and systems, efficiency and weight of the propulsion system and aerodynamic performance of the aircraft. Each SPD has used their own in-house tools for this, which are proprietary performance simulation tools.



SPD	Concept Aircraft				Reference Aircraft				Clean Sky 2 Environmental Goals			EIS* Window	TRL Target** @ CS2 close	
	Concept Vehicle	Range nm	Cruise speed	# PAX	Reference Vehicle	Range nm	Cruise speed	# PAX	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>	Δ Noise			
LPA	Advanced Short-Medium Range SMR+	2000	0.78 Ma	200	SMR 2014 A321neo	2800	0.78 Ma	200	-20%	-20%	-20%	2030	5	
	Ultra-Advanced Short-Medium Range SMR++	2000	0.75 Ma	200					-30%	-30%	-30%	2035+	4	
	Advanced Long Range LR+	6700	0.85 Ma	315	LR 2014 A350-900	6700	0.85 Ma	315	-20%	-20%	-20%	2030	4	
	Ultra-Advanced Long Range LR++	6700	0.85 Ma	315					-30%	-30%	-30%	2035+	3	
REG	Advanced Turboprop 90 PAX	1200	0.56 Ma at 20 kft	90	ATR 72 up-scaled	1000	0.52 Ma at 20 kft	90	-19 to -25%	-19 to -25%	-20 to -30%	2025+	5	
	Innovative Turboprop 130 PAX	1600	0.62 Ma at 30 kft	130	Bombardier CS300 (A220)	3000	0.78 Ma at 35 kft	130	-35 to -40%	> -50%	-60 to -70%	2035+	4	
	Regional Multi Mission Turboprop 70 PAX	Transport Airline	1000	0.5 Ma	70	EADS/CASA C295 civil	1000	0.4 Ma	50	-20 to -30%	-20 to -30%	-20 to -30%	2025+	6
		Transport Freighter	1000	0.5 Ma	--									
Search And Rescue (SAR)		400	0.5 Ma	15-25										
SAT	19 PAX Commuter	800	0.34 Ma	19	Generic 19-seater	800	0.34 Ma	19	-20%	-20%	-20%	2025	4-5	
AIR	Low Sweep Business Jet	2900	0.78 Ma	12	Dassault Falcon 2000 like	2900	0.75 Ma	12	> -30%	> -30%	> -30%	2035	≥ 4	
FRC	Airbus Helicopters Compound (RACER)	<350	220 kTAS	12	Twin-Engine Medium Baseline (TEM-B) generic helicopter	290	114 kTAS	12	-20%	-20%	-20%	2030	6	
	Leonardo Helicopters Tiltrotor (NGCTR)	<1000	250 kTAS	24	Leonardo Helicopters AW139 like	570	145 kTAS	15	-50%	-14%	-30%	2030+	6	
*All key enabling technologies at TRL 6 with a potential entry into service five years later.														
**Key enabling technologies at major system level.														

Table 1 - List of CS2 new aircraft concepts versus reference aircraft, with projected EIS, environmental goals and TRL target at programme close.



## 3.2 Reference Aircraft

In order to assess the improvement in terms of environmental performance, a ‘most relevant’ reference vehicle (“best in class”) has been defined for each new aircraft concept for fair comparison purposes, see Table 1. A note has to be made here regarding the difficulty of an appropriate choice for the reference aircraft.

For mainliners, this reference aircraft is fairly easy to identify as year 2014 state-of-the-art (SoA): A321neo-like for the SMR concept and A350-900 like for the LR concept, although these effectively entered into service respectively in 2016 and 2015.

However, in other cases, due to different passenger capacity (i.e. REG-90 or REG-130 pax), range or cruise speed, there is no exact match in terms of existing aircraft. For the Advanced Regional TP concept, this required to choose the closest aircraft (ATR-72) and up-scale it to 90 pax.

For regional turboprop aircraft in general (ATR-72, C-295, etc.), the latest SoA regional aircraft in service in 2014 are based on technology standards of year 2000, whereas regional jets (Bombardier CS300 or A220-300) are using recent geared turbofan technology (and are approaching the lower end of the SMR market, i.e. A319 (in terms of range (3000nm) and cruise speed ( $Ma=0.78$ )).

In cases where the technologies are intended to be flight-tested on a given aircraft (e.g. the Multi-Mission TP 70 pax technologies will be flown on a C-295 aircraft within the framework of the REG FTB#2 demonstration), the flying testbed aircraft has been selected naturally as the reference, requiring an appropriate re-scaling methodology, well known by the aircraft manufacturers.

For Small Air Transport, all existing aircraft in service have technology standards well prior to year 2000, which required to develop a “generic” 19-seater model with SoA technologies of 2014.

Finally, the identification of an appropriate reference for the fast rotorcraft concepts was the most difficult as the cruise speed of the new concepts is almost twice that of any existing helicopter, closer to an aircraft in terms of cruise speed and altitude, but with VTOL capability. Some of these reference aircraft will be updated for the second assessment.

## 4 Methodology

### 4.1 Assessment at three Levels: Mission, Airport and Global Fleet

For the set of concept aircraft, the Clean Sky 2 Technology Evaluator has performed a first assessment based on three major pillars (Figure 7):

	<p><b><u>Innovation potential at Mission level</u></b></p> <p>Clean Sky 2 Concept Aircraft are compared with 2014 Reference Aircraft on relevant missions regarding emissions and noise. The results are the basis to quantify the success level versus the CS2 environmental goals.</p>
	<p><b><u>Realistic impact at Airport level</u></b></p> <p>A typical day at representative EU-airports (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>
	<p><b><u>Aviation footprint at Air Transport System (ATS) level</u></b></p> <p>A year with all global flights (fleet mix from 2014 historical and 2035/2050 forecast data) is compared for a fleet with and without Clean Sky aircraft and analysed regarding emissions and noise.</p>

Figure 7 – TE Assessment levels.

### 4.2 Forecast and Scenarios

Based on forecasts of average wealth and population<sup>8</sup>, the CS2 Technology Evaluator has elaborated for each market segment (Mainliner, Regional Aircraft, Business Jet, Small Air Transport and Rotorcraft) one **forecast** until 2035 and two **scenarios** (High and Low) from 2035 until 2050, addressing the increasing uncertainty for long term projections and considering vehicle-specific developments, see Figure 8.

The forecast and scenarios include a global mobility demand projection for air travel (see also the forecasts of ICAO<sup>9</sup> and IATA<sup>10</sup>) along with a flight network projection to derive a prevision of a global fleet. The originality of this prevision is that it includes the impact of airport capacity constraints, an assumption generally not made in other currently available forecasts.

<sup>8</sup> United Nations (UN), Department of Economic and Social Affairs, Population Division, 2015. World Population Prospects: The 2015 Revision, DVD Edition.

<sup>9</sup> ICAO Long-Term Traffic Forecasts – Passenger and Cargo, Montreal, July 2016.

<sup>10</sup> IATA 20 Year Passenger Forecast, Montreal, 2018.

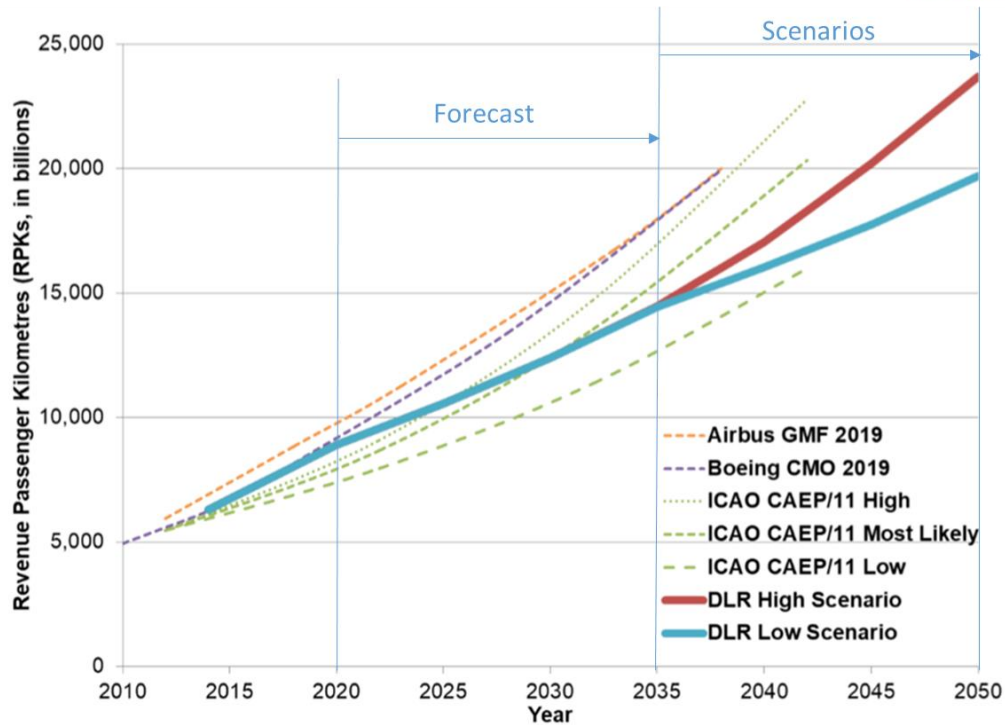


Figure 8 - Comparison of Forecast and Scenarios to other available air traffic predictions.

#### 4.2.1 Overall Assumptions and Airport Capacity Constraints

This fleet projection forms the basis of the conducted global impact and airport assessments; it relies on the following main assumptions, which may have to be reconsidered for the second assessment following the disruption caused by the COVID-19 pandemic (see Section 7):

- No big disruption in mobility behaviour and mobility technology, e.g. no big shift among transport modes and no new transport mean and mode, like urban aerial, autonomous cars and buses for short trips, hybrid-electric commuting, soar of high-speed trains, etc.
- Income per capita, population and airfare development are the key drivers of air transport demand. Available gross domestic product<sup>11</sup> and forecasts on national level were considered, whereas for the airfare development a yearly decline of 1.5% until 2035, then a decline of respectively 0.5% and 2.0% was assumed in the low and high scenarios.
- Economic conditions remain static, excluding wild card effects (e.g. pandemics, economic crises, wars, etc.) affecting specific industries, economic supply chains, or countries. The DLR model is nevertheless based on and calibrated with historical data, which reflect to some extent also previous crises.
- As Clean Sky 2 does not cover all aircraft seat classes, additional “virtual” aircraft were inserted into the fleet using technology diffusion models between neighbouring seat classes five years after an initial entry into service. A dedicated project (TeDiMo<sup>12</sup>) is currently ongoing to study the assumptions and validity of these technology diffusion models within and across the particular aircraft categories in order to assess future aircraft fleet compositions.

<sup>11</sup> IHS Markit, 2017. Global Economy – Forecast of Selected Socio-economic Measures.

<sup>12</sup> TeDiMo, “Technology Diffusion Model”, <https://cordis.europa.eu/project/id/821354>

- Aircraft retirements were based on the empirical model used by ICAO. Aviation is known to be characterized by extremely long life cycles for aircraft, as shown in Figure 9, where the average age of aircraft lies between 20 years (regional jets) and 29 years (turboprops), with narrow- and wide-bodies between 22 and 25 years.

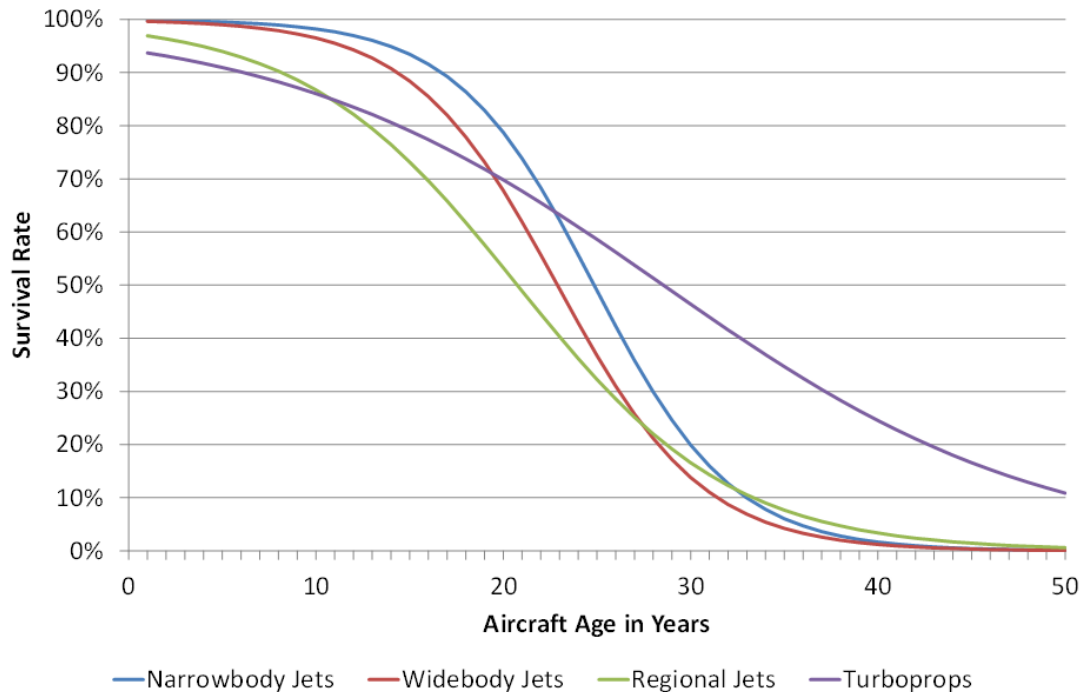


Figure 9 – Aircraft retirement curves.

- Passenger load factors (the relation of passenger kilometres to seat kilometres, i.e. aircraft occupation rate) were assumed to increase from 80.4% in 2014 to 88% in 2050, using the ICAO assumptions for airline efficiency gains predicted until 2037 only, but extrapolated to 2050.
- The future development of aircraft sizes was modelled based on empirical data<sup>13 14</sup>, i.e. on historical data to extrapolate a/c size evolution.
- Airport capacity constraints were taken into account (comparing required and expected runways) for the largest 4000 airports worldwide including major hubs. The number of required runways is based on the traffic forecast and reflects the capacity required to satisfy the demand, while the number of expected runways is based on probabilities, considering technical and political barriers such as the opposition of the neighbouring population fearing increased noise emissions and reduced local air quality. As a result, it was found that less than 100 airports, the major hubs however, are expected to be the main driver for the limitations introduced by this constraint. The remaining 3900 airports will therefore have an increasing role in air mobility as well, as they will need to absorb part of the traffic which can no longer be offered from the main hubs.
- The global flight network considered the airports worldwide, assuming the hub structure to remain unchanged and assuming additional direct connections - especially in intercontinental

<sup>13</sup> Cirium Fleet Analyzer (previously ASCEND Fleet Database, previously FlightGlobal Fleet Analyzer).

<sup>14</sup> Sabre AirVision Market Intelligence (MI), Data based on Market Information Data Tapes (MIDT).



travel if served by aircraft with about 200 to 300 seats<sup>15</sup> - to contribute to accommodating the demand.

- Potential future regulation and the introduction of alternative fuels were not considered in the present study. These aspects are addressed within several currently running Clean Sky projects closing in 2021 (GLIMPSE2050<sup>16</sup>, TRANSCEND<sup>17</sup>) allowing additional insights to be provided by the second assessment.
- The continuous product improvement through the introduction of (CS2) technologies, by means of retrofit in operational aircraft or introduction in the production line of pre-CS2 aircraft, were not taken into account.

Airport capacity constraints is an assumption generally not explicitly taken into account in other existing forecasts, other than through historical data trends on increasing load factors and increasing aircraft size.

The largest 120 airports (3% of all airports) handle about half of the total global traffic.

Enlarging the capacity of big hubs with large traffic numbers, for example London Heathrow, Paris Charles de Gaulle or Atlanta Hartsfield-Jackson is very difficult because of the opposition of the neighbouring population fearing increased noise emissions and reduced local air quality.

The difficulty of enlarging a smaller airport with one or two runways varies according to the region of the world. Opposition is high in countries with high welfare and participation level. However, the majority of those small airports handles only a small share of the global flight volume.

Furthermore, adding additional runway capacity at an airport produces less and less capacity gains the larger the airport is. For example, adding a second independent runway to an airport with just one runway typically doubles runway capacity, while adding a new runway to a multi-runway airport with three or more runways yields far smaller capacity gain because of increased interferences between runways.

As a result, the capacity problems of the large hubs (very important for the global air traffic system) also impact the traffic of smaller airports, which do not have a capacity shortage of their own, but are limited by the capacity problems of the hubs.

In short,

- the analysis focused on new (additional) runways without considering technical or operational measures which increase the capacity by only a few movements per hour.

---

<sup>15</sup> Wilken, D., Berster, P. and Gelhausen, M.C., 2016. Analysis of demand structures on intercontinental routes to and from Europe with a view to identifying potential for new low-cost services, *Journal of Air Transport Management*, 56B, 79-90.

<sup>16</sup> GLIMPSE2050, “Global Impact Assessment of Regulations and Policies for Sustainable Aviation by 2050”, <https://cordis.europa.eu/project/id/865118>

<sup>17</sup> TRANSCEND, “Technology Review of Alternative and Novel Sources of Clean Energy with Next generation Drivetrains”, <https://cordis.europa.eu/project/id/864089>



- runway extensions would deliver little additional capacity (only allowing more aircraft of larger size).
- the realisation probability of a runway expansion project was modelled differently across Europe (Region 1), North/Central America, Australia, New Zealand, Oceania, Japan, South Korea, Taiwan and Singapore (Region 2) and Others (Region 3) including China.
- new airports are not taken into account.

Therefore, considering the huge effect of this particular assumption, DLR has performed both the high and low forecast and scenario calculations with and without the airport capacity constraint, i.e. referred to in the next as the constrained and unconstrained forecast and scenarios.

#### 4.2.2 Passenger and Flight Volumes

Neglecting airport capacity constraints, the passenger volume between 2014 and 2050 was estimated to grow at 4.1% p.a. in the High Scenario and 3.5% p.a. in the Low Scenario, while the number of flights was assumed to increase at a yearly rate of 2.2% in the High Scenario and 1.8% in the Low Scenario.

Taking airport capacity constraints into account, growth rates were only slightly affected until 2035 but decreased significantly thereafter. Overall, passenger volumes were estimated to grow yearly by 3.9% and 3.3% in the High and Low Scenario respectively and flight volumes by 2.0% and 1.7% respectively in the timeframe from 2014 to 2050.

Based on all airport pairs, the number of passengers and flights was translated into the number of seats and aircraft in the various seat classes in the global fleet. New aircraft accommodated the gap between the predicted transport performance and the transport capacity of legacy aircraft remaining in service.

The forecasted number of flights movements has a significant impact on the subsequent fleet modelling / indicators of aircraft deliveries and in-service fleet in each seat class.

A comparison is shown in Figure 10 between the DLR unconstrained/constrained forecasts and compared to the ICAO/CAEP11 forecast until 2035 in terms of number of flights.

The DLR unconstrained forecast closely matches the flight forecast of ICAO CAEP/11 (2018) for 2035 (difference in 2035: CAEP/11 = 58.9 million flights, DLR Forecast = 57.9 million flights, both with aircraft of more than 19 seats).

In 2045, see Figure 11, the difference increases to 6.4 million flights (CAEP/11 = 79.1 million flights, DLR High Scenario Unconstrained = 72.7 million flights, both with aircraft of more than 19 seats).

This difference of 6.4 million flights may however result in a difference of the order of 3,500-4,000 aircraft deliveries. The difference, however, between the DLR constrained scenario and ICAO's CAEP/11 forecast in 2045 increases up to 22.7 million flights (CAEP/11 = 79.1 million flights, DLR High Scenario Constrained = 56.4 million flights, both with aircraft of more than 19 seats).



The aforementioned comparisons with ICAO’s forecast are limited to the year 2045, as this is the final year of the ICAO forecast. They highlight the substantial impact of the airport capacity constraint assumption.

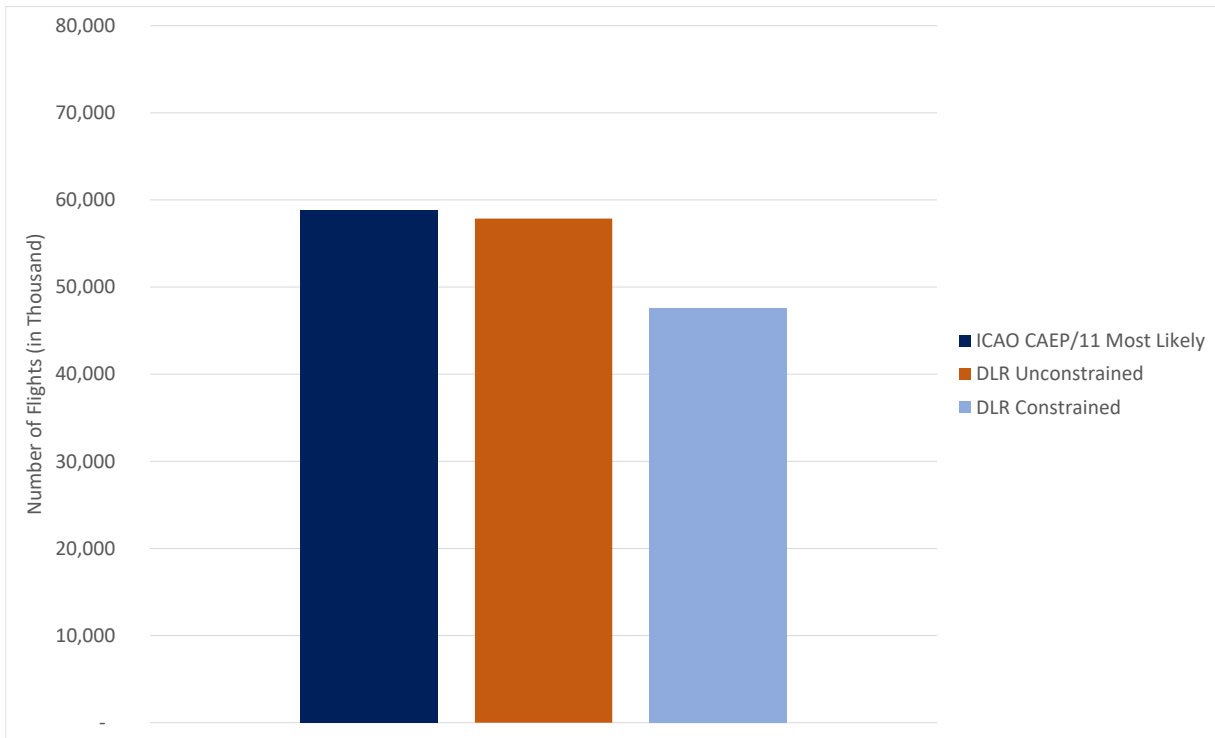


Figure 10 - 2035 DLR Forecast vs. ICAO CAEP/11 Forecast in terms of number of flights.

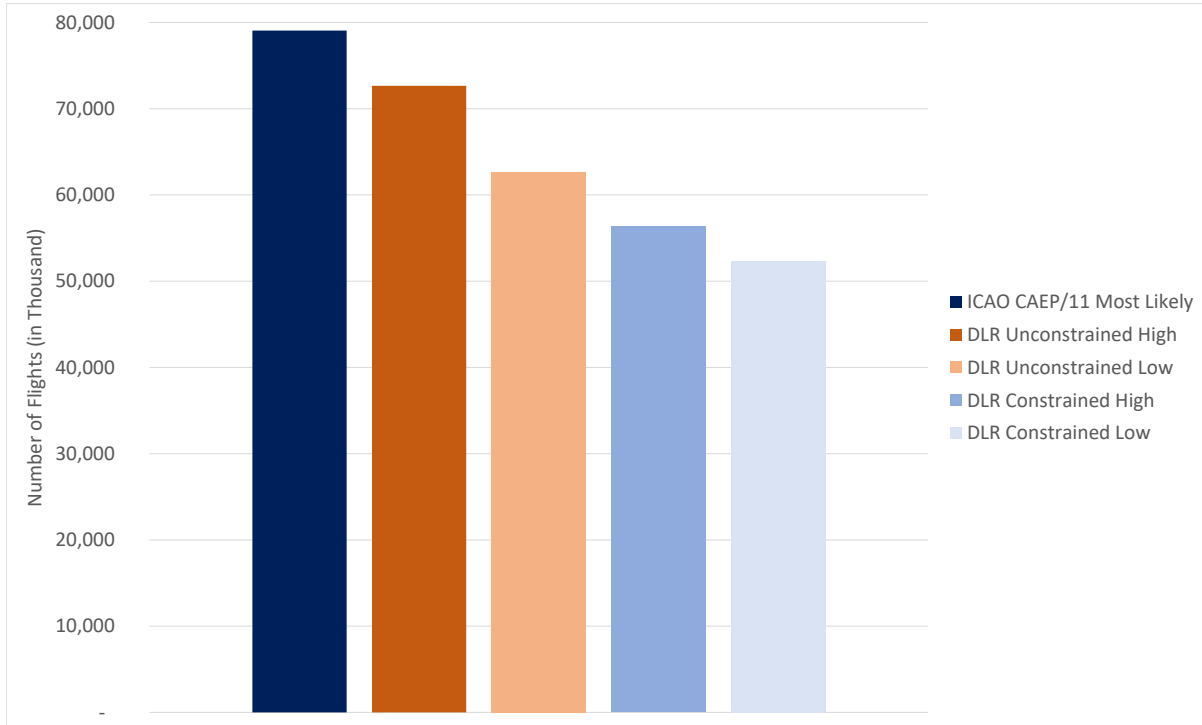


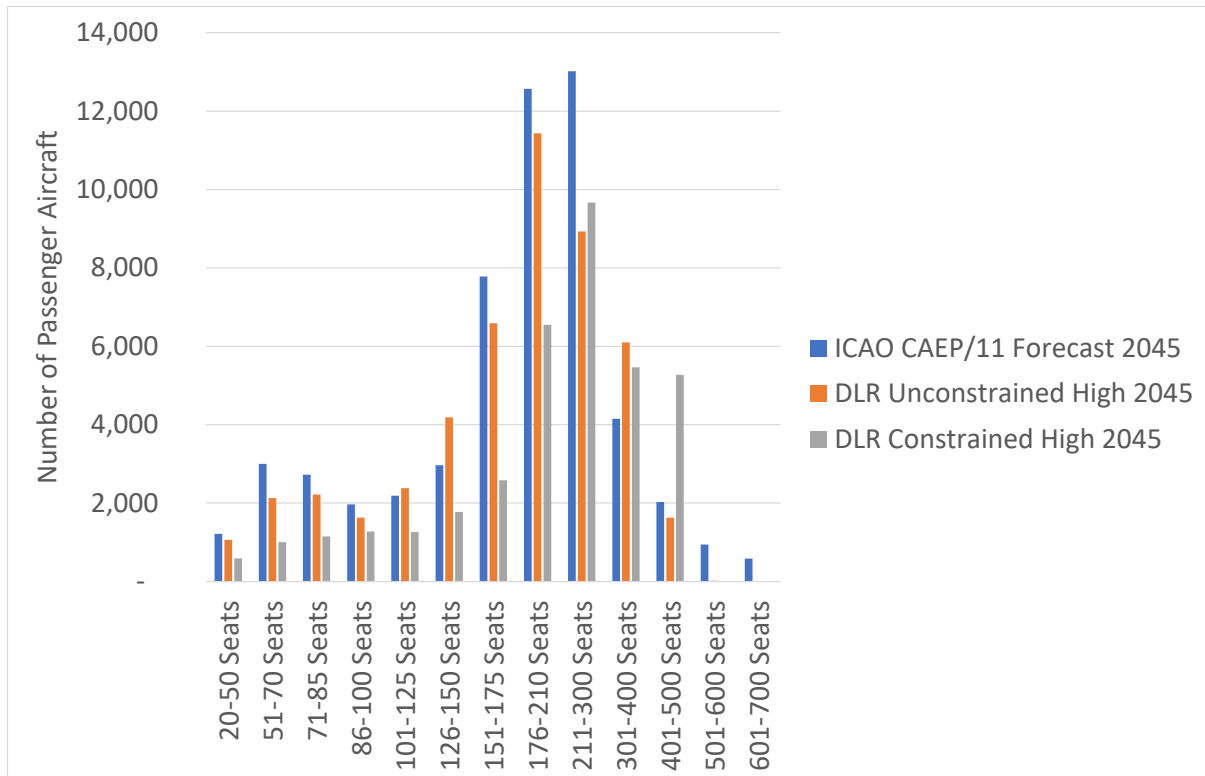
Figure 11 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of number of flights.

#### 4.2.1 Aircraft In Service

An unconstrained scenario (ICAO/CAEP, Airbus GMF, Boeing CMO, etc.) will predict roughly 30% more flights (by year 2045), with a direct impact on expected aircraft in service, hence aircraft deliveries.



Concerning the number of active passenger aircraft with more than 19 seats, ICAO reports 42,238 in 2035 and 55,138 in 2045. DLR forecasts 39,905 aircraft in 2035 (-5.5% compared to ICAO) and 48,304 (-12.4% compared to ICAO) in its unconstrained high forecast/scenario and 31,850 (-24.6% compared to ICAO) in 2035 and 36,589 (-33.6% compared to ICAO) in 2045 in the constrained high forecast/scenario.



**Figure 12 - 2045 DLR Scenarios vs. ICAO CAEP/11 Forecast in terms of in-service passenger aircraft by seat classes.**

#### 4.2.2 Aircraft Size

However, the average aircraft size in the DLR forecasts/scenarios significantly differs from the ICAO forecast. Average aircraft size (calculated by total seats in the global fleet divided by the number of aircraft) in ICAO’s forecast increases from 163 in 2015 to 195 in 2035 and 210 in 2045.

DLR’s *unconstrained* high forecast/scenarios estimate average aircraft size to be 179 seats per aircraft in 2035 and 203 in 2045. In the DLR *constrained* high forecast/scenarios average aircraft size in 2035 increases to 214 and in 2045 to 249 seats per aircraft. These differences are most likely caused by differing assumptions on available airport capacity, seat load factors and aircraft utilisation.

The regional segment (20-100 seats) as well as the short-medium range segment (101-300 seats) are seen to decline in terms of demand whereas a significantly higher demand is seen in the large aircraft category (301-500 seats). This is mainly due to airport capacity constraints but also to airline economic considerations (unit cost reduction on high frequency routes). The main scenarios here exclude very large aircraft with 501-700 seats, following Airbus’ announcement of the end of production of the A380 (a new very large aircraft has been covered in a side scenario, not published here).



Another major effect of airport capacity constraints is therefore that the average aircraft size is gradually increasing (see Figure 12), especially at hub airports with the necessary infrastructure – a compensatory measure already apparent today<sup>18 19</sup>. In other words, even considering measures taken at constrained airports, infrastructure/runway constraints will lead to larger size aircraft.

---

<sup>18</sup> Berster, P., Gelhausen, M.C. and Wilken, D., 2015. Is increasing aircraft size common practice of airlines at congested airports?, *Journal of Air Transport Management*, 46, 40-48.

<sup>19</sup> Gelhausen, M.C., Berster, P. & Wilken, D. (2020). *Airport Capacity Constraints and Strategies for Mitigation – A Global Perspective*. Academic Press, Elsevier.



## 5 Environmental Impact

### 5.1 Mission Level

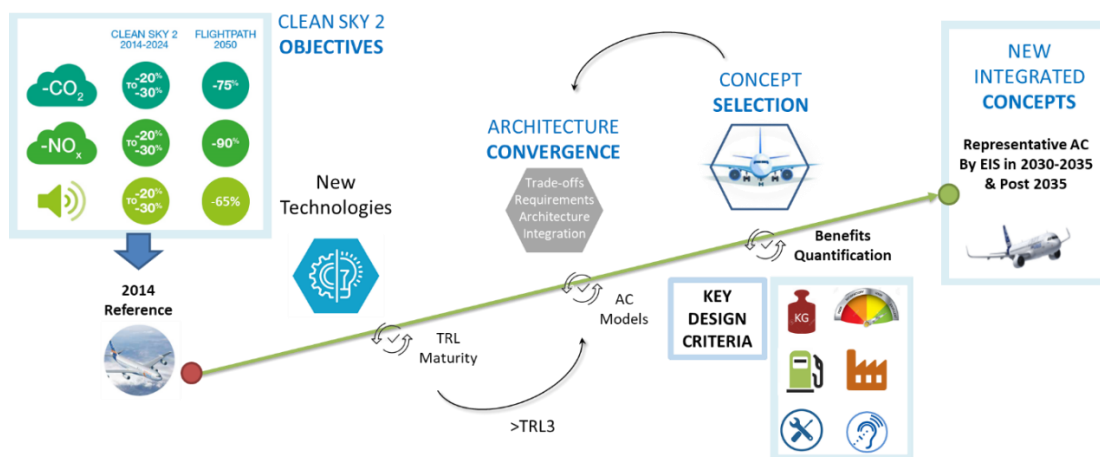
In the following section, we will review the performance achieved for the various aircraft concepts at mission level when compared to a relevant reference aircraft of year 2014 technology standards.

Whereas environmental performance is reported in terms of percentage reduction of CO<sub>2</sub>, NO<sub>x</sub>, and noise, aircraft performance is reported in terms of SFC (Specific Fuel Consumption), impact on weight and on aircraft drag. Technologies for CO<sub>2</sub> and NO<sub>x</sub> reduction can be categorised mainly as Aerodynamics (considering both low and high-speed performance), Structures (airframe, composite versus metallic, ...), Systems and Engines (propulsion system).

Each type of technology will have an impact on those performance indicators (SFC, weight and drag), though unfortunately this is not always simultaneously positive for all indicators. A typical example is the substantial improvement in fuel burn reduction provided by a new engine design (e.g. increased By-Pass Ratio), which will inevitably introduce penalties in terms of weight and drag because of the increased size of the engine, despite having a much better propulsive efficiency.

Similarly, noise reduction technologies may be effective and also have a positive effect on drag, but may come at a cost of increased weight of the aircraft; reducing fuel burn of the engine would require increasing combustion temperature to improve cycle efficiency, which is exactly what must be avoided to reduce NO<sub>x</sub>.

It must be noted therefore, that it is extremely difficult to optimise the aircraft for all environmental objectives simultaneously (CO<sub>2</sub>, NO<sub>x</sub>, and noise) because of the conflicting requirements inherent to each of those objectives individually.



The performance presented for the following concepts is therefore the result of a complex optimisation to balance at best the positive and negative effects of integrating a given technology on-board of the aircraft. This optimisation cycle takes about a year (including trade-off studies and generation of models) and therefore in order to provide results in 2019 as an input for the airport and fleet assessment (performed from 07/2019 to 03/2020), the technologies had to be selected already in Q1/Q2 2018.



## 5.1.1 Fixed-Wing Aircraft



### 5.1.1.1 Advanced Long Range Aircraft Concept (LR+)

This concept (as well as the SMR+ and SMR++ concepts) has been elaborated and modelled by Airbus with the internal tool PANEM (v1.8.0) under the LPA IADP. All models are derived from internal softwares, in production today for commercial aircraft programmes, and aero/engine data are extracted from performance data libraries.

The selected technology inputs were given from technology streams developed under CS2 research since 2015 and that had reached a sufficient maturity level (>TRL3) already by 2018 :

- LPA Platform 1: Riblets, Excrescence Reduction\*, NLF Nacelle\*, NLF Wing\*, HLFC VTP\*, HLFC Wing\*\*, HLFC HTP\*\*.
- LPA Platform 2 & ITD Airframe: Composite versus Metallic, Optimisation on Fuselage, Wing, Tails
- LPA Platform 3 & ITD Systems: Active CG control, Cabin ECS, Enhanced FMS\* & Cockpit\*\*
- ITD Engines: New Engine (scaled data) – UHPE\* (SAFRAN WP2) and Ultrafan\*\* (Rolls-Royce WP5-6).

The above mentioned technologies developed under the CS2 research programme have also been complemented by additional technology inputs from Airbus internal research, i.e. on noise reduction technologies (landing gear fairing and low noise design, flap side edge treatment and slat gap optimization) or electrical integration\*, advanced load alleviation\*, and wing design.

The overall aircraft performance improvement results mainly from the propulsion system efficiency improvement. The technical objectives of the Ultrafan® development are to achieve a ~ 10% reduction in fuel burn and CO<sub>2</sub> emissions relative to year 2014 baseline (corresponding to a 23% fuel burn and CO<sub>2</sub> reduction relative to the year 2000 baseline). The major challenge is the introduction of a gearbox into the engine architecture, yielding an additional 5% fuel burn reduction relative to equivalent direct drive engines.

The performance targets of the power plant envisaged for the LR+ (the Rolls-Royce Ultrafan®) are given in Figure 13, i.e. -9% to -12% SFC and -35% to -40% NO<sub>x</sub> emissions.

The introduction of a gearbox into the engine architecture is a key enabler to ultra high by-pass ratios with a low speed fan which is a significant contributor to reducing fuel burn and reducing noise by its lower rotational speed and pressure ratio. The by-pass ratio will exceed 15, with a fan diameter of around 3.5 m (see Figure 14), almost equivalent to the fuselage diameter of an A320 mainliner!

This clearly underlines the increasing challenge at the level of aircraft integration for Ultra-High Bypass Ratio engines.

---

\* SMR+ only

\*\* LR+ only

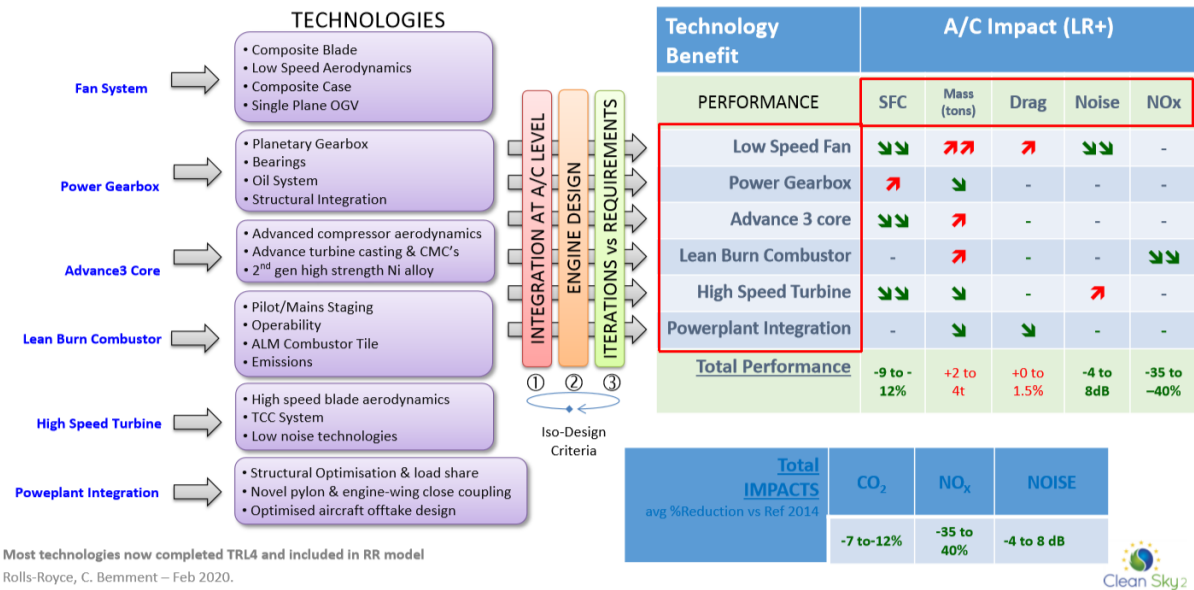


Figure 13 – Technology insertion and expected engine performance improvements for LR+ before aircraft integration (Rolls-Royce Ultrafan®).



Figure 14 – Rolls-Royce Ultrafan® engine concept (left), and comparison of fan diameter with A320 fuselage diameter (right), courtesy Rolls-Royce & Airbus.

Figure 15 shows the emissions and noise performance evolution since year 2000, as well as the targets for the Clean Sky 2 demonstrators (Advance3® and Ultrafan®) that are on the way to achieving the ACARE 2050 targets.

In terms of noise reduction technologies and metrics, noise levels are provided to the TE in “certification ICAO annex 16 conditions” representative of noise certification (EPNL, EPNdB) in addition to the PANEM evaluations in operational conditions.

These noise levels aim at evaluating the noise technology benefits whereas the PANEM noise footprints in SEL (or EPNL) allow to assess the noise in operation.

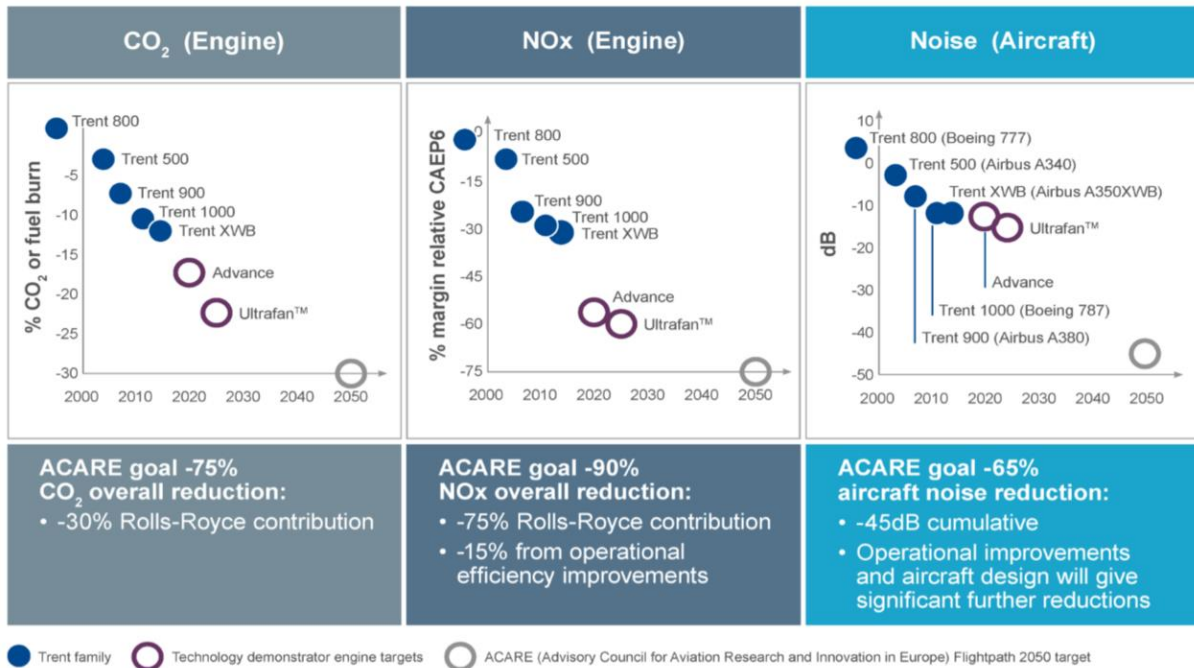


Figure 15 - Emissions and noise performance evolution vs year 2000 and ACARE 2050 targets (courtesy Rolls-Royce).

Noise levels in “certification ICAO annex 16 conditions” are assessed by Airbus as described in Figure 16, using an internal and validated static to flight transposition tool and were provided to the TE in the mission report. A noise reduction of -20% is equivalent to -3 EPNdB and -30% is equivalent to -5 EPNdB on each certification point.

The technical objectives of the Ultrafan® are to achieve a significant step forward towards the ACARE 2035 targets, i.e. -11 EPNdB per operation relative to 2000 situation, -4 to -8 EPNdB versus year 2014 baseline.

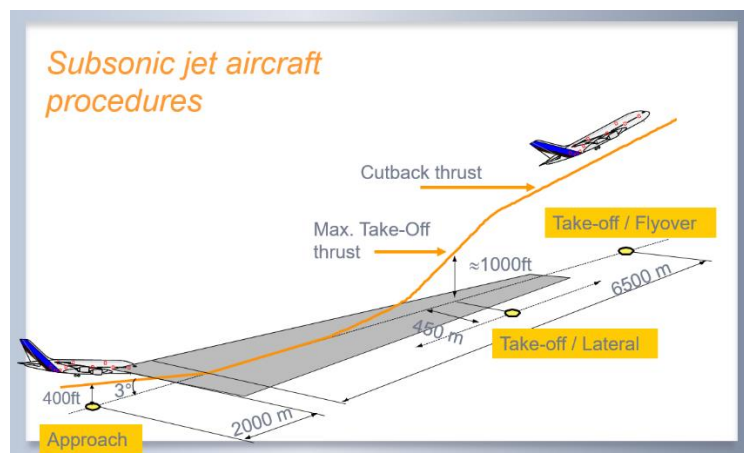


Figure 16 - Noise levels in “certification ICAO annex 16 conditions”.

A summary of the overall performance achieved for the LR+ concept is shown in Figure 17, illustrating the contribution of the various key technologies that are integrated into the model.

A moderate CO<sub>2</sub> reduction of -12% is achieved together with a substantial NO<sub>x</sub> reduction of -36% versus the Airbus A350-900 as a reference. This aircraft had its first flight in June 2013 and entered into service



in January 2015, a very recent, very advanced and highly optimised aircraft. These numbers are an average over the long range missions (4000 – 7000 nm). On the longest range missions, the aircraft demonstrates up to -13% CO<sub>2</sub> and -38% NO<sub>x</sub> reductions.

The current aircraft concept is not frozen and this is the current state of play based on the technologies selected. There are still technology opportunities to bridge the gaps: higher TRLs are expected by the end of CS2 and additional integration scenarios have to be investigated (innovative powerplant integration, deeper system integration, disruptive cockpit, trajectory optimisation, multi-functional fuselage, ...).

The excellent result regarding NO<sub>x</sub> reduction (-36%) originates from early work in Clean Sky 1 under the SAGE 6 Lean Burn work package, continued under Clean Sky 2 with the ALECSYS development by Rolls-Royce, and which is now integrated in the Ultrafan<sup>®</sup> concept.

Finally, substantial noise reduction is achieved with -5% at Take-Off, hampered mainly by the higher speed of the LP turbine in the geared Ultrafan<sup>®</sup> concept, and up to -15% in Approach, which is significant considering once again the compromise to be made versus weight and drag increase of the noise reduction technologies (see Table 2).

<b>Noise reductions</b> <b>“certification ICAO annex 16 conditions”</b> (negative value = noise reduction versus Ref 2014)	<b>LR+ impact on EPNL</b>
<b>Approach</b>	-2.4 EPNdB (~ -15%)
<b>Take-Off</b>	-0,75 EPNdB (~ -5%)

**Table 2 - Noise reduction achievements for LR+ Concept.**

The LR+ aircraft concept was designed based on technology maturity adequate to enter into service in 2030.

The overall concept sizing chain used by the Future Project Office, enables light scaling and loss model calibration. However, aircraft sizing rules, today kept equivalent to the ones used for the reference aircraft (EIS 2014) are 12-14 years old (200 pax for SMR, 315 pax for LR) and may no longer be aligned with EIS 2030.

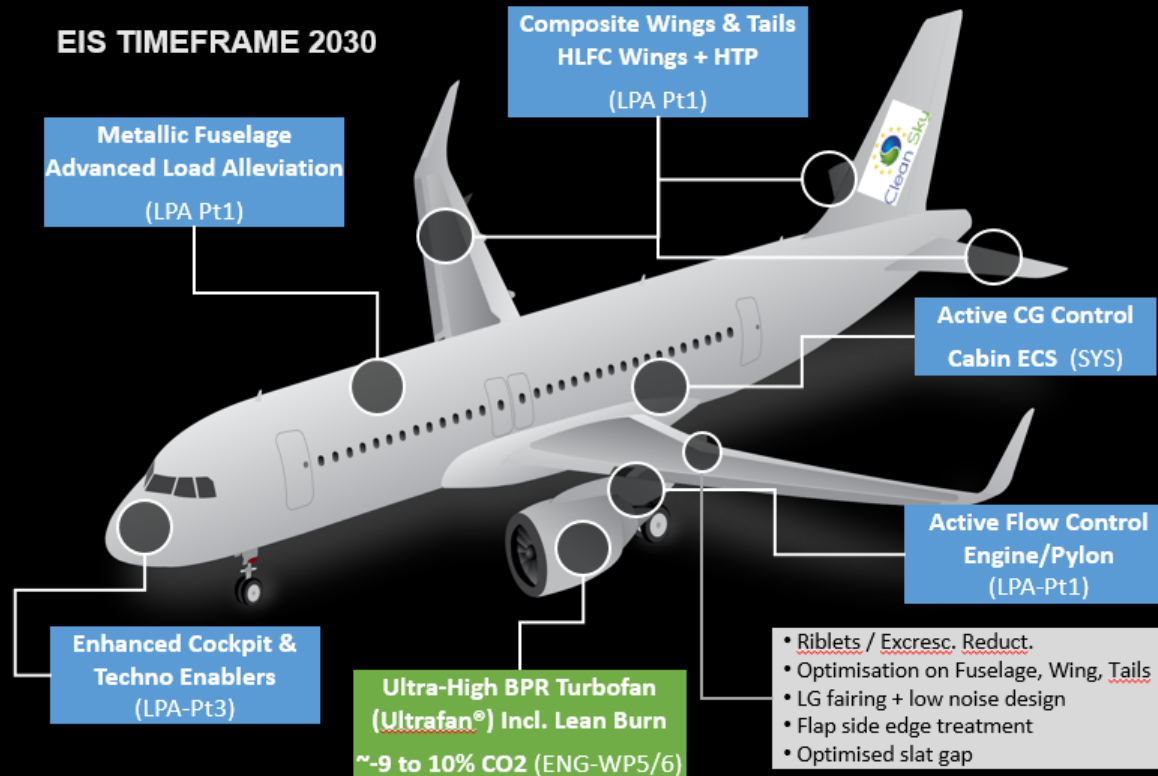
This may lead to the consideration of new concept aircraft which may become more relevant in the future, and better meet the demand of the fleet in 2030/2035, i.e. high capacity/short range aircraft ([Section 8](#), Outlook towards the Second Assessment).



# Advanced Long Range (LR+) Aircraft Concept

6,700 nm (12,400km) - Mach 0.85 - 315 PAX – MTOW 274 t

EIS TIMEFRAME 2030



Ref. LR 2015 – A350-900

6,700 nm - Mach 0.85 - 315 PAX – MTOW 274 t

Benefits	LR+ May 2019		
	SFC	Mass (tons)	Drag
<b>PERFORMANCE</b>			
<b>Aerodynamics</b> High & Low speeds	↗	↗	↘↘
<b>Structure</b>		↘↘	-
<b>Systems</b>	↘	-	↘
<b>Improvements for noise</b>	-	↗	↘
<b>Engine</b>	↘↘	↗	↗
<b>Total Performance</b>	-9.8%	+5.2t	-3.4%
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	CO <sub>2</sub>	NO <sub>x</sub>	NOISE
	-12%	-36%	TO~ -5% AP~ -15%

TO : Take-Off

AP : Approach / Certification ICAO annex 16 conditions

Figure 17 – Advanced Long Range Concept LR+.



### 5.1.1.2 Ultra-Advanced Long Range Aircraft Concept (LR++)

The LR++, i.e. Ultra-Advanced Long Range Aircraft Concept has not been modelled so far in terms of detailed performance model. This task was planned to start after the first assessment and will be performed by DLR in coordination with Airbus.

As an engineering approach, the LR++ concept has been integrated into the fleet calculation with an assumption of a 7%-8% further CO<sub>2</sub>/NO<sub>x</sub> reduction improvement versus the LR+ concept (-21% CO<sub>2</sub> and -45% NO<sub>x</sub> reduction) and entry into service as of 2035.



For the Ultra-Advanced Long Range Aircraft Concept, advanced technologies such as boundary layer ingestion, ultra-high aspect ratio wings or even more disruptive aircraft configurations such as blended wing body may be considered. Trade-off studies will determine which concept is most promising.



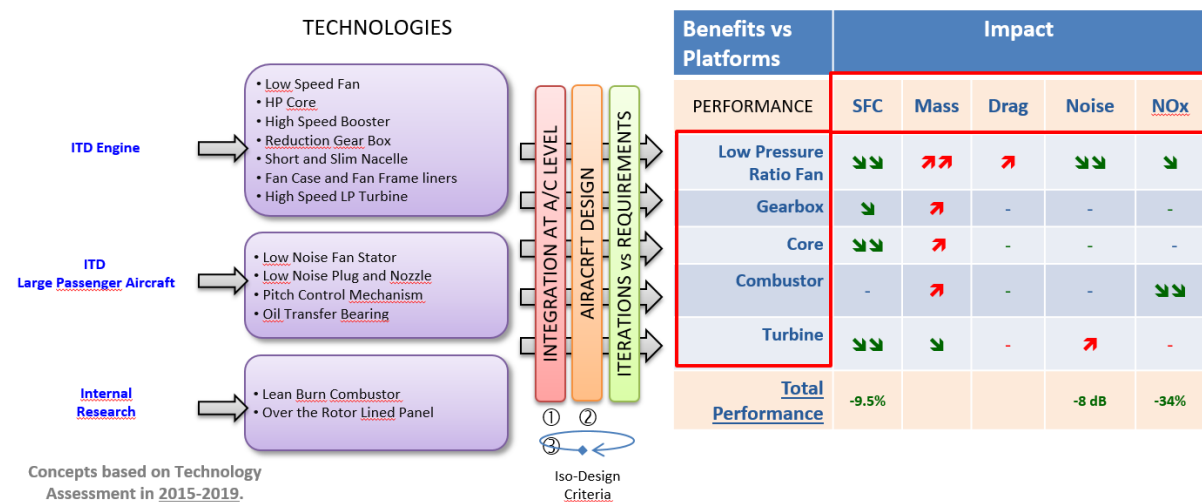


### 5.1.1.3 Advanced SMR Aircraft Concept (SMR+)

Most of the technology inputs applied to the Advanced SMR+ concept have been described in the previous section and are summarized in Figure 18 below. Here as well, this concept has been elaborated and modelled by Airbus with the internal tool PANEM (v1.8.0) under the LPA IADP. The aircraft performance presented are the results of a second iteration loop on the model, i.e. SMR+ v2.

A CO<sub>2</sub> reduction of -17% is achieved together with a NO<sub>x</sub> reduction of -34% versus the A321neo as a reference aircraft. This aircraft first flew in February 2016 and entered service in May 2017. Part of the A320neo family, and re-engined with the CFM LEAP-1A or Pratt & Whitney PW1100G and fitted with sharklets as standard, it is 15% to 20% more fuel efficient than the A320ceo family. Achieving an additional 17% CO<sub>2</sub> reduction is therefore a substantial step forward.

This improvement stems for a large part from the strides made in engine technology, under development in the ENG ITD WP2 by Safran Aircraft Engines. The performance targets of the power plant envisaged for the SMR+ (the Safran UHPE) are given in Figure 19. The UHPE concept, Ultra-High Propulsive Efficiency engine, is targeting a -9.5% CO<sub>2</sub> reduction mainly through an increase of the bypass ratio above 15, a -34% NO<sub>x</sub> reduction (assessed at aircraft level) and a -8 EPNdB noise reduction.



**Figure 18 - Technology insertion and expected engine performance improvements for SMR+ before aircraft integration (Safran Aircraft Engines UHPE).**

The main technology contributions (key enabling technologies) are shown at engine level in Figure 20 for CO<sub>2</sub> and NO<sub>x</sub> reduction and in Figure 21 for noise reduction.

Substantial noise reduction (from engine technologies, nacelle treatments and engine integration improvements) is achieved with -15% at Take-Off, and up to -20% in Approach (Table 3), which is significant considering once again the compromise to be made versus weight and drag increase of the noise reduction technologies.

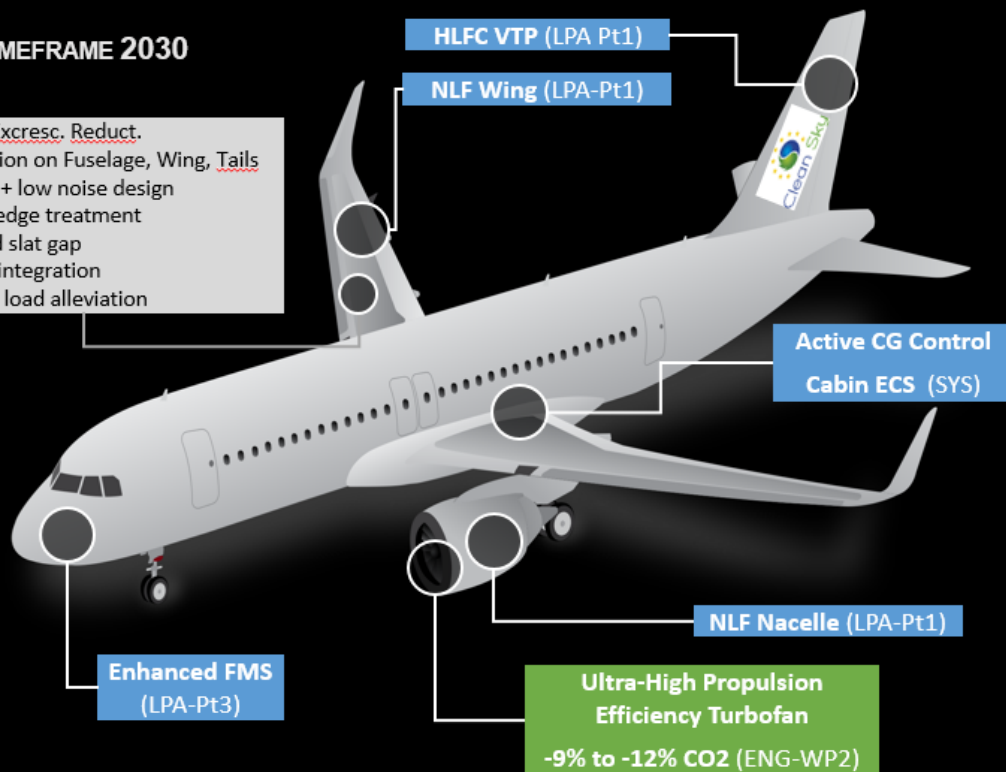
The SMR+ aircraft concept was designed based on technology maturity adequate to enter into service in 2030.

# Advanced Small-Medium Range (SMR+) Aircraft Concept

2,900 nm (5,370km) - Mach 0.78 - 200 PAX – MTOW 87 t

EIS TIMEFRAME 2030

- Riblets / Excrec. Reduct.
- Optimisation on Fuselage, Wing, Tails
- LG fairing + low noise design
- Flap side edge treatment
- Optimised slat gap
- Electrical integration
- Advanced load alleviation



Ref. SMR 2015 – A321neo

2,800 nm - Mach 0.78 - 200 PAX – MTOW 87 t

Benefits vs Platforms	SMR + Dec 2019		
	SFC	Mass (tons)	Drag
<b>PERFORMANCE</b>			
<b>Aerodynamics</b> High & Low speeds	-	↗	↘↘
<b>Structure</b>	-	↘↘	-
<b>Systems</b>	↘	-	↘
<b>Improvements for noise</b>	-	↗	↘
<b>Engine</b>	↘↘	↗	↗
<b>Total Performance</b>	<b>-9.5%</b>	<b>-0.7t</b>	<b>-3.9%</b>
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
	<b>-17%</b>	<b>-34%</b>	<b>TO~ -15% AP&lt; -20%</b>

TO : Take-Off

AP : Approach / Certification ICAO annex 16 conditions

Figure 19 – Advanced Short-Medium Range Concept SMR+v2.

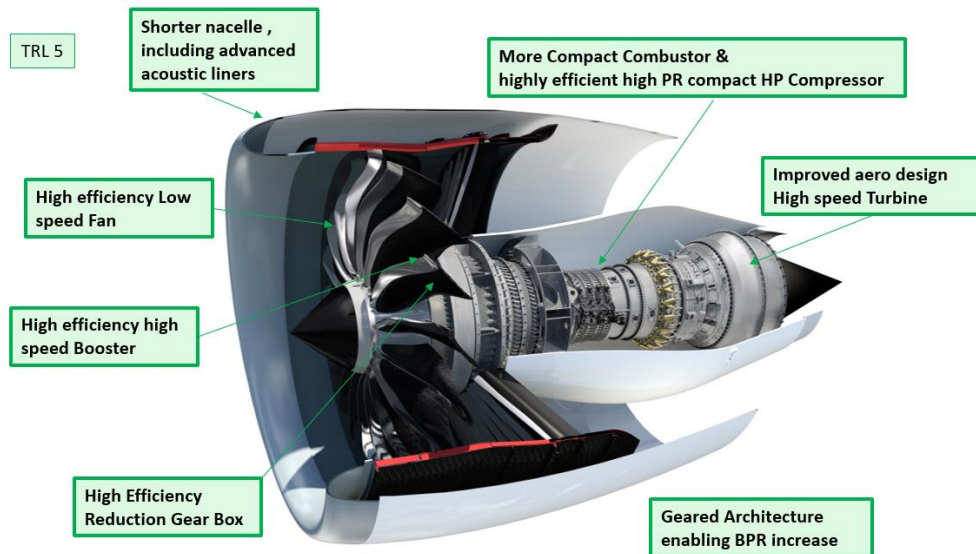


Figure 20 – Key enabling technologies for UHPE concept (Safran Aircraft Engines).

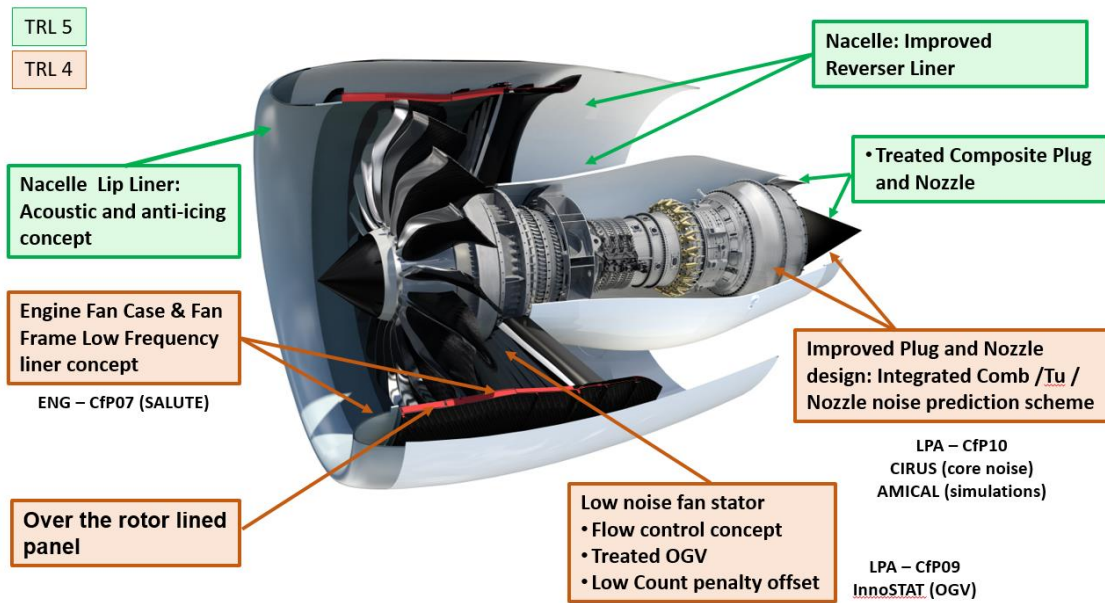


Figure 21 - Noise reduction technologies for UHPE concept (Safran Aircraft Engines).

Noise reductions “certification ICAO annex 16 conditions” (negative value = noise reduction versus Ref 2014)	SMR+ impact on EPNL
<b>Approach</b>	-3,2 EPNdB (<-20%)
<b>Take off</b>	-2,4 EPNdB (~ -15%)

Table 3 - Noise reduction achievements for SMR+ Concept.

5.1.1.4 Ultra-Advanced SMR Aircraft Concept (SMR++)

The SMR++ concept differs from the SMR+ concept by a slightly lower cruise Mach number (0.75 instead of 0.78) to allow for the integration of an open-rotor type of engine and facilitate the NLF (Natural Laminar Flow) wing technology, all other top level aircraft requirements being kept the same (range, passenger capacity and MTOW).

The power plant envisaged for the SMR++ is the Safran Contra-Rotating Open Rotor (CROR), Figure 22, largely based on earlier work from the Clean Sky 1 programme within the SAGE2 ITD. Ground tests completed in 2017 (Figure 24) have confirmed a -30% SFC reduction versus reference year 2000 and compliance with Chapter 14 noise limit with margin. Its performance targets for application to the SMR++ concept are given in Figure 23 versus reference year 2014, i.e. a -14% SFC reduction.

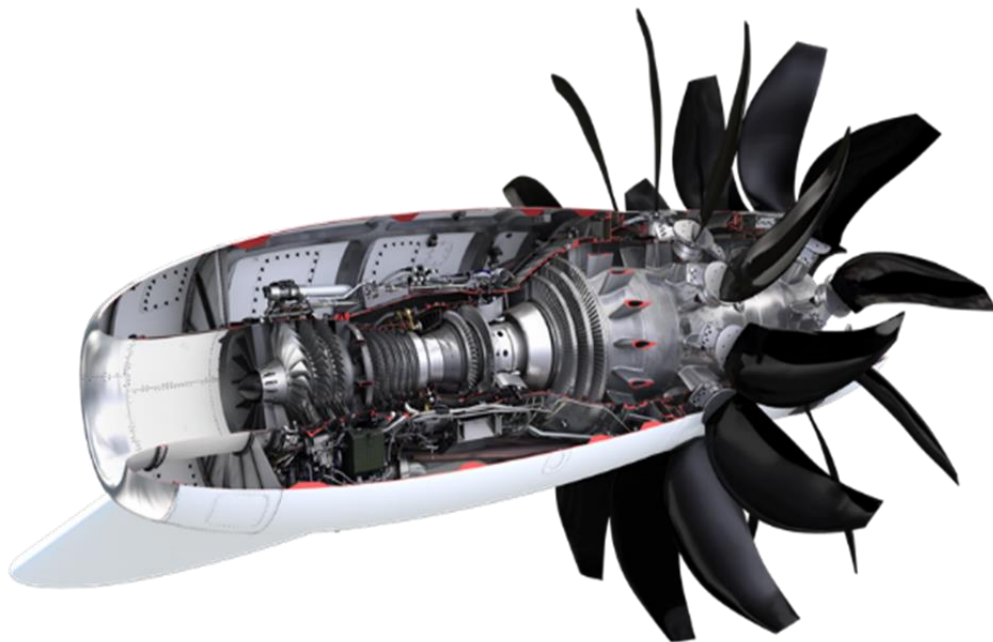
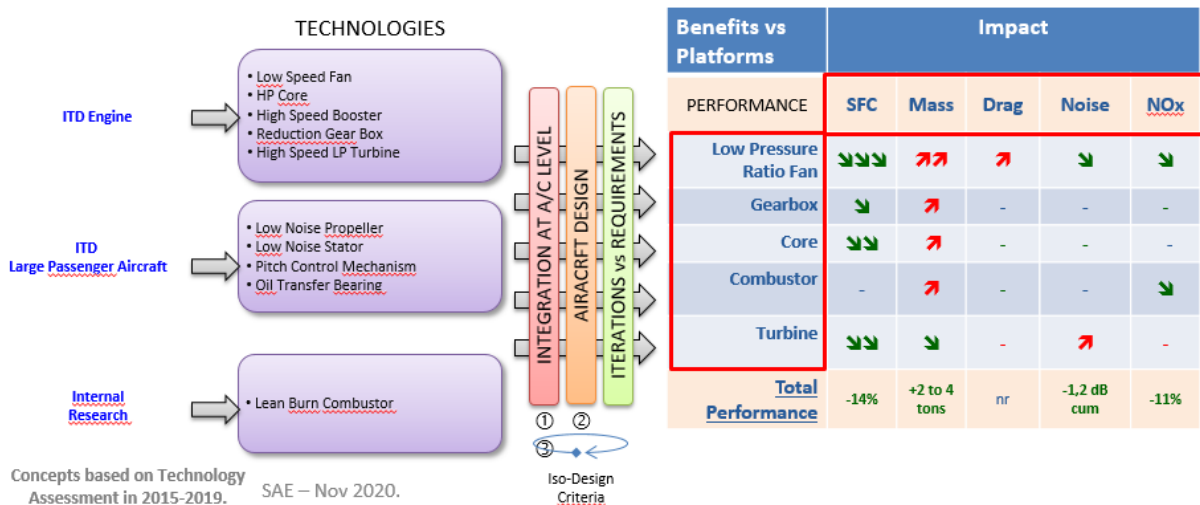


Figure 22 – Contra-Rotating Open Rotor demonstrator, Clean Sky 1, SAGE2, Safran Aircraft Engines.



Concepts based on Technology Assessment in 2015-2019. SAE – Nov 2020.

Figure 23 – Technology insertion and expected engine (CROR) performance improvements for SMR++ before aircraft integration (Safran Aircraft Engines).



Figure 24 – CROR ground test demonstrator at Safran Aero Engines' ground testing facility for Open Rotors and Ultra High By-Pass Ratio engines (Istres, France) – Courtesy SAFRAN.



The superior performance of the Contra-Rotating Open Rotor (CROR) in terms of SFC, combined with additional substantial gains in terms of aerodynamic/airframe technologies (~-15%) leads to an overall CO<sub>2</sub> reduction of -27% even with some integration penalties.

This major performance improvement comes indeed at the cost of a totally redesigned fuselage rear end, and increased weight due to shielding in case of blade-off event. The benefit in terms of performance is the result of the extremely large by-pass ratio achieved with unducted fans, with a slight penalty on noise, especially at Take-Off, even though recent ground tests of the engine prototype have confirmed compliance with ICAO Chapter 14 with margin.

The technology inputs applied to the Ultra-Advanced SMR++ concept have been described in the previous section and are summarised in Figure 25.



The SMR++ aircraft concept was designed based on technology maturity adequate to enter into service as of 2035.

# Ultra-Advanced S/M Range (SMR++) Aircraft Concept

2,900 nm (5,370km) - Mach 0.75 - 200 PAX – MTOW 87 t

EIS TIMEFRAME 2035

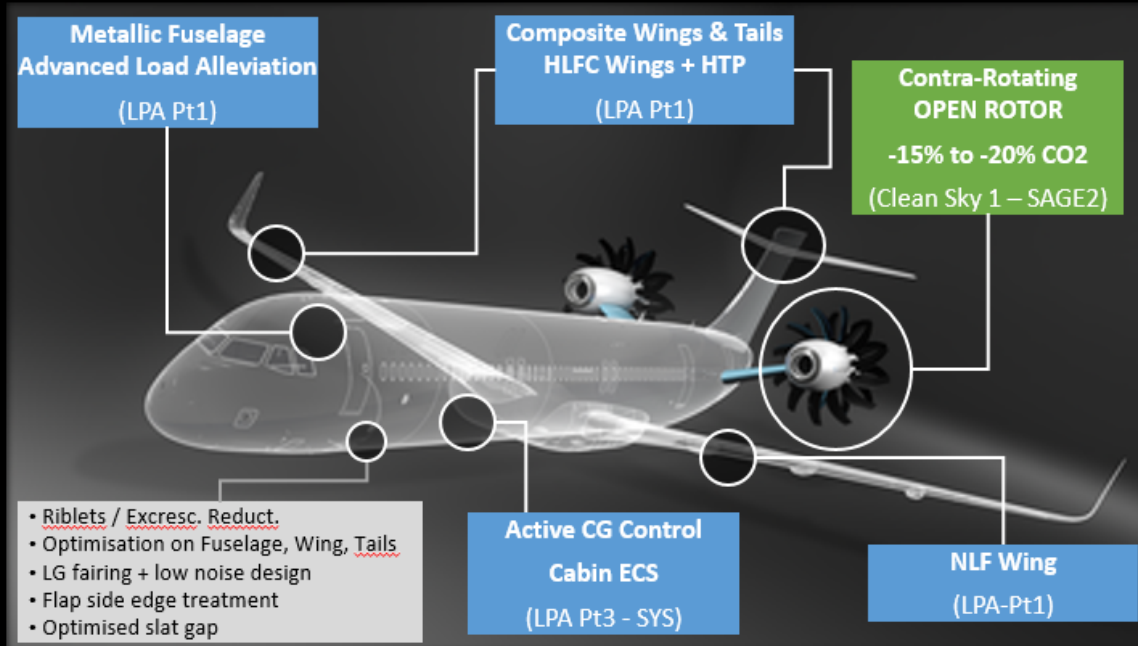


Image courtesy of Safran

## Ref. SMR 2015 – A321neo

2,800 nm - Mach 0.78 - 200 PAX – MTOW 87 t

Techno benefits vs Platforms	SMR ++ CROR 2019		
	SFC	Mass	Drag
PERFORMANCE			
Aerodynamics	-	↗	↘↘
Structure	-	↘↘	-
Systems	↘	-	↘
Noise improvements	-	↗	↘
Engine	↘↘	↗	↗
<b>Total Performance</b>			
Technical issues			
<b>MTOW</b> Ref 2014: 93.5t		<b>82.7t</b>	
<b>Total impacts</b> avg %Reduction vs Ref2014 <b>Iso Pax sizing</b>	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
	<b>-27%</b>	<b>-11%</b>	TO ~ +1.1db AP ~ -3,4db

TO : Take-Off

AP : Approach / Certification ICAO annex 16 conditions

Figure 25 – Ultra-Advanced Small-Medium Range SMR++ Concept.



### 5.1.1.5 Advanced Regional Turboprop 90 pax Aircraft Concept.

This concept (as well as the Innovative Regional Turboprop 130 pax concept) was designed by Leonardo S.p.A. (Aircraft Division).

Technologies have been considered in *all* technical areas of the aircraft. The environmental impact was evaluated with respect to a reference aircraft which was determined by means of a re-sizing process of the ATR72-500 up to the Clean Sky 2 specifications listed in Table 4. This platform is not an existing airplane but it allows for an homogeneous and consistent comparison with respect to fuel burn and community noise reduction.

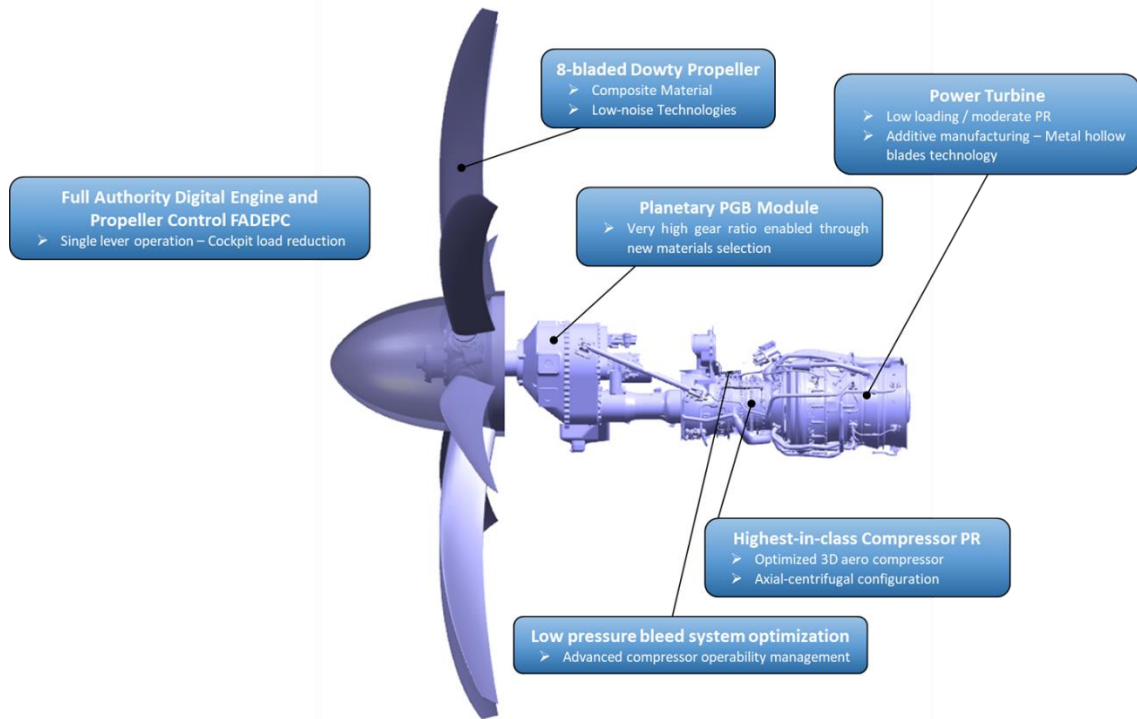
	Aircraft	Range nm	Cruise speed	# PAX	Time to Climb	T.O.F.L.	L.F.L.	EIS* Window	TRL Target** @ CS2 close
<b>Concept</b>	<b>Advanced Turboprop 90 PAX</b>	1200	0.56 Ma at 20 kft	90 @32"	< 13 min 1500-20000 ft @MTOW ISA	1400 m MTOW ISA SL	1300 m MLW ISA SL	2025+	5
<b>Reference</b>	ATR 72-500 up-scaled	1000	0.52 Ma at 20 kft	68 @31"	< 13 min 1500-20000 ft @MTOW ISA	1400 m MTOW ISA SL	1300 m MLW ISA SL	1996 upscaled SoA 2014	n/a

**Table 4 - Comparison of TLARs for conceptual and reference 90 pax regional aircraft.**

The selected technology inputs come from technology streams that have been developed under CS2 research since 2015, mainly from the REG IADP and the AIR ITD:

- REG IADP:
  - Aerodynamics: Advanced HLD, Morphing LC&A, NLF outer wing, Riblets
  - On board systems architecture: Advanced Electrical Power Generation and Distribution System (A-EPGDS), Partial Bleed ECS, EMA Electro-Mechanical Actuation for Primary Flight Control, Low Power Ice Protection System, Electrical Landing Gear System (E-LGS).
- ITD Airframe:
  - Structural Configuration: Low Cost Manufacturing, Green Low Weight Material (Cabin), Liquid Resin Infusion, Advanced Multifunctional Materials, SHM Systems
- REG IADP: IRON Core Partner project (GE Avio)
  - Advanced turboprop engine: new power plant with innovative features in terms of both specific fuel consumption and community noise. Additional studies are also in progress in order to evaluate suitable propeller design oriented to minimize near field noise (cabin noise).

The key technologies and qualitative performance targets of the power plant envisaged for the Advanced TP 90 pax are given in Figure 26, an advanced very large diameter (16 ft / 4.87 m) new generation turboprop with low noise 8-bladed composite propeller. Total impacts vs Ref 2014 given in Figure 26 are for the overall aircraft concept.



PERFORMANCE	SFC	Mass (tons)	Drag
Noise improvement	-	-	-
Engine	↘↘	↘	-
<b>Total IMPACTS</b> vs Ref 2014	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE ICAO Ch14</b>
	<b>-37%</b>	<b>-67%</b>	<b>-15dBA</b>

Figure 26 - Expected qualitative engine performance improvements for the Advanced TP 90 pax (EIS 2025) before aircraft integration (Avio Aero). Total impacts vs Ref 2014 are for the overall aircraft concept.

A summary of the overall performance achieved for the Advanced Regional TP 90 pax concept is shown in Figure 27, illustrating the contribution of the various key technologies integrated into the model.

A substantial CO<sub>2</sub> reduction of -34% is achieved together with a substantial NO<sub>x</sub> reduction of -67% versus the resized ATR-72-500 as a reference.

In terms of noise, a -15 EPNdb is obtained versus ICAO/CAEP Chap14. This is mainly due to the very large propeller diameter (16 ft / 4.87 metres), possible only thanks to the high-wing architecture, with very low rotational speed, which increases efficiency and decreases external noise. As already mentioned, additional studies are in progress in order to evaluate suitable propeller designs oriented to minimize near field noise (cabin noise) as well.

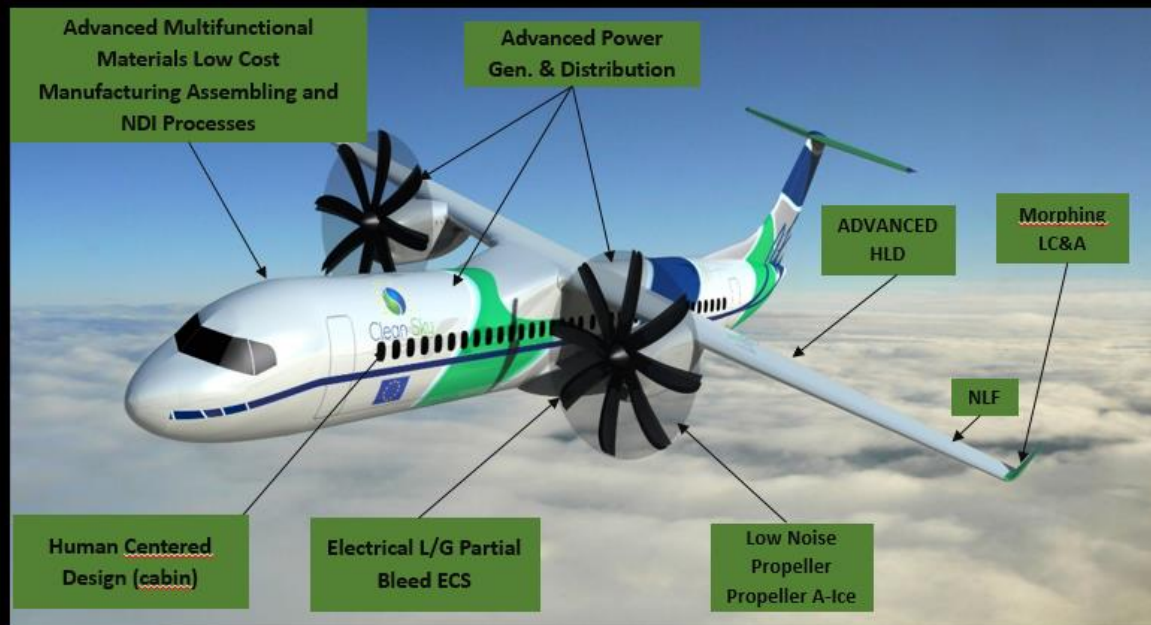
The Advanced Regional TP 90 pax aircraft concept was designed based on technology maturity adequate to enter into service as of 2025.



# ADVANCED REGIONAL TURBOPROP CONCEPT 90 SEATS

1200 nm (2222km) - Mach 0.56 - 90 PAX – MTOW 32,5 t

EIS TIMEFRAME 2025



## Ref. 2014 Resized ATR72

1200 nm - Mach 0.56 - 90 PAX – MTOW 35.6 t

Techno benefits vs Platforms	ADV TP 90 2019		
	SFC	Mass	Drag
PERFORMANCE			
Aerodynamics	-	↗	↘
Structure	-	↘	-
Systems	↘	-	-
Noise improvements	-	-	↘↘
Engine	↘↘	↘	-
<b>Total Performance</b>			
Technical issues			
<b>MTOW</b> Ref 2014: 35.6t		<b>32.5t</b>	
<b>Total impacts</b> avg %Reduction vs Ref2014 <b>Iso Pax sizing</b>	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
	-34%	-67%	CHAP14 - 15 epnDB

Figure 27 – Advanced Regional Turboprop 90 pax Aircraft Concept.



**5.1.1.6 Innovative Regional Turboprop 130 pax Aircraft Concept.**

The conceptual Innovative Regional TP 130 pax is shown in Figure 30 and has the following technological assumptions:

- Intensive composite material
- All electrical on board systems architecture
- Laminar flow wing, advanced high lift device
- USF – Unducted Single Fan engine

The 130 seats concept is mainly an aero-propulsive design. The objective was to understand the efficiency of a large turboprop aircraft with a high number of passengers. For on-board systems, an all electric architecture was selected, adapting it to aircraft size and flight operation (pax, altitude, speed, etc.). For structural design, a full composite material was adopted for the fuselage, wing and tail planes and the weight has been derived following these assumptions. On-board systems architecture features and structural design were directly derived from results already obtained in Clean Sky 1 about these technologies.

The aerodynamic design was conducted having, as target, the demanding objectives both in terms of low speed (stall performance) and high speed (high efficiency at Mach=0.62).

The conceptual A/C has been designed following the technical specifications of Table 5. Compared to the reference aircraft (the Bombardier CS-300, which entered service end of 2016, now A220-300), the Innovative Regional Turboprop 130 pax has been designed for shorter range missions (1600 nm instead of 3000 nm), with a slightly lower cruise speed (Ma=0.62 at 30,000 ft versus Ma=0.78 at 35,000 ft). The original aircraft is a jet airliner, powered by two geared turbofans (P&W 1500G) whereas the conceptual aircraft is a turboprop airliner, but with shorter take-off and landing field lengths.

	Aircraft	Range nm	Cruise speed	# PAX	Time to Climb	T.O.F.L.	L.F.L.	EIS* Window	TRL Target** @ CS2 close
<b>Concept</b>	<i>Innovative Turboprop 130 PAX</i>	1600	0.62 Ma at 30 kft	130	<13 min @MTOW up to FL250	1400 m MTOW ISA SL	1300 m MLW ISA SL	2035+	4
<b>Reference</b>	Bombardier CS300 (A220)	3000	0.78 Ma at 35 kft	130	12.5 min @MTOW up to FL250	1524 m MTOW ISA SL	1463 m MLW ISA SL	2016	n/a

**Table 5 – Comparison of TLARs for conceptual and reference 130 pax regional aircraft.**

In terms of aerodynamic design, Natural Laminar Flow (NLF) has been applied with High Lift Devices (HLD). The wing has been designed with proper section and planform in order to meet the challenging cruise efficiency target. The flap system includes a Fowler flap and morphing droop nose in order to achieve desired maximum CL (Lift Coefficient) to meet the demanding requirements for take-off and landing, see Figure 28.

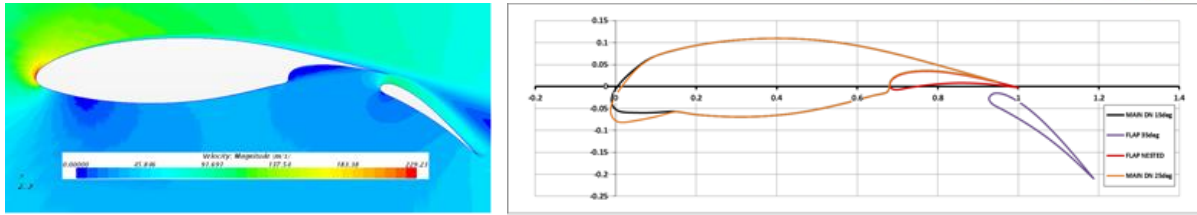


Figure 28 – Velocity field around wing profile (left) and details of droop nose and Fowler flap (right).

In order to fully exploit the benefits of natural laminar flow on the wings, a rear-mounted open rotor engine configuration has been selected. The engine studies have been performed by Avio Aero in the frame of the REG Core Partner project IRON. This engine architecture is unducted and composed of a single rotating fan followed by a fixed row of stator vanes, both rows having variable pitch (see Figure 29).



PERFORMANCE	SFC	Mass (tons)	Drag
Noise improvement	↗	-	-
Engine	↘↘	↘	↘
<b>Total IMPACTS</b> vs Ref 2014	<b>CO<sub>2</sub></b> -25%	<b>NO<sub>x</sub></b> -57%	<b>NOISE ICAO Ch14</b> -9dBA

Figure 29 - Expected qualitative engine performance improvements for the Innovative TP 130 pax (EIS 2035) before aircraft integration (GE Avio) – IRON USF engine (REG – CS2 IRON WP1.1.2). Total impacts vs Ref 2014 are for the overall aircraft concept.

# INNOVATIVE REGIONAL TURBOPROP CONCEPT 130 SEATS

1600 nm (2963km) - Mach 0.62 - 130 PAX – MTOW 51 t

EIS TIMEFRAME 2035



Ref. 2014 Ex Bombardier CS-300

3300 nm - Mach 0.78 - 130 PAX – MTOW 67.5 t

Techno benefits vs Platforms	ADV TP 130 2019		
	SFC	Mass	Drag
PERFORMANCE			
Aerodynamics	-	↗	↘
Structure	-	↘	-
Systems	↘	-	-
Noise improvements	-	-	↘
Engine	↘↘	↘	-
<b>Total Performance</b>			
Technical issues			
<b>MTOW</b> Ref 2014: 67.5t		<b>51.0t</b>	
<b>Total impacts</b> avg %Reduction vs Ref2014 <b>Iso Pax sizing</b>	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
	-26%	-56%	CHAP14 -9 ePNDB

Figure 30 – Innovative Regional Turboprop 130 pax Aircraft Concept.



A summary of the overall performance achieved for the Innovative Regional TP 130 pax concept is shown in Figure 30, illustrating the contribution of the various key technologies integrated into the model.

Thanks mainly to the USF engine, a substantial CO<sub>2</sub> reduction of -26% is achieved together with a substantial NO<sub>x</sub> reduction of -56% versus the CS-300 / A220 as a reference.

This performance increase turns out to be less than for the Regional TP90 concept which can be easily explained by the engine selection which strongly depends on the architectural choices.

The two platforms have two different specifications.

The 90 seats concept is the most stretched evolution of the ATR-72 with more passengers (from 68 to 90), faster speed (Mach from 0.52 up to 0.56) and with underfloor baggage compartment. Maintaining the same architecture common to the ATR family (high wing and landing gear in fuselage) allows to have very large propellers (diameter=16 ft, 4.87m) with limited propeller rotational speed that increases efficiency and reduces external noise. The high-wing architecture is a possible architectural choice up to 90- 100 pax, as above this aircraft size, it is no longer possible to accommodate the increase of the landing gear length due to the available space for retraction in the fuselage bay. For aircraft with higher passenger capacity (>100 seats) the high-wing architecture has to be abandoned due to insufficient propeller-ground clearance and a low-wing architecture becomes a mandatory choice.

The 130 seats concept is therefore based on this configuration, however with a rear fuselage engine installation in order to explore an advanced laminar concept for the wing and also advanced low speed devices (fowler flap + droop nose). A rear engine installation, in turn, also allows to have high internal comfort but limits the maximum diameter of the propellers. This is where the USF engine becomes the most attractive as it has a more compact arrangement but with two blade rows (one rotating, one fixed), the propeller rotating at a higher speed which slightly decreases engine efficiency and penalises the noise performance. The noise performance for the Innovative TP 130 pax is therefore slightly lower than for the Advanced TP 90 pax due to the higher propeller speed of the USF and the interaction noise of the fan with the second fixed blade row (-9 EPNdb versus -15 EPNdb) in an unducted configuration, however with a similar or better propulsive efficiency than a single propeller turboprop engine.

This concept illustrates nevertheless the fact that substantial gains can be achieved by reducing range and cruise speed to cover most of the regional (e.g. intra-European) missions operating from regional airports with shorter runway lengths.

The Innovative Regional TP 130 pax aircraft concept was designed based on technology maturity adequate to enter into service as of 2035.



### 5.1.1.7 Regional Multi-Mission Turboprop 70 pax Aircraft Concept.

Airbus Defence & Space (CASA) is responsible for the Regional Multi-Mission aircraft concept within the Regional IADP in Clean Sky 2. The Regional Multi-Mission aircraft's purpose is not only to be an airline aircraft that competes with many other aircraft in the passenger regional transport market, but also to be capable of reliably operating in extreme airport conditions providing a truly multi – mission capability to the operators (Figure 31):

- in remote areas,
- with poorer aero infrastructures,
- with short and non-prepared fields, or
- located within mountainous regions



**Figure 31 – C-295 landing on a grass strip in Kenya, courtesy Airbus Defense & Space.**

The Future Regional Multi-Mission aircraft shall be ideal for any kind of civic/humanitarian mission for the benefit of society: robust, solid, rugged, and with outstanding low level flight and short take-off and landing characteristics from unprepared rough, soft and short airstrips.

These 'civic' activities shall include surveillance and control activities such as search and rescue, monitoring of illegal immigration, drug smuggling, piracy, illegal fishery, maritime pollution control and deterrence, wild deforestation, bringing supplies to people living in remote locations (isolated islands, deserts, etc) with a flying endurance of more than 11 hours.

From an internal market assessment, expecting a growth in the regional market in the next 20 years, and the evaluation of the main world zones where the operational concept of the current Baseline Regional Multi-Mission aircraft (the EADS-CASA C-295) best fits in terms of type of missions and geographical location, leads to a regional aircraft in the range of 20 to 30 tons of Maximum Take-off Weight. The Baseline and the Future Regional Multi-Mission aircraft cover the lower and upper range extremes respectively.



**Figure 32 - Airbus C295, purchased by the Government of Canada for the Royal Canadian Air Force's (RCAF) Fixed Wing Search and Rescue Aircraft Replacement (FWSAR) programme, October 2019, courtesy Airbus Defense & Space.**

Performance, emissions and noise results are evaluated on a basis of three characteristic mission profiles:

- Passenger Transport / Combi Transport
- Pure Freighter
- SAR (Search And Rescue, First aid to people delivering medical supplies, food, etc.)

The range, mission profile and type of cruise will be in accordance with the specific role of the regional aircraft in each moment. Each role may also include different items to define the internal and external configuration of the aircraft providing the Operative Empty Weight for each mission. Differences between baseline and concept Regional Multi - Mission Aircraft missions will only be in performance capabilities but not in the mission profile.

The target for concept aircraft in terms of transported payload (passengers, cargo or both) compared with the current baseline aircraft capability is as follows:

Range (NM)	BASELINE REGIONAL MULTIMISSION	FUTURE REGIONAL MULTIMISSION
500 NM	24 Pax & 3600 kg of supplies	36 Pax & 4500 kg of supplies
1000 NM	50 Pax	70 Pax
1500 NM	20 Pax & 1750 kg of supplies	30 Pax & 2250 kg of supplies
<b>Note: considering 95 kg per pax.</b>		

**Table 6 – Characteristics in terms of payload and range for the baseline (C-295) and future multi-mission regional aircraft concept.**

Other than the increase in payload or passenger capacity (from 50 to 70 pax), the future aircraft will be designed for a cruise Mach number of 0.5 instead of 0.4.

A brief summary of the technologies related to the Future Regional Multi – Mission configuration coming from REGIONAL IADP, LPA IADP, AIRFRAME ITD and SYSTEMS ITD are detailed in Figure 33:



**Figure 33 – Technology lines integrated in the Regional Multi-Mission TP 70 pax aircraft concept.**

The two main objectives for the development and implementation of these technologies are:

- To minimise the impact on the environment (gaseous emissions and far field noise). This is evaluated by taking into account the reduction of weight and the improvement in aerodynamics resulting from the implementation of these technologies.
- To improve the manufacturing, maintenance and the lead time of the aircraft. These aspects are directly related with the cost savings (recurring costs, maintenance costs).

Analysis of results is done considering all the missions and the mission mix based on fleet estimated utilisation that allows global comparison with Clean Sky 2 global targets.

The results are presented in Figure 34 together with the aircraft key technologies for two representative missions: passenger transport over 1000 nm and a typical SAR mission of 400 nm.

The Airliner mission will yield a CO<sub>2</sub> reduction of -7% which is to be attributed mainly to aerodynamic (-2.5%) and weight improvements (-0.5t).

This aircraft concept has been elaborated with an extremely short EIS target (2025). This strategic choice resulted in the use of a commercially available engine, the P&W 150 series versus the P&W 127G installed on the C295. Only a moderate SFC improvement can therefore be accounted for whereas a more substantial NO<sub>x</sub> reduction (-49%) comes out as a result of the updated engine model provided.

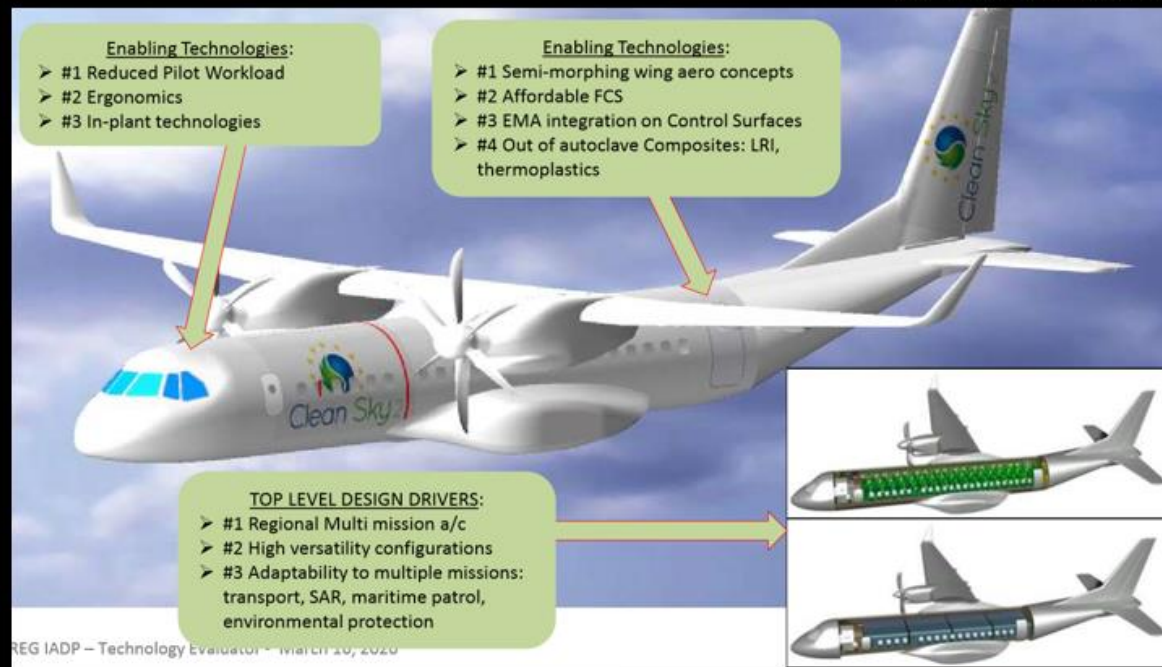
The Search and Rescue mission yields a CO<sub>2</sub> reduction of -43% and a NO<sub>x</sub> reduction of -70%, as a result of reduced speed of the aircraft in the surveillance or observation part of the mission. The Freight Transport missions were estimated to provide a CO<sub>2</sub> reduction gain of -13% and a NO<sub>x</sub> reduction gain of -59%.

Applying a typical utilisation share of 10% airliner, 65% freighter and 25% SAR/surveillance missions, a weighted average CO<sub>2</sub> reduction of 20% and NO<sub>x</sub> reduction of -59% is obtained.

# Advanced Regional Multi-Mission 70 pax Aircraft Concept

1,000 nm (1,852km) - Mach 0.5 / 300 kts - 70 PAX – MTOW 30 t

EIS TIMEFRAME 2025



## Ref. EADS-CASA C-295 Civil

1,000 nm - Mach 0.40 - 50 PAX – MTOW 21 t

Benefits vs Platforms	MISSION: Airliner 1,000 NM Dec 19			MISSION: SAR 400 NM RoA Dec 19		
	SFC	MASS	Drag	SFC	MASS	Drag
<b>PERFORMANCE</b>						
<b>Aerodynamics</b> High & Low speeds	↓	↑	↓↓	↓	↑	↓↓
<b>Structure</b>	↓	↓↓	-		↓↓	-
<b>Systems</b>	-	↓	-	-	↓	-
<b>Improvements for noise</b>	-	↓	↓	-	↓	↓
<b>Engine</b>	-	-	-	-	-	-
<b>Total Performance</b>	-7%	-0.5t	-2.5%	-43%	-0.5t	-2.5%
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	CO <sub>2</sub>	NO <sub>x</sub>	NOISE	CO <sub>2</sub>	NO <sub>x</sub>	NOISE
	-7%	-49%	TO~ -45% AP~ -20%	-43%	-70%	TO~ -45% AP~ -35%

TO : Take-Off  
AP : Approach / Certification ICAO annex 16 conditions

Figure 34 – Advanced Regional Multi-Mission TP 70 pax concept.



#### 5.1.1.8 SAT 19 pax Commuter Aircraft Concept.

This concept has been developed and modelled by Piaggio Aero Industries with the support of Evektor by using a Clean Sky simulation model to assess aircraft performance.

The preliminary sizing of the aircraft was performed by using classical rules for aircraft preliminary sizing, based on an available database of similar aircraft.

SAT focuses on market innovations to reduce operational cost and environmental impact (-20% CO<sub>2</sub> and NO<sub>x</sub> emissions, -10 dB(A) noise reduction), ensuring good operational safety levels as well, to unlock the potential offered by small regional airports, which are closer and more accessible to the travelling society.

Since the operation of small aircraft needs only little or no additional infrastructure investments, it opens many opportunities for regional growth and employment, especially in remote areas far from big airports or with limited or absent road and railway connections to bigger cities.

To assess CS2 technology benefits, two different platforms have been designed inside the SAT Transversal Activity: a Reference and a Concept aircraft. The Reference aircraft is a virtual aircraft designed considering 2014 technologies with an existing engine assuring the requested take-off power (also of year 2014 SoA technology).

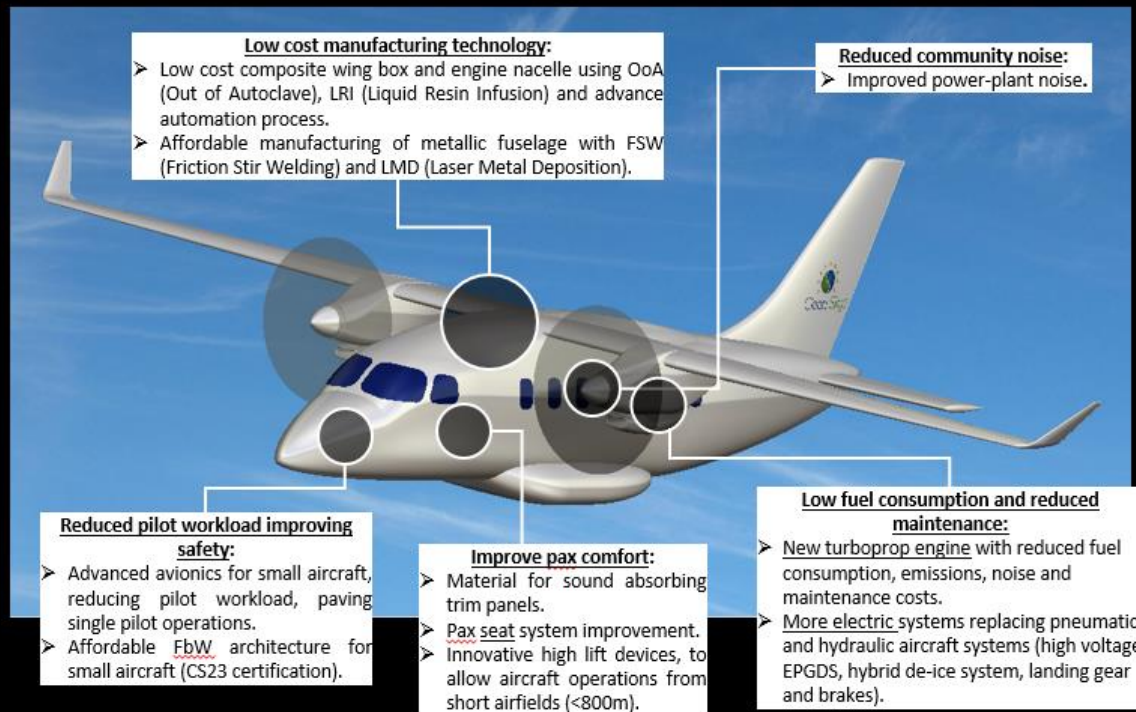
The Concept aircraft (see Figure 35), which has the same TLARs (Top Level Aircraft Requirements) as the Reference aircraft, integrates the following technologies addressed in the frame of Clean Sky 2 ITDs (Integrated Technology Demonstrators):

- Low cost composite wing box and engine nacelle using OoA (Out of Autoclave) technology, LRI (Liquid Resin Infusion) and advanced automation process.
- Innovative high lift devices, allowing aircraft operations from short airfields (<800m).
- Affordable small aircraft manufacturing of metallic fuselage by means of FSW (Friction Stir Welding) and LMD (Laser Metal Deposition).
- Affordable fly-by-wire architecture for small aircraft (CS23 certification rules).
- More electric systems replacing pneumatic and hydraulic aircraft systems (high voltage EPGDS -Electrical Power Generation and Distribution System-, low power de-icing system, landing gear and brakes).
- Advanced avionics for small aircraft, to reduce pilot workload, paving the way to single pilot operations for 19 seats.
- Advanced cabin comfort with new interior materials and more comfortable seats.
- New generation of turboprop engine with reduced fuel consumption, emissions, noise and maintenance costs for 19 seats aircraft.

# Advanced SAT 19 pax Commuter Aircraft Concept

300 nm (555 km) - Mach 0.3 / 195 kts - 19 PAX – MTOW 7,750 t

EIS TIMEFRAME 2025



## Ref. Generic 19 pax Commuter

300 nm - Mach 0.3 – 19 PAX – MTOW 8.435 t

Benefits vs Platforms	SAT 19 seats Dec 19		
	SFC	Mass (tons)	Drag
<b>PERFORMANCE</b>			
<b>Aerodynamics</b> High & Low speeds	-	↗	↘
<b>Structure</b>	-	↘↘	-
<b>Systems</b>	↘	↗↗	-
<b>Improvements for noise</b>	↗	-	-
<b>Engine</b>	↘↘	↗	-
<b>Total Performance</b>	<b>-18%</b>	<b>-0.7t</b>	<b>-3.4%</b>
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	<b>CO<sub>2</sub></b> <b>-21%</b>	<b>NO<sub>x</sub></b> <b>-27%</b>	<b>NOISE</b> <b>~-10dB(A)</b>

Figure 35 – Advanced 19 pax Commuter concept.



Overall dimensions and weights of both the Reference and Concept aircraft are shown in Figure 36.



Figure 36 – Comparison of overall dimensions and weight of 19 pax reference and concept aircraft.

Figure 37 shows the overall qualitative effect of CS2 technologies on SFC (Specific Fuel Consumption), aircraft mass and drag of the concept aircraft, while Figure 38 depicts the engine breakdown of technologies impact on emission reductions.

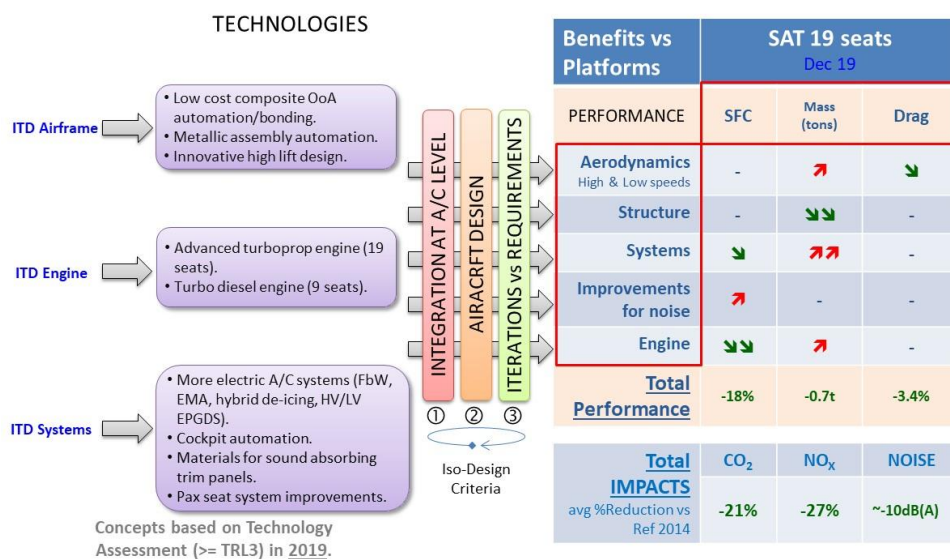


Figure 37 – List of technologies and overall impact at aircraft level for the SAT 19 seat concept.



**MAESTRO engine\* (SAT - CS2 ENG WP8)**

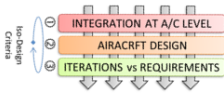
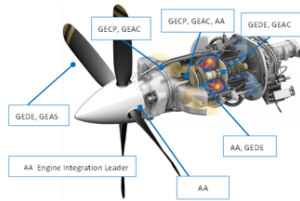
\*EIT: 2025+

Ref: SoA 2014

ITD Engine

TECHNOLOGIES

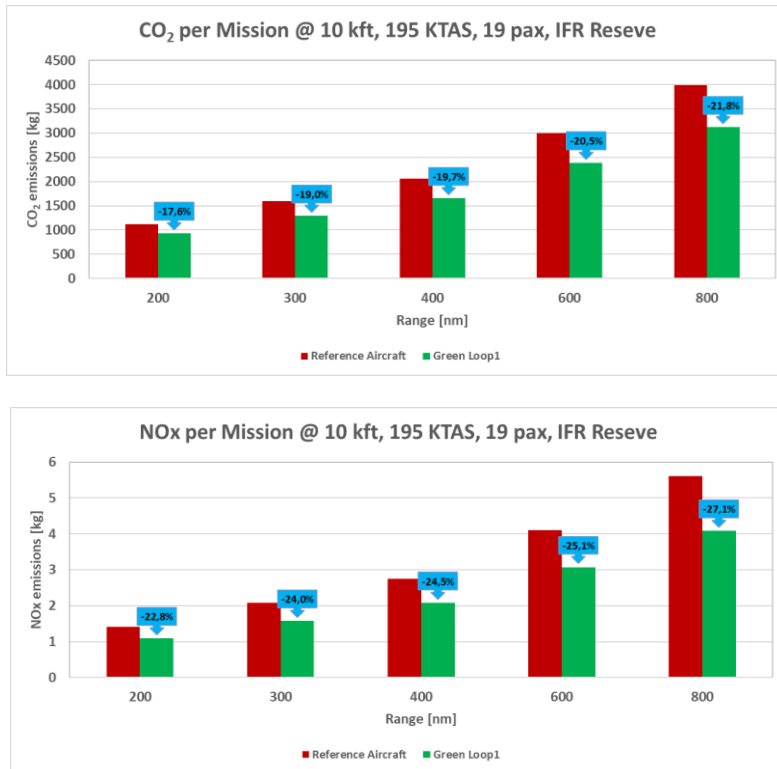
- Low noise propeller
- High Pressure Ratio compressor
- All additive combustor
- Advanced low pressure turbine
- Hybrid-electric architecture studies



PERFORMANCE	SFC	Mass (tons)	Drag
Noise improvement	-	-	-
Engine	↘	↗	-
<b>Total IMPACTS</b> vs Ref SoA 2014 EIT: 2025+	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE ICAO Ch10</b>
	<b>-18%</b>	<b>-24%</b>	<b>-10dBA</b>

**Figure 38 – Expected engine performance (MAESTRO) improvements for 19 pax Commuter concept before aircraft integration.**

Technologies coming from AIR, ENG and SYS ITDs evaluated at PDR level have been integrated at aircraft level to assess their impact on the environment for different mission ranges (200, 300, 400, 600 and 800 nm) and cruise speed (195 and 230 KTAS), see Figure 39. In particular, CO<sub>2</sub> and NO<sub>x</sub> emissions have been derived on the basis of the knowledge of the amount of pollutant released per unit of fuel burn, with the emission indexes provided by engine manufacturers for the requested conditions: max take-off, max climb, cruise (at several engine ratings) and ground idle.



**Figure 39 – CO<sub>2</sub> and NO<sub>x</sub> reductions achieved for various mission ranges for the 19-seat Commuter concept (@10kft, 195KTAS, IFR Reserve).**

Noise emissions have been evaluated for both the certification point and community noise around the airport. Figure 40 shows the methodology of measuring noise at take-off, showing a 10 dB(A) reduction, and the noise footprint area reduction between reference and concept 19 seat aircraft (green loop 1).

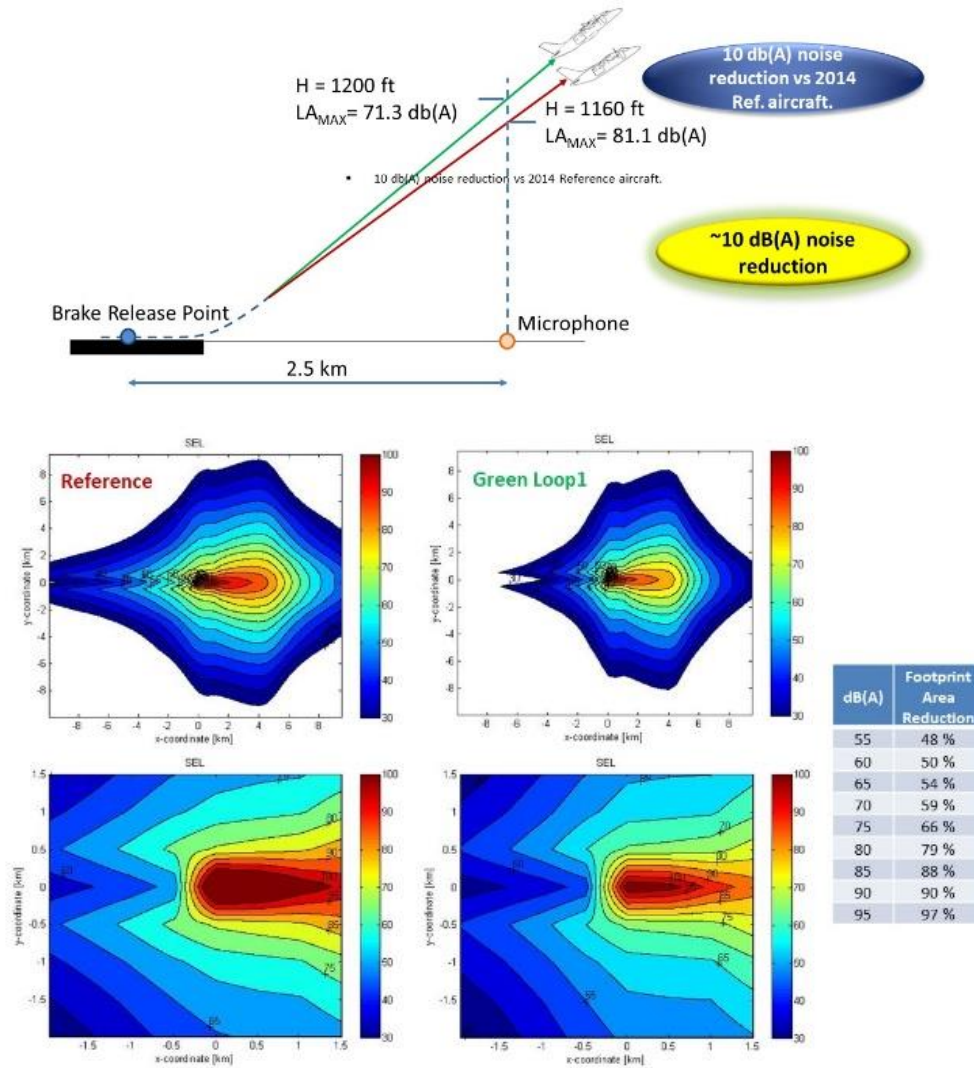


Figure 40 – Comparison of noise footprint area reduction for reference and concept 19 seat aircraft (green loop 1).

The results to date show that original CS2 SAT goals have been reached with the designed configuration. The next step is to review the SAT EIS2025 a/c performances, based on CS2 Technologies CDR outcomes from each ITDs, which are in completion phase (see Figure 41).

The airliner mission of the 19 pax Commuter concept yields a CO<sub>2</sub> reduction of -21% and a NO<sub>x</sub> reduction of -27%, the breakdown of technology contribution being shown in Table 7.

Technology	Emissions reduction vs Ref	
	(800 nm @ 195 kts)	
	CO <sub>2</sub>	NO <sub>x</sub>
Advanced Engine	16%	20%
More-Electric Systems (bleedless)	2%	3%
Airframe Technologies	3%	4%
<b>Total Reduction</b>	<b>21%</b>	<b>27%</b>

Table 7 – Breakdown of technology contributions to the overall emissions reductions at aircraft level.

This aircraft concept has been elaborated with an extremely short EIS target (2025) and achieves remarkable gains considering the small aircraft size. These improvements are reported for a typical 800 nm mission @ 195 KTAS - 360 km/h. However the versatility of the aircraft permits faster flying (230 KTAS – 425 km/h) or to perform two consecutive missions of 300 nm without refuelling, thereby maximising its potential to serve as a “miniliner” or commuter aircraft, improving mobility and connectivity (see [Section 6.1](#). Connectivity and Mobility).

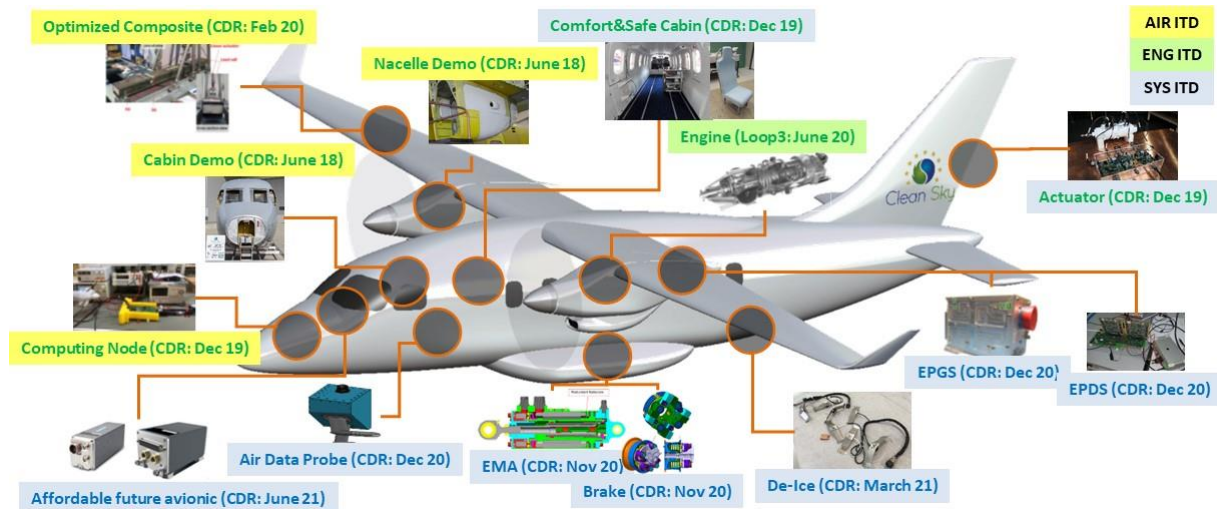


Figure 41 – Calendar of CDRs (Critical Design Reviews<sup>20</sup>) for the technologies selected within the ENG, AIR, and SYS ITDs for the 19 pax Commuter concept.

Furthermore, and in parallel to the development of this EIS 2025 concept, advanced studies of an innovative E-STOL (Electrical/Hybrid Short Take-Off and Landing) 19 seats commuter with a planned market entry in 2032 have been initiated to assess a potential further reduction of emissions.

A hybrid propulsion system has been received as input from the engine supplier consortium (ENG WP8, MAESTRO Core Partner project), which re-scoped the planned activities inside Engine ITD, on the basis of a trade-off activity. In particular, two architectures have been traded (see Figure 42):

- **Series-Hybrid (SH):** electric power generated by both a thermal powerplant and a battery pack.
- **Turbo-Electric (TE):** electric power generated by two thermal powerplants.

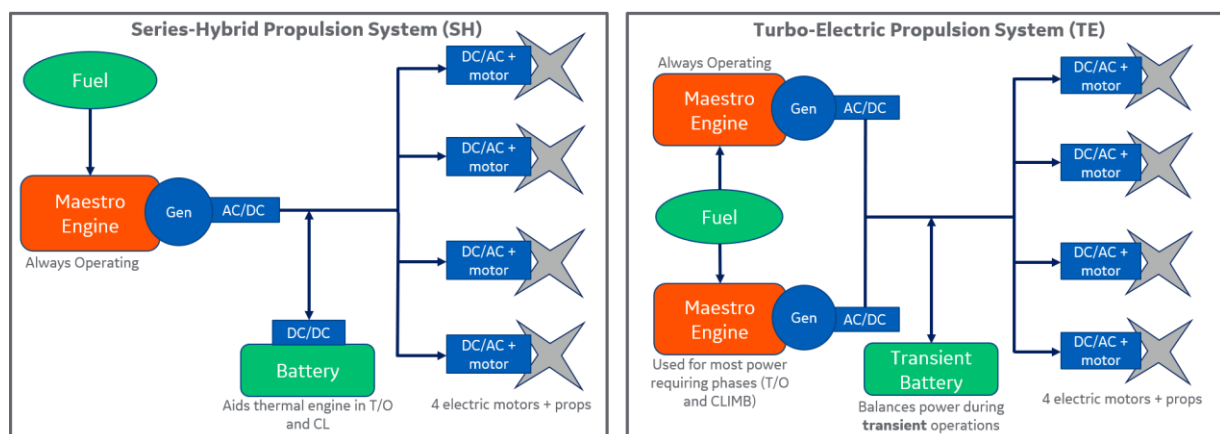


Figure 42 – Schematic view of Serial-Hybrid (SH) and Turbo-Electric (TE) powertrain configurations.

<sup>20</sup> A Critical Design Review (CDR) is a multi-disciplinary technical review to ensure that a system can proceed into fabrication, demonstration, and test and can meet stated performance requirements within cost, schedule, and risk.



Both architectures, although increasing aircraft MTOW, provide additional reductions in CO<sub>2</sub> emissions. In particular, the series-hybrid architecture has been down-selected, since preliminary assessments show a potential reduction of about 27% CO<sub>2</sub> emissions with respect to concept aircraft (Green Loop 1, EIS 2025).

A comparison of the different architectures of the EIS2025 Concept and the EIS2032 E-STOL airplane concept (Figure 43) is shown in Figure 44 with an overview of the hybrid configuration with additional wing-tip propellers.



Figure 43 – Future E-STOL (Electrical/Hybrid Short Take-Off and Landing) 19 seat commuter concept, EIS 2032.

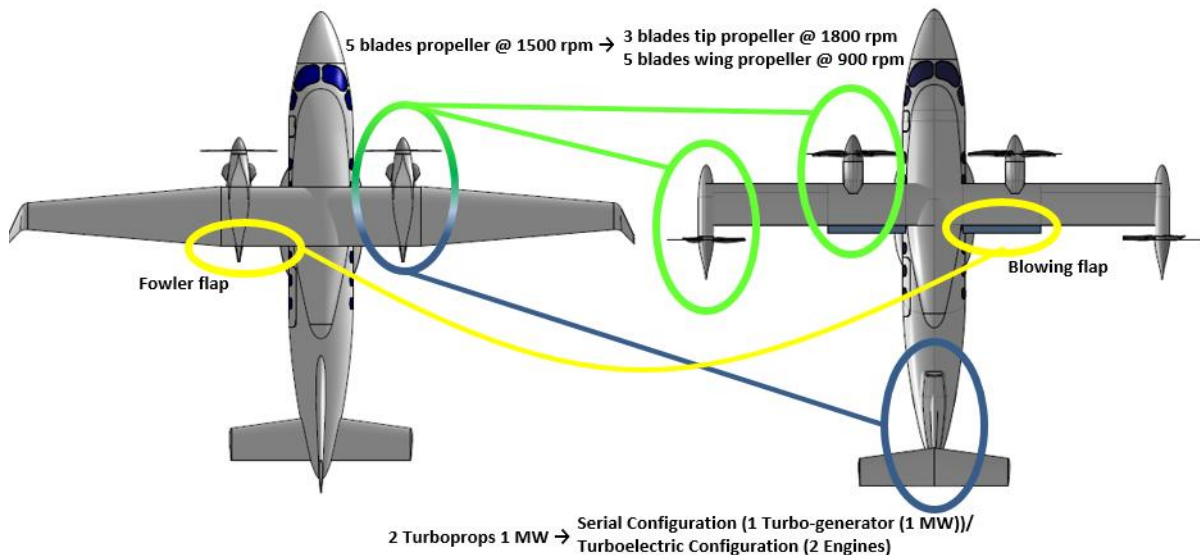


Figure 44 - Architectures of the EIS2025 Concept (left) and the EIS2032 E-STOL airplane concept (right).



These conceptual studies will benefit from the participation of Piaggio Aero in the Advisory Boards of three currently ongoing CS2 thematic projects (HECARRUS<sup>21</sup>, ELICA<sup>22</sup> and UNIFIER19<sup>23</sup>).

These projects started mid or late 2019 and focus on novel concepts for innovative small commuters up to 19 seats targeting near zero emissions by means of hybrid/electric technologies, or even fuel cells and hydrogen.

These projects are targeted to deliver a full preliminary design of a selected aircraft configuration up to CDR, including aerodynamic and structural calculations, and should be concluded by end of 2022.

An example of preliminary concept is shown in Figure 45, using on-board hydrogen storage and hybrid propulsion including fuel cells.



Figure 45 - Artistic impression of a 19-seater with liquid hydrogen hybrid propulsion technology (based on preliminary sizing evaluation), courtesy Pipistrel, <https://www.pipistrel-aircraft.com/unifier19-2>.

---

<sup>21</sup> HECARRUS, “Hybrid ElectriC smAll commuteR aiRcraft conceptual deSign”, <https://cordis.europa.eu/project/id/865089>, <https://www.hecarrus.eu>

<sup>22</sup> ELICA, “Electric Innovative Aircraft”, <https://cordis.europa.eu/project/id/864551>

<sup>23</sup> UNIFIER19, “Community Friendly Miniliner”, <https://cordis.europa.eu/project/id/864901>, <https://www.unifier19.eu>



### 5.1.1.9 Low Sweep Business Jet Aircraft Concept.

Two business jets models have been elaborated by Dassault Aviation and submitted by the Airframe ITD to the Technology Evaluator:

- the BJ reference aircraft, which represents a SoA 2000, classical business jet
- the BJ conceptual aircraft, which represents what could be a 2035\* business jet with new technologies for the airframe, systems and propulsion, in order to:
  - increase overall cruise efficiency by a better L/D, weight decrease and fuel specific consumption decrease
  - decrease the community noise levels

The selected technology inputs come from technology streams developed under both Clean Sky 1 (Smart Fixed-Wing Aircraft – SFWA) and CS2 research since 2015, having reached a sufficient maturity level (>TRL3) already in 2018, see Table 8 :

Integrated Technology	Coming from	Main Benefit	Expected benefit over conventional technology
High aspect ratio Natural Laminar Flow Wing	CS SFWA CS2 AIR TS A-2 LPA WP 1.4.6	Drag reduction	-10% to -15% drag, depending of laminarity extension and feasible aspect ratio
U tail	CS SFWA CS2 AIR TS A-1	Noise shielding	Up to -6 dB on fly over, -2.5 dB on approach
Composite wing	CS2 AIR TS A-3	Wing weight reduction	-5% to -10% of overall wing weight (-12% of wing box, i.e ~-6% of total wing weight taken into account) – enables more aggressive wing planform (sweep angle + aspect ratio)
Flight control load alleviation	CS SFWA CS2 AIR TS A-4	Weight reduction	
IPPS : High BPR, more efficient components	Internal Research	SFC reduction	-12% SFC taken into account (~-5% due to BPR increase, ~-7% on component efficiency)

**Table 8 – Integrated technologies and expected benefits for the business jet concept.**

Figure 46 shows the key technologies which were applied (stemming mainly from research under the AIRFRAME ITD) and their impact in terms of SFC, weight and drag. Based on the information from Table 8, it can be seen that the new engine will provide a -12% reduction in SFC, while other airframe and aerodynamic technologies will provide respectively a weight reduction of ~ 1 ton and a -10% to -15% drag reduction.

In terms of engine contribution, Figure 47 depicts raw engine data on both the 2000 reference airplane (using the SN2000 engine data) and 2035 concept airplane (using the SN2020 engine data). The SFC

\* many technologies have sufficient maturity for 2025-2030 EIS, progress on noise and CO<sub>2</sub> in the 15-20% class would be possible by then.



reduction of -12% is attributed for -5% to BPR increase and -7% to improvements in component efficiencies.

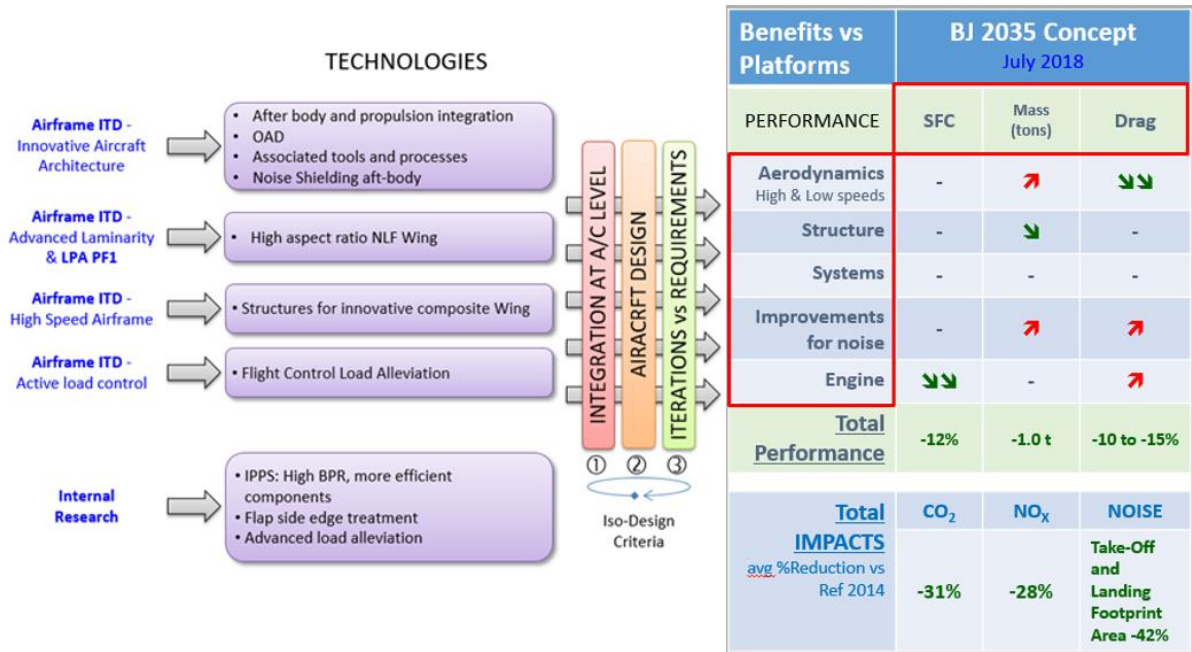


Figure 46 – Technology insertion and expected overall performance impacts for the business jet concept. SFC performance at engine level only before integration.

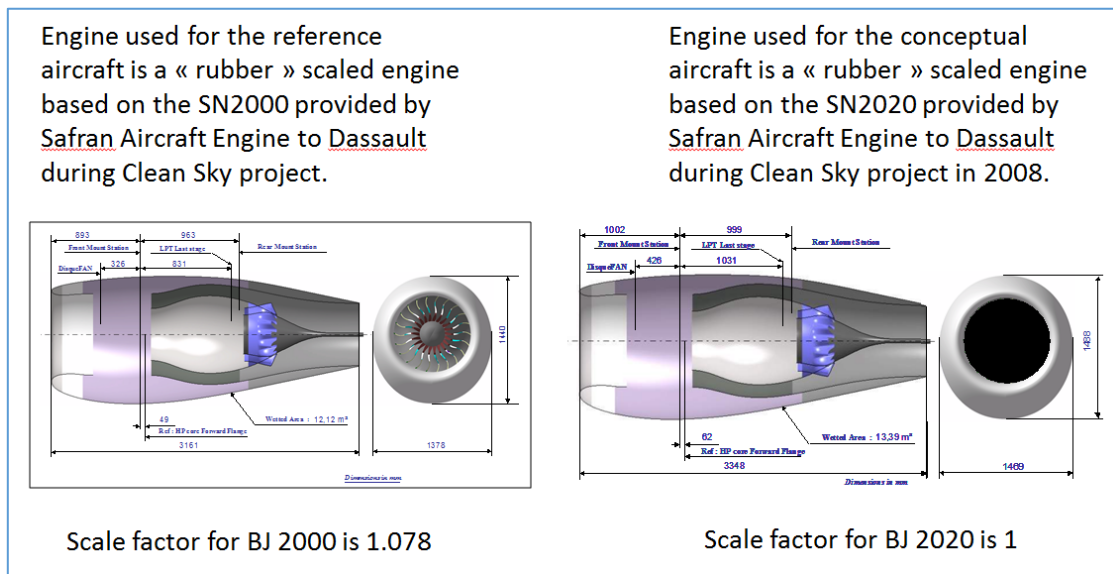


Figure 47 – Engine data and scale factors for BJ2000 (with SN2000) and BJ2035 (with SN2020).

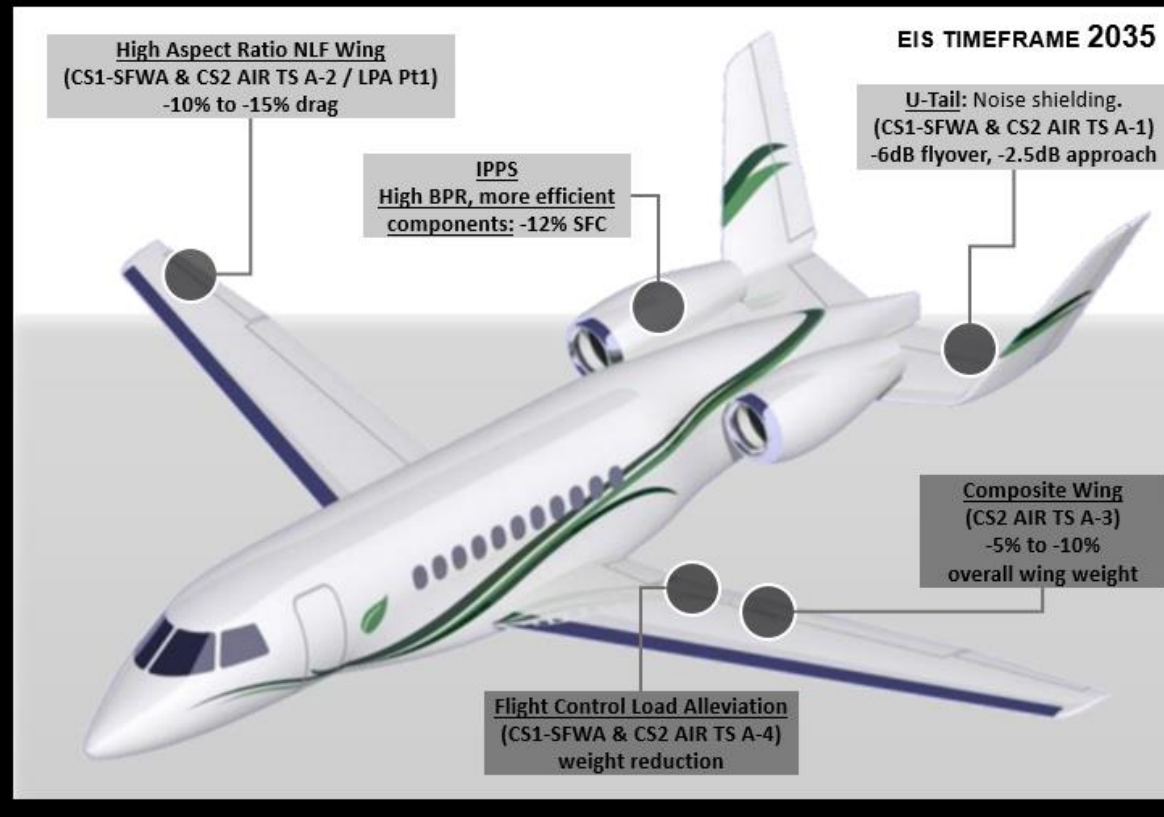
The conceptual aircraft (Figure 48) achieves a -31% CO<sub>2</sub> reduction and a -28% NO<sub>x</sub> reduction.

Laminarity is one of the key technologies that enables the observed gain. It is easier to achieve on a business jet thanks to the small size of the aircraft and its ability to fly at high altitude.

Even if the empty weight does not decrease, it is important to note that the key feature of a composite wing is to permit the design of higher aspect ratio without large decrease of the sweep angle, thus permitting an acceptable cruise speed and a better overall cruise efficiency.

# Low Sweep Business Jet Aircraft Concept

2900 nm (5370 km) - Mach 0.78 - 12 PAX – MTOW 18.8 t



Ref. BJ2000 – Falcon 2000 like

2900 nm - Mach 0.75 – 12 PAX – MTOW 19.9 t

Benefits vs Platforms	BJ 2035 Concept July 2018		
	SFC	Mass (tons)	Drag
<b>PERFORMANCE</b>			
<b>Aerodynamics</b> High & Low speeds	-	↗	↘↘
<b>Structure</b>	-	↘	-
<b>Systems</b>	-	-	-
<b>Improvements for noise</b>	-	↗	↗
<b>Engine</b>	↘↘	-	↗
<b>Total Performance</b>	-12%	-1.0 t	-10 to -15%
<b>Total IMPACTS</b> avg %Reduction vs Ref 2014	<b>CO<sub>2</sub></b>	<b>NO<sub>x</sub></b>	<b>NOISE</b>
	-31%	-28%	Take-Off and Landing Footprint Area -42%

Figure 48 - Advanced Low Sweep Business Jet concept.



In terms of aircraft efficiency, it is difficult to isolate independent contributions from each technology after integration because of their interactions and interdependencies at overall aircraft level.

Concerning CO<sub>2</sub> reduction between reference and concept airplane, Table 9 gives nevertheless an estimate of a detailed breakdown of each technology contribution and an explanation supporting the anticipated CO<sub>2</sub> and SFC reductions, highlighting these interactions and interdependencies.

Item changed	Impact on aircraft efficiency	Impact on cruise consumption
<b>Engine Change</b>	SFC -12%, weight change neglected	-12%
<b>Aspect Ratio increased from 7,65 to 11</b>	Lift to drag ratio: +12% Weight: +3% of Empty Weight (limited to this value thanks to load alleviation and use of a CFRP wing)	-9%
<b>Static Margin reduction</b>	Lift to drag ratio: +2%, reduction of minimal static margin to 0 thanks of use of fly-by-wire	-2%
<b>Airfoil Design</b>	Keep lift to drag ratio unchanged while increasing cruise Mach Number from 0.75 to 0.78. (but Impact on SFC: +2%)	-2 %
<b>Natural Laminar Flow on Wing Upper Surface</b>	Lift to drag ratio: +8% Fuel reserve to obtain the range in case of laminarity not achieved during mission (due to leading edge pollution for example) : equivalent to 2% of OEW	-6%

**Table 9 – Breakdown of technology contributions to the overall gain in performance for the BJ2020.**

Regarding noise, the conceptual aircraft shows a -3 dB gain on the approach point and -5 dB on the flyover point. The overall noise footprint shows a significant reduction of around 40%. The two major contributors for this result are the higher engine BPR and the shielding empennage (U-tail).

In preparation for the second assessment, the reference aircraft will be updated to a generic business jet of year 2014 SoA technology. This will result in an expected decrease of performance from -31% CO<sub>2</sub> down to around -25%, but additional technologies will be added to the conceptual BJ model so as to regain part of this loss; the target is to reach -27%.



### 5.1.2 Fast Rotorcraft



Besides the fixed-wing aircraft concepts described in the previous section, the Clean Sky 2 programme also features two fast rotorcraft concepts and demonstrators: the compound helicopter and the tilt-rotor.

These concepts represent two different approaches to provide vertical take-off and landing capability to an air vehicle.

The first approach, proposed by Airbus Helicopters (AH), is to add forward thrust propellers to an existing helicopter in order to almost double its cruise speed. This concept is based on the Eurocopter X<sup>3</sup> first prototype, Figure 49. An average helicopter can reach a top speed of somewhere between 130 and 140 kts, which comes out to about 260 km/h. The Eurocopter X<sup>3</sup> targets a cruise speed somewhere in the neighbourhood of 220 kts (407 km/h) in stable and level flight. First flown in 2010, the X<sup>3</sup> achieved in 2013 an unofficial helicopter speed record of 255kts (472km/h) in level flight and 268 kts (491 km/h) in descent, showing a safe behaviour all across the flight envelope.

Airbus Helicopters is nearing the end of its development phase on this unique research aircraft, the RACER<sup>24</sup> technology demonstrator, that will ultimately be used to demonstrate various mission configurations. The company – working with 40 partners in 13 countries as part of the Clean Sky 2 project – recently submitted key subsystems of the demonstrator to a critical design review and is manufacturing and sourcing its components. The final assembly of the RACER prototype is expected by the end of 2021, with first flight early 2022.



**Figure 49 – The Airbus Helicopters first compound prototype X3.**

The second approach, proposed by Leonardo Helicopters, is to provide tilting capability to the propellers of an aircraft, which must be therefore designed as large lifting rotors for vertical take-off and hover. The prototype AW609 (see Figure 50), first flown in 2003, is a concept which answers the

---

<sup>24</sup> RACER: Rapid and Cost-Efficient Rotorcraft

need for an aircraft with the speed, range and altitude of a fixed-wing turboprop airplane and the vertical take-off and landing versatility of a helicopter.



**Figure 50 – LHD’s AW609 Tilt-Rotor development aircraft prototype.**

Leonardo’s NGCTR<sup>25</sup> concept is targeting its first flight in 2023 and is also an outstanding example of an extended European collaboration on innovative aeronautical projects. The collaboration includes over 70 organizations such as major aerospace companies, SMEs, research institutes and universities with over 25 different partnerships from 14 countries comprising Italy, Germany, The Netherlands, France, Austria, Switzerland, Latvia, Poland, Czech Republic, Greece, Spain, Portugal, Belgium and the UK therefore creating all new synergies.

These vehicles are most appropriate for vertical operations and hovering in many missions, in particular, oil and gas, construction or transport, mountainous operations but especially for life-saving missions such as search and rescue (SAR), or fast medical evacuation/emergency medical services (EMS). In the latter cases, *time* is most precious and for serious traumatic injuries, increasing the statistical chances of survival by enabling prompt medical or surgical intervention within “the golden hour” is the key factor, the “raison d’être” for this type of machines.

Aeromechanical engineers have long grappled with the challenge of making a vehicle able to take off and land vertically, hover, and achieve very fast cruise speeds—an almost-mythic combination of lift and forward thrust. Advances in the field of V/STOL<sup>26</sup> aircraft have given rise to scores of variations. Many models succeeded in experimental stages, some achieved production status—most at a significant cost or for a limited market.

Airbus Helicopters’ RACER demonstrator and Leonardo Helicopter’s NGCTR demonstrator both aim to go further, by showing that these particular concepts are the answer to cost-efficient, fast flight.

---

<sup>25</sup> NGCTR: Next Generation Civil Tilt-Rotor

<sup>26</sup> V/STOL: Vertical/Short Take-Off and Landing

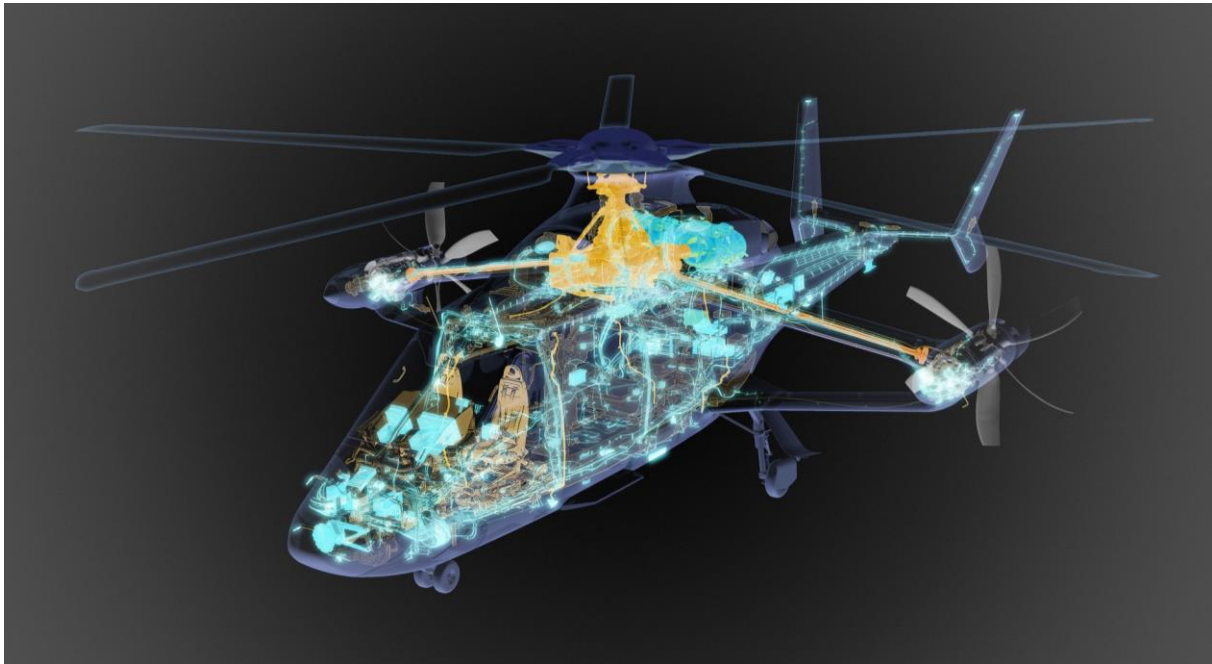
### 5.1.2.1 Compound Helicopter Concept: RACER.

The RACER (Rapid and Cost-Effective Rotorcraft) is a high-speed compound helicopter concept developed by Airbus Helicopters based on the Eurocopter X<sup>3</sup> prototype. Optimised for a cruise speed of 220 kts (~ 400 km/h), 50% faster than a conventional helicopter, it will consume 15% less fuel per distance at 180 kts (333 km/h) than a helicopter of equivalent weight at 130 kts (241 km/h), and aims for a 25% cost reduction per distance.

The lateral pusher propellers generate thrust and are isolated from passengers during ground operations by the box wings, which also serve to generate lift at cruise velocity. This allows the main rotor to be slowed down by up to 15% as the vehicle air speed increases and prevents the rotor blades breaking the sound barrier, which would reduce performance.



Figure 51 – The Airbus RACER Concept and its main technology features.



**Figure 52 – Airbus Helicopters RACER concept. X-Ray type image of internal components layout. Courtesy Airbus Helicopters.**

Driven by two engines, of which one is capable of shutting down and restarting once in flight to save fuel and increase range (the so-called “eco-mode”), it will have a low weight and low maintenance hybrid metallic-composite airframe and lower weight high voltage direct current electrical generation.

Most of the technologies integrated in the TE concept model of the RACER (Figure 51, Figure 52) come from the FRC IADP or from the Airframe ITD, see Table 11. The key design drivers for hover, for cruise and for acoustics are illustrated in Figure 53, Figure 54, and Figure 55, with major contributions from the Clean Sky Core Partner projects NACOR, PROPTER and NAFTI.

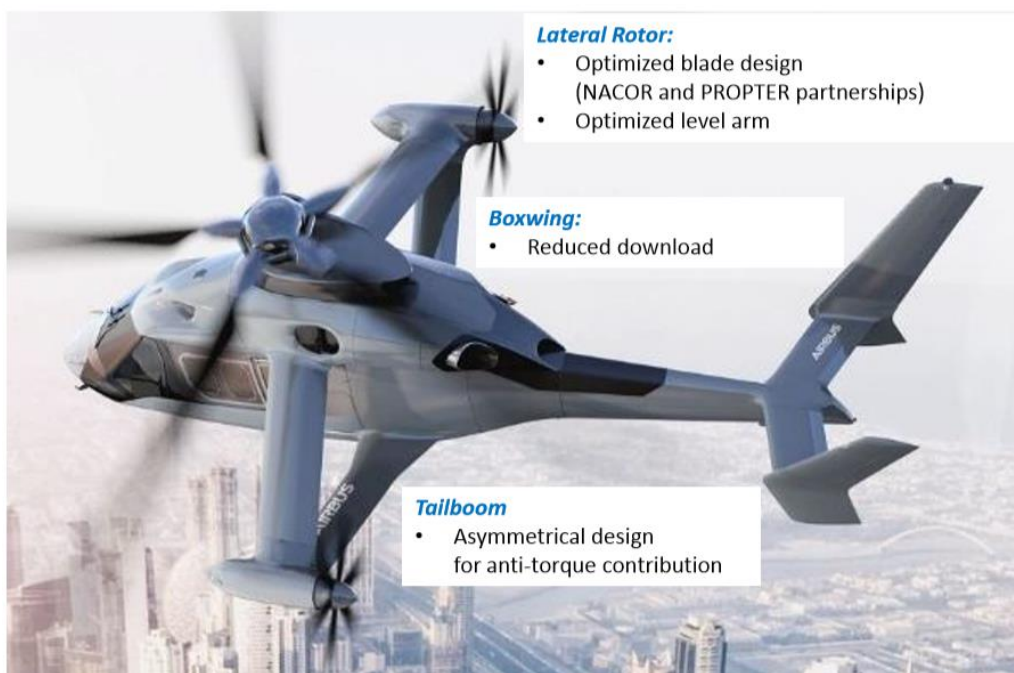
As to the performance evaluation of this concept, comparison has been made so far versus a generic helicopter of equal passenger capacity (12 pax) and typical rotorcraft characteristics, the TEM-B (Twin-Engine Medium Baseline, one of the virtual reference helicopter models developed in Clean Sky 1). It has a cruise speed of 114kts vs 185kts for the RACER and a range of 537km/290nm versus 741km/400nm. Two 2,500 hp (1,900 kW) Safran Aneto-1X were selected to power the RACER (over the RTM322 initially considered), being 25% more compact for the same power.

	Aircraft	Range nm	Cruise speed Max Speed	# PAX	Max Ceiling	MTOW	Power	EIS* Window	TRL Target** @ CS2 close
<b>Concept</b>	<i>High-Speed Compound Helicopter (RACER)</i>	400 (741 km)	185 kts (342 km/h) 220 kts (407 km/h)	12	10000 ft		2 x 2500 shp	2030+	4
<b>Reference</b>	Twin Engine Medium Helicopter (Baseline)	290 (537 km)	114 kts (211 km/h) 127 kts (235 km/h)	12	6562 ft	5069 kg	2 x 1442 shp	n/a	n/a

**Table 10 – Main flight performance characteristics of RACER and TEM-B generic reference helicopter.**

SPD	WP providing input	FRC WP interfacing to TE	FRC Platform	Technology	Integrated into TE concept model (y/n)
FRC	2B.2	4	RACER	Canopy : light weight composite hollow structure	No
FRC	2B.2	4	RACER	Windshield : polycarbonate windshield bird strike resistant for high speed	No
FRC	2B.3	4	RACER	Landing system : doors included in the landing gear system	Yes
Air	B-4.1	4	RACER	Rotorless tail for FastRotorcraft (RACER)	Yes
FRC	2C.4	4	RACER	Lifting rotor for 1 <sup>st</sup> flight	Yes
FRC	2C.5	4	RACER	Lateral rotors	Yes
FRC	2C.6	4	RACER	Mechanical drive	Yes
FRC	2C.7	4	RACER	Fuel tank bladders	No
FRC	2C.9	4	RACER	Lateral rotor actuator, lateral pitch control system	No
FRC	2D.8	4	RACER	Electrical system : high voltage	No
FRC	2D.9	4	RACER	New sensors for lateral rotors pitch command	No
FRC	2D.12	4	RACER	FMS providing smart trajectories for noise reduction	Yes

**Table 11 – Clean Sky 2 technology streams contributing to the RACER concept.**



**Figure 53 – Key design drivers for Hover, RACER, Airbus Helicopters.**

**Boxwing:**

- Optimized wing/nacelle junction (NACOR partnership)
- Stability

**Lateral Rotor:**

- >+10% of efficiency with pusher configuration



**General design**

- Reduced parasite drag (faired rotor head, retractable landing gear)
- Last generation engines (>2000 hp range)

Figure 54 - Key design drivers for Cruise, RACER, Airbus Helicopters.

**Main Rotor:**

- Optimized Nr law

**Lateral Rotor:**

- Nr reduction w.r.t. X3



**General design**

- Optimized flight paths (NAFTI partnership)

Figure 55 – Key design drivers for Acoustics, RACER, Airbus Helicopters.

The current emission indicators which were used for the comparison were the normalized metrics kg(CO<sub>2</sub>)/passenger/km, kg(NO<sub>x</sub>)/passenger/km and the noise footprint maps. The equivalent overall travel time was used as the current mobility criteria.

The analysis covered a number of simulated missions, always at maximum payload (12 pax) except for SAR and EMS, see some examples in Table 12:



- Search and Rescue (SAR),
- Emergency Medical Services (EMS)
- Airport Hub Feeder (AHF),
- Passenger transport DTD and CIT (Door To Door and Commercial Intercity Transport)

SPD	Concept vehicle		Intermediate mission level		Clean Sky 2 Improvements	
			$\Delta\text{CO}_2$	$\Delta\text{NO}_x$	$\Delta\text{CO}_2$	$\Delta\text{NO}_x$
FRC	Airbus Helicopters: Compound	SAR 2	+12%	-26%	20%	20%
		EMS 5	+8%	-26%		
		PAT-DTD 2	+10%	-30%		
		PAT-AHF 5	+3%	-36%		
		PAT-CIT 4	+7%	-34%		

**Table 12 – Preliminary results for CO<sub>2</sub> and NO<sub>x</sub> emissions reduction for a few typical RACER missions.**

The overall fuel burn and CO<sub>2</sub> increase is easily explained by the higher weight and speed of the new vehicle versus the conventional helicopter. Such superior flight performance characteristics can be achieved only through higher power installed for the power train. The fuel and CO<sub>2</sub> metric (kg/pax/km) was seen to increase only by 2.3% to 17.3% over all calculated missions. NO<sub>x</sub> emissions were reduced by 23.8% to 35.7%.

While the NO<sub>x</sub> emissions objectives are achieved, even largely exceeded mainly thanks to the engine low NO<sub>x</sub> combustor characteristics, the CO<sub>2</sub> performance deserves a note of caution and must be considered as a preliminary result for a number of reasons.

None of the missions simulated include cruise flight in “eco mode”. This feature has been specifically designed to achieve the ambitious targets in reducing CO<sub>2</sub> emissions, and has already been demonstrated on the “Bluecopter”, a development largely covered by company self-funding, of which certain technologies integrated into the demonstrator were developed in the framework of Clean Sky (the fast starter motor) and Germany’s LuFo-IV research program. The “eco mode” consists of shutting off one engine during cruise. In that phase of flight, it is more fuel-efficient to use one engine at high power than two engines at medium power. The fuel saving is estimated a 15 percent for a given mission. In just 10 seconds, using a specially-designed electric motor, the idling engine can rapidly and automatically be restored to full power for acceleration, landing or emergencies. A dedicated engine power management is implemented, based on an automatic control system that assists the pilot and ensures safe operation of the aircraft. This would deliver on average about a -15% of CO<sub>2</sub> on any mission for the cruise phase, bringing the results of the currently simulated missions back down to an overall CO<sub>2</sub> reduction instead of a CO<sub>2</sub> increase.

This CO<sub>2</sub> or fuel burn increase should actually be considered as very low compared to the increased weight, range, and most of all, cruise speed performance of the new vehicle. This is again mainly due to the improved performance of the new generation engines selected to power the RACER, with a 10% better fuel efficiency and a 25% better power density than the previous generation engines.

Another reason to consider the above results as preliminary, is that the demonstrator vehicle, currently designed for 12 pax, could be easily extended to 16 pax (by extending the fuselage), because

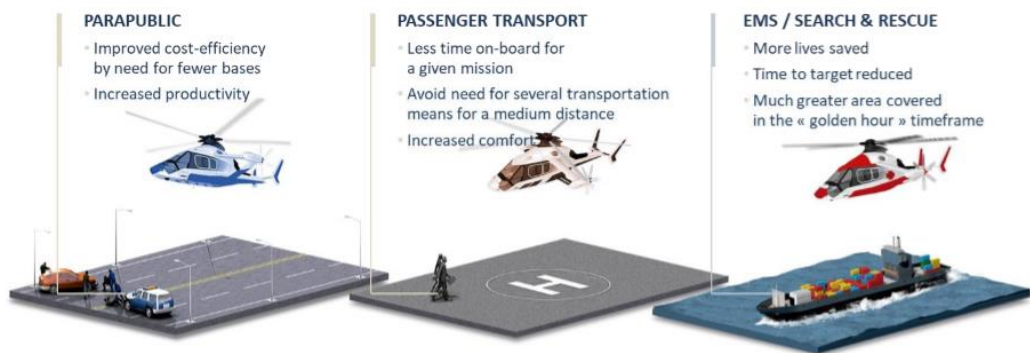


of the sufficient security margins which have been taken on the main gearbox and the engine power currently installed. This would result in a substantial additional improvement in the kgCO<sub>2</sub>/pax/nm metrics (>-10%), even if the reference helicopter is updated to a 16 pax helicopter as well.

In conclusion, there is real confidence and evidence that, based on these engineering assumptions, the target of -15% CO<sub>2</sub> can be reached on average, probably even -20%, for the second assessment.

On the other hand, for SAR and EMS missions in particular, emissions reduction may not be considered as the key criterion. Here, the key performance indicators are the area covered in less than 1 hour for SAR, and for EMS, a direct criterion is the distance reached in 1 hour or an indirect criterion is the survival rate of victims of accidents. It is clear that all missions which the RACER concept is able to cover provide an attractive solution for mobility, in terms of range, speed and payload (see Figure 56).

In all cases simulated, the overall mission time was reduced by 25.9% to 43.5% and the RACER allows to double the area covered in 1-hour for SAR missions (Figure 57), and save more people with eventually lower infrastructure needs, i.e. the number of required rescue bases (Figure 58).



	Parapublic	Passenger Transport	EMS/SAR
New mobility (speed / range / payload)	High	High	High
Emissions (CO <sub>2</sub> / NO <sub>x</sub> )	Low (if none)	High	Low (if none)
Emission noise	Medium	High	Medium

Figure 56 – Key assessment criteria versus mission goals for the RACER.



Figure 57 – Area covered within 1 hour for SAR interventions at 140kts and 220kts.

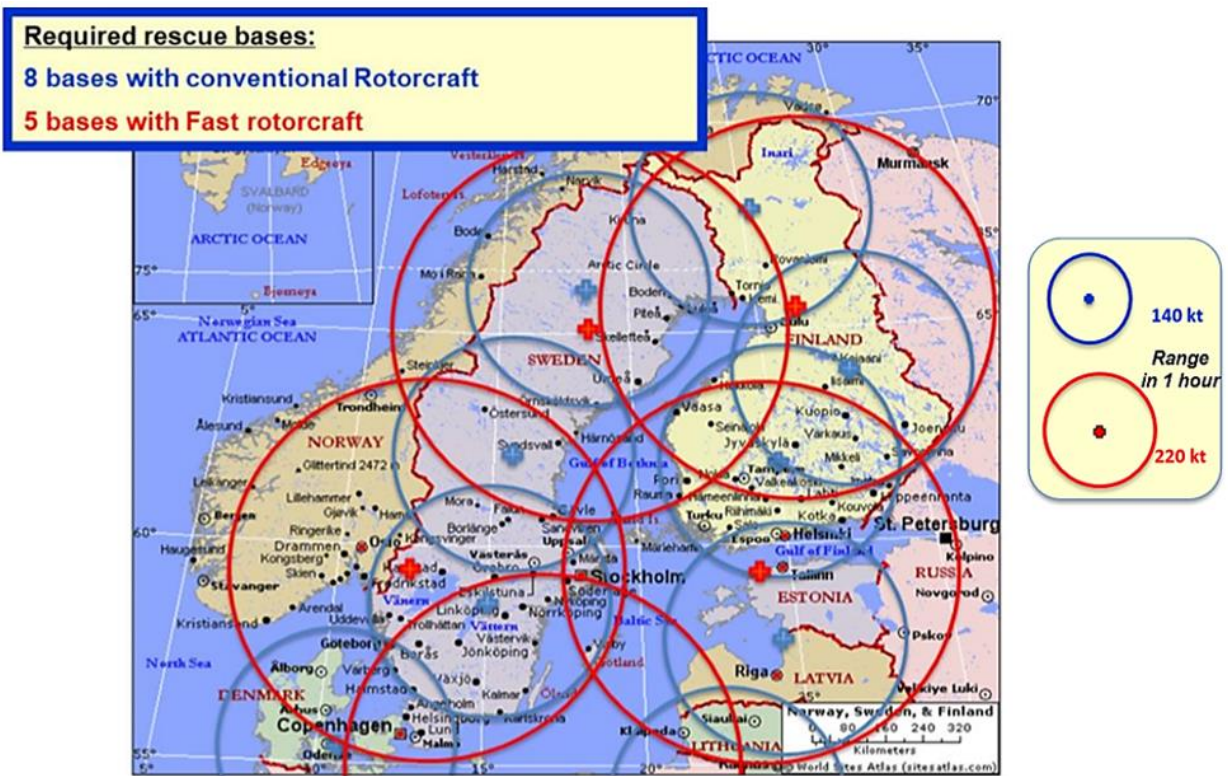


Figure 58 – Reduction of the number of heliports required to serve a given area based on the RACER performance.



Finally, noise performance has been evaluated at airport and fleet level as a separate assessment for rotorcraft than for the mainliner airport and fleet assessment. The results are summarized below.

**RACER – Summary of Airport Level Assessment (Heliport).**

- Simulated missions: Search and Rescue, Emergency Medical Services, Airport Hub Feeder, Passenger transport – Door to Door and Intercity Transportation.
- Overall fuel burn and CO<sub>2</sub> increased due to higher weight and speed.
- Fuel and CO<sub>2</sub> (metric - kg/pax/km) increased by 2.3% to 17.3%.
- Mission time reduced by 25.9% to 43.5%.
- NOX emissions reduced by 23.8% to 35.7%.
- For Noise at the lower limit, the levels reduced by 8.2% (> 70 dB(A) SELA), and indicated higher reductions for higher noise level thresholds. (> 90 dB(A) SELA) and 80 dB(A) SELA).

**RACER – Summary of ATS (Fleet) Level Assessment.**

- In general the RACER performs better at longer distances flown.
- Mission time reduced by 31% to 40%.
- Fuel and CO<sub>2</sub> (metric - kg/pax/km) ranged from an increase of 13% to a reduction of 20%.
- NOX emissions reduced by 25% to 50%.
- At the ATS level mobility benefits were found to be mission-dependent. Depending on the mission flown the total travel time reductions ranged between 9.74% and 36.2%.
- For Noise at the lower limit, the levels reduced by 16.2% (> 70 dB(A) SELA), and indicated higher reductions for equivalent and higher noise level thresholds for different missions (> 90 dB(A) SELA) and 80 dB(A) SELA).

This new vehicle concept has been designed with a target EIS of 2030+. The flight demonstration campaign of the prototype is planned to start in 2021.



### 5.1.2.2 VTOL Aircraft Concept: Next Generation Civil Tilt-Rotor (NGCTR).

Leonardo Helicopters Division (LHD) responded to the CS2 challenge by proposing the Next Generation Civil Tilt Rotor (NGCTR), with the purpose of increasing performance and operational capability over current tilt-rotor configurations. It envisions a substantial increase in productivity and operational capability for various civil missions and public service scenarios, thanks to a cruise speed in the order of 280 kts – about twice the typical helicopter speeds and closer to that of a turboprop aircraft – and a maximum operating range of about 1,000 nautical miles (1,850 km).

This aircraft will have dimensions comparable to those of a helicopter and will operate in all weather conditions and comfort level similar to those of an airliner thanks to its pressurized cabin and very high maximum ceiling (25,000 ft), that of an aircraft. This will allow to expand the opportunities to ensure people’s mobility and freight transportation, reaching remote geographical areas that today helicopters and airplanes cannot reach easily. This will be achieved by minimizing the environmental impact through reduced emissions (CO<sub>2</sub>, NO<sub>x</sub>, noise) and without the need to create large and expensive infrastructures.

The NGCTR concept (Figure 59) involves several technological demonstrators of the main systems, as well as a full-scale Technological Demonstrator (NGCTR TD) necessary to perform the experimental flights and the validation of architectures and new technologies. Its first flight is planned in 2023.

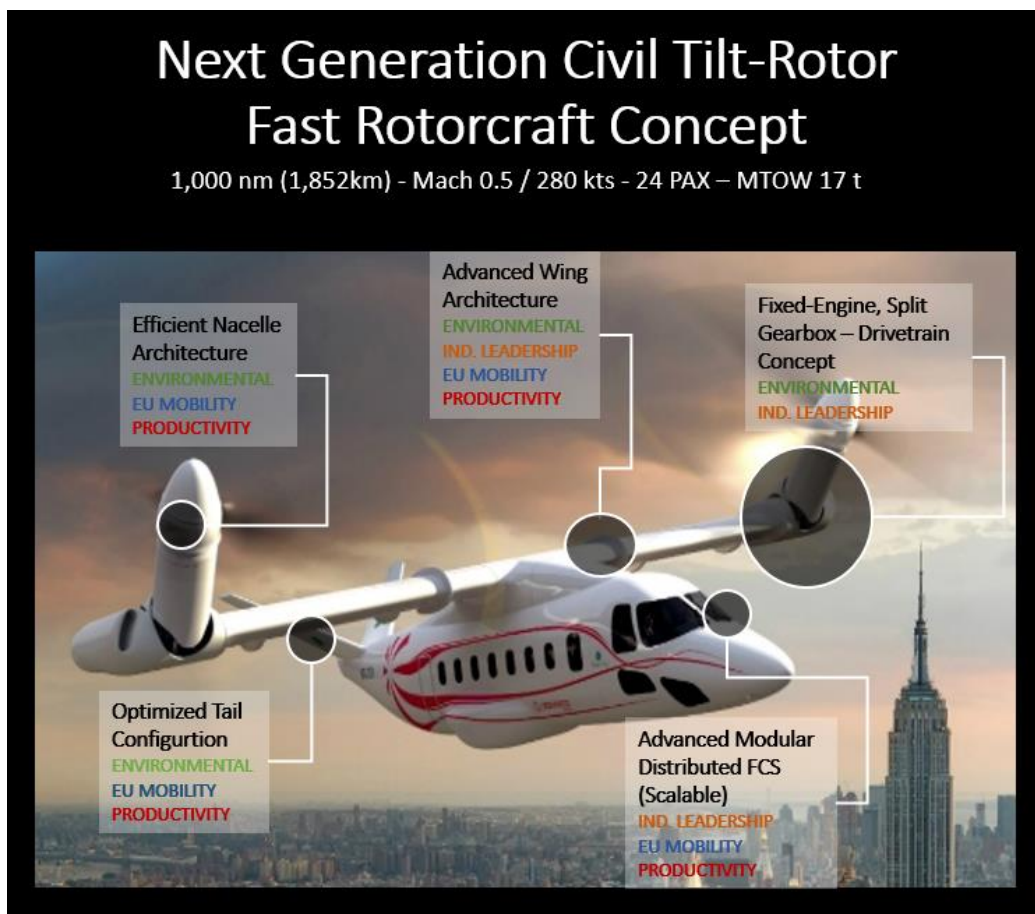


Figure 59 – The Tilt-Rotor Concept and its main technology features.

The demonstrator activities within CS2 are aimed at validating five enabling technologies which are the main features of the concept vehicle:



- Split gearbox drivetrain concept and non-tilting engine installation (referred to as static engine)
- Advanced modular, distributed and scalable flight control system
- Advanced wing architecture
- Efficient nacelle architecture
- Optimized tail configuration

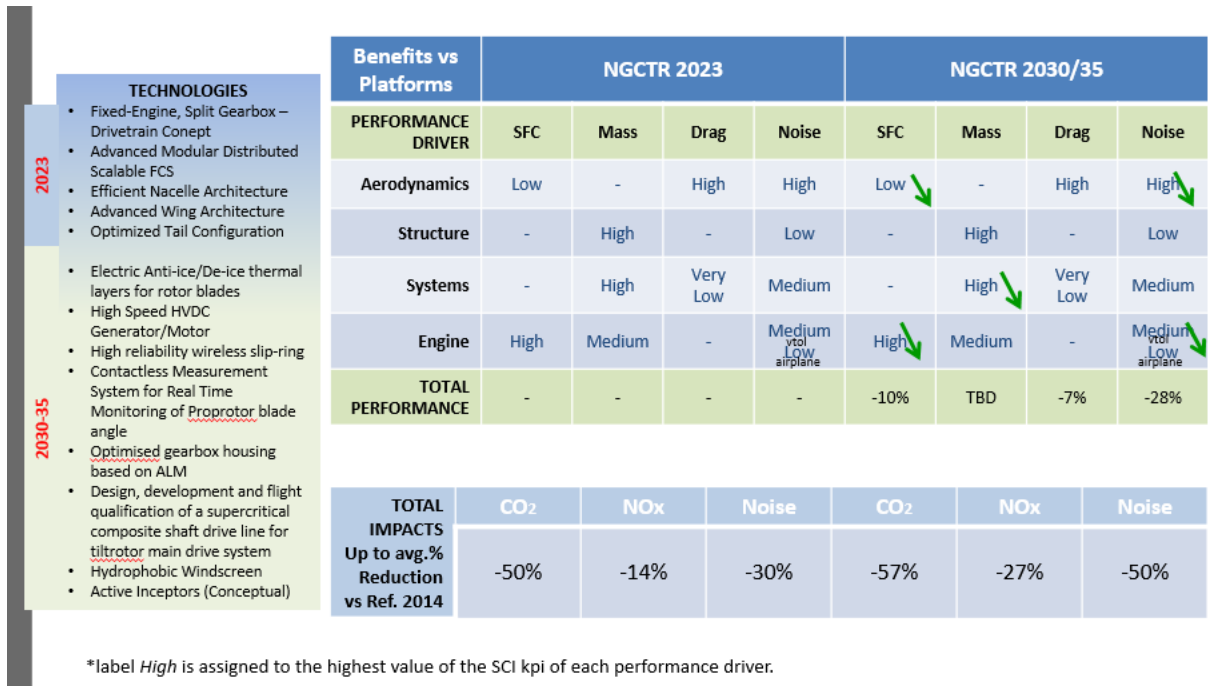
SPD	NGCTR CS2 enabling technologies		Technologies' targets
FRC	<b>Fixed-Engine, Split Gearbox – Drivetrain Concept</b>		<ul style="list-style-type: none"> <li>• Expand the choice of non-tilting engines with more efficient SFC</li> <li>• Transmit torque, from the engines to the proprotors, by two engine fixed gearboxes, two proprotor tilting gearboxes, one mid wing gearbox and the interconnecting driveshaft system</li> </ul>
	<b>Advanced Modular Distributed Scalable FCS</b>		<ul style="list-style-type: none"> <li>• Provide satisfactory handling qualities</li> <li>• Ensure increased safety</li> <li>• Minimize crew workload</li> <li>• Implement approach maneuvers for noise minimization</li> </ul>
	<b>Efficient Nacelle Architecture</b>		<ul style="list-style-type: none"> <li>• Guarantee optimal accessibility of all systems</li> <li>• Reduce overall drag in cruise</li> </ul>
	<b>Advanced Wing Architecture</b>		<ul style="list-style-type: none"> <li>• Generate force to share aircraft lift with rotors during conversion</li> <li>• Guarantee high aerodynamic efficiency</li> <li>• Reduce rotor download</li> </ul>
	<b>Optimized Aerodynamics</b>	<b>Tail</b>	<ul style="list-style-type: none"> <li>• <i>Vee type</i> configuration to ensure longitudinal and lateral, stability and controllability, and to sustain flight and ground loads</li> </ul>
<b>AIR</b>	<b>Advanced Materials</b>	<b>Configuration</b>	

**Table 13 – Technology mapping and targets for the NGCTR concept.**

A mapping of the different enabling technologies and their respective targets is shown in Table 13.

The impact of the technologies has been calculated thanks to dedicated KPIs which enable to assess how much a single system/subsystem, part of an enabling technology, affects each performance driver (e.g. mass, drag, SFC, noise) at aircraft level and, consequently, how much a modification of a single technology affects the entire aircraft's performance driver. Related outcomes have been classified thanks to threshold levels and then translated with the impact labels *small, medium, high*, see Figure 60.

The results of NGCTR demonstrator are related to technologies which will fly in 2023 on the Technology Demonstrator while further improvements are expected by 2030/35, in accordance with the Leonardo Helicopters Division's roadmap of tiltrotor development; here indicated with a green arrow.



**Figure 60 – Impact of technologies on SFC, mass, drag and noise performance for the Tilt-Rotor flight test demonstrator (2023) and the EIS 2030-2035 concept.**

Regarding the performance assessment of the NGCTR, the difficulty arises of comparing the benefit of a tiltrotor versus a reference helicopter which has, by nature, very different specifications or characteristics. A sensitivity analysis has been performed on a reference mission representative of all the scenarios taken into account for the environmental assessment (OAG, PAT-AHF, PAT-CIT and CGT).

The environmental impact has been calculated with respect to a reference 2014 state-of-the aircraft: an intermediate class helicopter, with a payload capability of up to 15 passengers, the AW139. This reference helicopter was chosen also because it represents a large portion of the current OAG fleet, and the NGCTR specifically targets fleet replacement in this market segment.

Typical mission results show that in general the NGCTR performs better at longer distances flown. At ATS level, mobility benefits were found to be mission-dependent. For Oil and Gas missions, time benefits between 23.2% and 36.5% have been observed, depending on the average mission distance: the longer the mission, the higher the benefits. A 100% replacement of current OAG fleet with tiltrotor aircraft would lead to a 30% to 70+% increase in transport capacity (i.e. in terms of ASK). Mission times for passenger transport were found to be reduced by 32% to 39%.

The results in terms of CO<sub>2</sub> and NO<sub>x</sub> emissions for the NGCTR concept are very much dependent on the choice of the AW139 helicopter as a reference vehicle. We have already addressed the issue related to the difficulty of choosing an appropriate reference vehicle. Although an attempt has been made in a first instance to compare to a helicopter, there are still too many design parameters which render the comparison difficult. The NGCTR has a much higher maximum speed: 280KTAS (520 km/h) instead of 145 KTAS for the reference helicopter (270 km/h). This is almost twice that of a normal helicopter, therefore also requiring a higher power installed for the engines. The maximum range (<1000 nm) and passenger capacity (24) for the NGCTR have been almost doubled too, and the

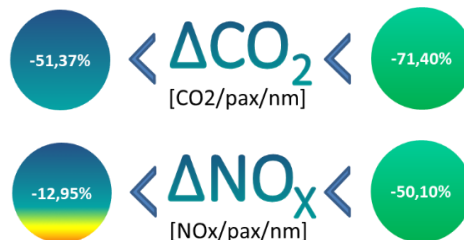


maximum ceiling is 25,000 ft, that of a pressurized aircraft. The NGCTR concept vehicle has therefore a very different overall weight than that of a typical helicopter.

	Aircraft	Range nm	Cruise speed Max Speed	# PAX	Max Ceiling	MTOW	Power	EIS* Window	TRL Target** @ CS2 close
Concept	<i>Next Generation Civil TiltRotor (NGCTR)</i>	1000 (1852 km)	280 kts (518 km/h) 330 kts (611 km/h)	24	25000 ft	17000 kg		2030 - 2035	4
Reference	AW-139	573 (1061 km)	145 kts (269 km/h) 165 kts (306 km/h)	15	10000 ft	6400 kg	2 x 1531 shp	n/a	n/a

**Table 14 - Main flight performance characteristics of NGCTR and AW139 reference helicopter.**

Even by using normalised fuel burn by passenger and nautical miles, the comparison turns out to provide a very wide range of results depending on the missions and the payload-range diagram of both vehicles. For the longest missions selected, more similar in distance to an optimal usage of the tiltrotor, CO<sub>2</sub> reductions up to -90% can be reached. These are missions which are clearly out of the typical design range of the AW139, which needs an intermediate stop for refueling. At the lower end, for the short missions (i.e. PAT-AHF-1, 162 nm), where both vehicles fly at max payload (15 pax for AW139 and 24 pax for NGCTR), the performance of the NGCTR is nearly equivalent to the AW139 (+0,53% CO<sub>2</sub>), but with a reduction of the flight time by 40% and an increase in productivity of 60% (in terms of passengers transported). The NO<sub>x</sub> emission results vary accordingly between +100% and - 50%. However the current NO<sub>x</sub> model is based on empirical relations which overestimate the results at high engine power. Work is ongoing to refine this model in the near future. On average, for the selected typical missions which were simulated for comparison, the following numbers are presented:

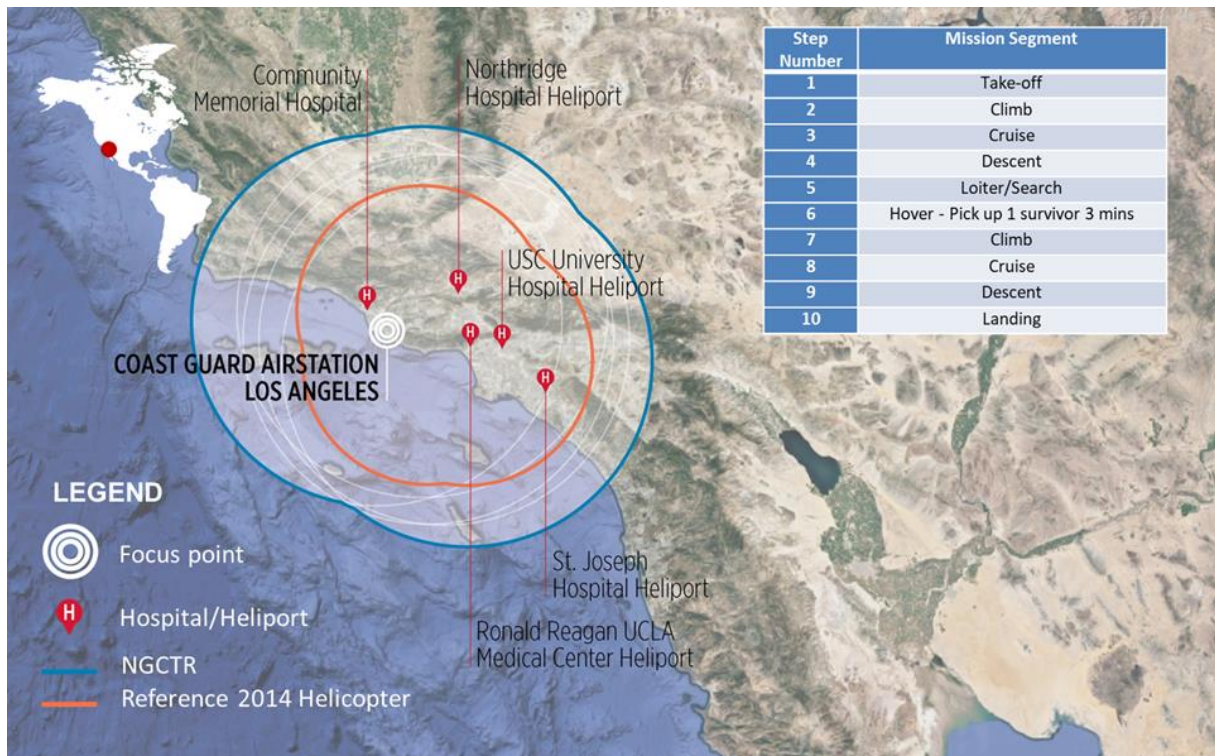


Work will continue towards the second assessment on choosing a different reference vehicle, potentially a ‘generic’ vehicle, similarly to the approach taken for the 19-seat reference commuter, but as a generic tilt-rotor. Work is currently ongoing in the related project DEPART2050<sup>27</sup> to develop such a model. Relevant work from the Clean Sky 1 GRC programme might be helpful here as well, considering the availability of another generic helicopter model, the Twin Engine Heavy (TEH), more similar in terms of payload-range diagram to the NGCTR.

Emission reduction, on the other hand, may not be considered as the key criterion for SAR missions. Here, one of the key performance indicators is the area covered in less than 1 hour. The latter time interval is often referred to as the Golden Hour, the window within which a fast intervention including

<sup>27</sup> DEPART2050, “Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050”, <https://cordis.europa.eu/project/id/776900>

take-off, patient pick up and fly back to the nearest hospital for treatment has shown to be effective to save lives. The NGCTR is capable of doubling the coverage area when compared with a 2014 state-of-the-art reference helicopter.



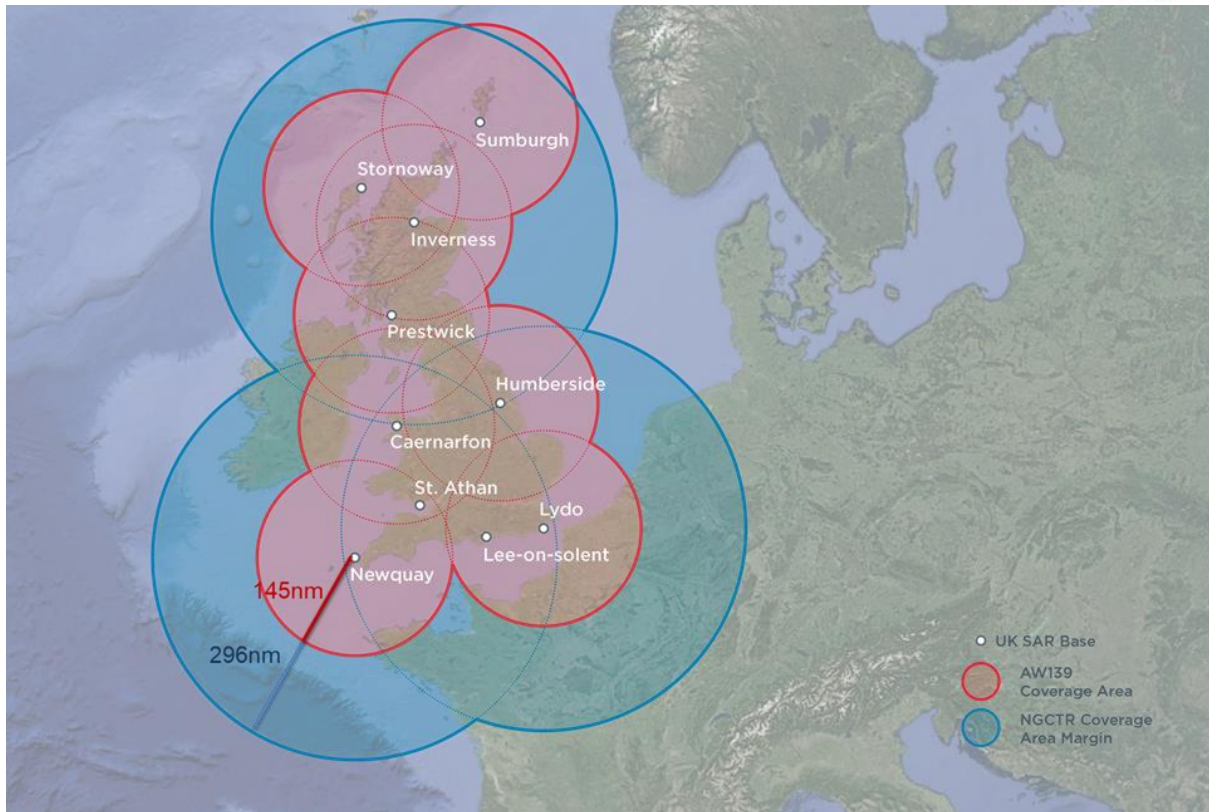
**Figure 61. Increased coverage area for SAR missions based on NGCTR performance.**

The advantage of these enhanced capabilities is twofold: to cover in a shorter time the actual helicopters coverage area and to extend the actual coverage area capabilities. The latter can be translated into a fleet substitution rate, that is assessing the number of conceptual vehicles required to serve the same SAR coverage area of a reference/existing fleet.

The fleet substitution rate has been evaluated in a reference scenario for a mission aimed at rescuing 1 person; for both the aircraft (reference helicopter and concept vehicle) a dedicated SAR equipment is considered as part of the configuration. The picture shows how a fleet of three NGCTR vehicles is sufficient to cover the same area guaranteed by eight reference vehicles. The increase in productivity in this case means safety and social benefits.

In general the NGCTR performs better over longer range missions, but time and fuel benefits are attained for all missions assessed.

Noise aspect is another fundamental pillar of the environmental impact. For all missions calculated, the noise contour area of the NGCTR is significantly smaller than the area of the reference helicopter, up to 90% in cruise. This difference can be attributed to a great extent to the much higher cruise altitude of the NGCTR, in combination with a lower blade loading in airplane mode. The analysis has indicated that for all ATS missions examined, the technology surpasses its target, indicated as -30%. The improvement was found to be -67.7% (> 80 dB(A) LAMAX) and -88.9% (> 90 dB(A) SELA) at the lower limit, and indicated higher reductions for lower noise level thresholds.



**Figure 62. A fleet of three NGCTR vehicles is sufficient to cover the same area guaranteed by eight reference vehicles.**

Noise performance has been evaluated at airport and fleet level as a separate assessment for rotorcraft than for the mainliner airport and fleet assessment. The results are summarized below.

**NGCTR – Summary of Airport Level Assessment (Heliport).**

- Simulated missions undertaken include - Airport Hub Feeder, Cargo Transport, Oil & Gas and Passenger Transport.
- Overall fuel burn and CO<sub>2</sub> increased due to higher weight and speed.
- Fuel and CO<sub>2</sub> (metric - kg/pax/km) reduced by 24.9% to 90.6%.
- Mission time reduced by 30.5% to 50.7%.
- NOX emission results are currently not definitive as the emission prediction model is still being developed, however preliminary results varied from +29.5% to -83%.
- For Noise at the lower limit, the levels reduced by -86.5% (> 90 dB(A) SELA), and indicated higher reductions for lower noise level thresholds (> 80 dB(A) SELA) and 70 dB(A) SELA).

**NGCTR – Summary of ATS (Fleet) Level Assessment.**

- In general the NGCTR performs better at longer distances flown.
- Mission time reduced by 32% to 39%.
- Fuel and CO<sub>2</sub> (metric - kg/pax/km) reduced by -51% to -71%.
- At the ATS level mobility benefits were found to be mission-dependent. For Oil and Gas missions, time benefits between 23.2% and 36.5% have been observed, depending on the average mission distance: the longer the mission, the higher the benefits.



- A 100% replacement of current OAG fleet with tilt-rotor aircraft would lead to a 30% to 70+% increase in transport capacity (i.e. ASK).
- For Noise at the lower limit, the levels reduced by 88.9% (> 90 dB(A) SELA), and indicated higher reductions for equivalent and lower noise level thresholds for different missions (> 80 dB(A) SELA) and 70 dB(A) SELA).

Due to its significantly higher cruise speed and cabin capacity, it is expected that the tiltrotor concept vehicle will yield much higher productivity. However, the quantification of these gains will be more explicitly addressed in the second TE assessment.

This new vehicle concept has been designed with a target EIS of 2030/2035. The flight demonstration campaign of the prototype is planned to start in 2023.



### 5.1.3 Synthesis of Interim Results at Mission Level

In the previous sections, we described the main characteristics of nine new fixed-wing aircraft concepts and two fast rotorcraft concepts.

The synthesis results of the mission level assessment for each of those vehicle concepts are presented in Table 15, listed by aircraft category and seat class.

Category	Seats	Concept Aircraft			Clean Sky 2 Environmental Goals			EIS* Window	Clean Sky 2 1st Assessment Results			TRL Target** @ CS2 close		
		Concept Vehicle	Range nm	Cruise speed	# PAX	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>		Δ Noise	ΔCO <sub>2</sub>	ΔNO <sub>x</sub>		Δ Noise	
SAT-FRC-BJ	0-19	19 PAX Commuter		300	0.34 Ma	19	-20%	-20%	-20%	2025	-21%	-27%	> -20%	4-5
		Low Sweep Business Jet		2900	0.78 Ma	12	> -30%	> -30%	> -30%	2035	-31%	-28%	-50%	≥ 4
		Airbus Helicopters Compound (RACER)		<350	220 kTAS	12	-20%	-20%	-20%	2030	+2 to +17% <sup>(4)</sup>	-24 to -36%	-16%	6
Regional (Extra-Small)	20-100	Leonardo Helicopters Tiltrotor (NGCTR)		<1000	250 kTAS	24	-50%	-14%	-30%	2030+	-50 to -71% <sup>(5)</sup>	-12 to -50%	-86%	6
		Regional Multi Mission Turboprop 70 PAX	Transport Airline	1000	0.5 Ma	70	-20 to -30%	-20 to -30%	-20 to -30%	2025+	-20%	-59%	-20%	6
			Transport Freighter	1000	0.5 Ma	n/a								
			Search And Rescue (SAR)	400	0.5 Ma	15-25								
Advanced Turboprop 90 PAX		1200	0.56 Ma at 20 kft	90	-19 to -25%	-19 to -25%	-20 to -30%	2025+	-34%	-67%	-68%	5		
Small	101-210	Innovative Turboprop 130 PAX		1600	0.62 Ma at 30 kft	130	-35 to -40%	> -50%	-60 to -70%	2035+	-26%	-56%	-25%	4
		Advanced Short-Medium Range SMR+		2000	0.78 Ma	200	-20%	-20%	-20%	2030	-17%	-39%	-20%	5
		Ultra-Advanced Short-Medium Range SMR++		2000	0.75 Ma	200	-30%	-30%	-30%	2035+	-26%	-8% <sup>(3)</sup>	<-30%	4
Large - Medium	>300 / 211-300	Advanced Long Range LR+		6700	0.85 Ma	315	-20%	-20%	-20%	2035+	-13% <sup>(1)</sup>	-38%	<-20%	4
		Ultra-Advanced Long Range LR++		6700	0.85 Ma	315	-30%	-30%	-30%	2035+	-21% <sup>(2)</sup>	-45% <sup>(2)</sup>	n.a.	3

(\*) All key enabling technologies at TRL 6 with a potential entry into service five years later.  
(\*\*) All key enabling technologies at major system level.  
(1) LR+ CO2 reduction (-13%) is made versus the A350-900 as reference aircraft, EIS 2015, a very highly optimized platform.  
(2) LR++ engineering assumption of an additional -8% on CO2 reduction and -7% on NOx reduction versus LR+ concept.  
(3) SMR++ (-8% NOx) as CROR core engine model does not yet include low NOx combustor technology, unlike SMR+ model (-39%).  
(4) RACER results do not yet include ECO-Mode for single engine operation in cruise (an additional potential CO2 reduction of -15%)  
(5) NGCTR performance compared to AW139 helicopter  
n.a. - not yet available  
n/a - not applicable

**Table 15 - Synthesis results of mission level assessment for the Clean Sky 2 aircraft concepts, by aircraft category and seat class.**

**Substantial progress has been achieved to date and the Clean Sky 2 programme can be considered well on-track. Most of the concepts achieve or even exceed their targets.**

The regional aircraft are good examples of substantial improvements in terms of performance and promising solutions for better mobility (e.g. the Advanced Regional TurboProp 90 pax with -34% CO<sub>2</sub> and -67% NO<sub>x</sub> reduction or the Innovative Regional TP 130 pax with -26% CO<sub>2</sub> and -56% NO<sub>x</sub>).



Three vehicle concepts have a target EIS date as early as 2025, and all of them achieve or exceed their environmental performance objectives, sometimes well over -30% CO<sub>2</sub> emissions reduction, demonstrating the potential short-term impact of the CS2 programme.

For the mainliners (targeting an Entry-Into-Service date of 2030), the Short-Medium Range concept (SMR+) will achieve a significant improvement of -17% CO<sub>2</sub>. The moderate improvement for the LR+ concept (-13% CO<sub>2</sub>) results from the comparison with the A350-900 as a reference, a very recent and already very highly optimised platform, while a substantial reduction in NO<sub>x</sub> emissions has been obtained (-38%) thanks to the Ultrafan® lean burn technology.

For the Ultra-Advanced concepts with EIS 2035 and beyond, even more substantial gains can be expected, with -26% CO<sub>2</sub> for the SMR++ concept (thanks to the Open Rotor architecture) and -26% CO<sub>2</sub> for the Innovative Regional TP 130 pax compared to a Regional Jet. The low NO<sub>x</sub> reduction for the SMR++ (-8%) may be disregarded as it results from the core engine model of the Open Rotor not yet including low NO<sub>x</sub> combustor technology (currently being updated). NO<sub>x</sub> reduction values close to -40% are expected as confirmed by the low NO<sub>x</sub> combustion technology of the SMR+ core engine model.

The LR++ (Ultra-Advanced LR concept) has not been modelled as a full aircraft concept but an engineering approach with an additional -7% to -8% improvement versus the LR+ concept has been assumed (-21% CO<sub>2</sub> reduction and -45% NO<sub>x</sub>). This concept will be fully developed by DLR in collaboration with Airbus and Rolls-Royce for the 2<sup>nd</sup> assessment.

Commuter and business jet concepts achieve and exceed their targets as well, whereas the results reported so far for rotorcraft are highly dependent on the choice of the reference vehicle as no commercially available helicopter can compete with these new hybrid concepts in terms of performance.

Still, this is a snapshot of the results at programme mid-term. ***More progress and further performance improvements are expected over the second part of the programme through further maturation of the technologies and updates of the models as well as inclusion of additional technologies not yet considered today.***

Significant progress has already been achieved up to this mid-term first TE assessment, not only in terms of technology progress but also in terms of aircraft design optimization and understanding of the flight physics of all of those concept vehicles.

The Clean Sky 2 programme can be considered on track to deliver and fully meet its environmental goals and socio-economic objectives by 2024.

The mission level performance results presented in this section are the basis for the subsequent airport and fleet level calculations.

## 5.2 Airport Level

Airport level assessments for the first Clean Sky 2 TE assessment have been carried out for five European airports, ranging from primary-hub, through secondary-hub, to regional airports. These airports are: Amsterdam Airport Schiphol, Rome Fiumicino Airport, Stockholm Arlanda Airport, Hamburg Airport, and Toulouse Blagnac Airport. These selected airports result from an airport categorisation scheme (to define more homogeneous groups of airports from the large heterogeneous mix of airports) and a selection scheme (to select one or more airports from each category).

A major contribution to the Airport Level assessment comes from the currently ongoing project CLAIRPORT<sup>28</sup>, aiming to quantify the environmental impact at airport level of technologies developed in Clean Sky 2 for fixed-wing aircraft. This impact includes noise on ground and population exposed to noise, and emissions and their contribution to air quality. Quantifications are carried out for real European and generic airports (CAEPport), and timescales 2015/2020/2035/2050. Relevant improvements in airport operations from SESAR/SESAR 2020 are taken into account.

Noise impacts were estimated by comparing the noise performance of future airport-traffic scenarios with and without CS2 technologies in the year 2050 for the above mentioned airports. **The reductions for 2050 in surface area of Lden contours for relevant noise levels (60-65 dB(A)) are about 10-15%** (Figure 63).

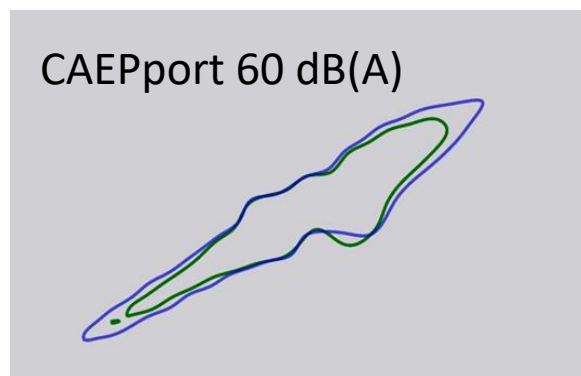


Figure 63 - Surface area reduction for 60 dB noise level.

For the same noise levels (i.e. 60-65 dB(A) Lden) the noise results also highlight **significant reductions in 2050 of population exposed and population highly annoyed, i.e. in the range of 10-25%**.

In 2050, **reductions of CO<sub>2</sub> emissions amount to about 8-13.5% for the European airports considered, while the associated NO<sub>x</sub> reductions are roughly in the range 6.5-10.5%**.

For fast rotorcraft, a number of mission types have been simulated to perform assessments at airport level. These missions cover Search and Rescue (SAR), Oil and Gas (OAG), Emergency Medical Service

<sup>28</sup> CLAIRPORT, “Clean Sky 2 - Airport Environmental Impact Assessments for Fixed-wing Aircraft“, <https://cordis.europa.eu/project/id/777035>



(EMS) and Passenger Air Transport (PAT). Results are encouraging: for example in the oil and gas domain, time benefits of between about 23% and 36% could be achieved leading to a more than 30% increase in transport capacity if 100% of the OAG fleet was replaced.

In terms of noise the contour area of the Clean Sky rotorcraft are significantly smaller than their reference one's, which is due to the higher cruise altitude of the concept rotorcraft.

For the NGCTR noise (at the lower limit), the levels are reduced by 86.5% (> 90 dB(A) SELA), and the results indicated higher reductions for lower noise level thresholds (> 80 dB(A) SELA) and 70 dB(A) SELA). For the RACER noise (at the lower limit), the levels are reduced by 8.2% (> 70 dB(A) SELA), and indicated higher reductions for higher noise level thresholds. (> 90 dB(A) SELA) and 80 dB(A) SELA).

The current airport level assessment does not include business jets, however these will be included in the second assessment especially by considering airports with important business jet traffic (such as Geneva, Zurich or Le Bourget).



## 5.3 Fleet Level (ATS)

### 5.3.1 Fleet Replacement

With its strong focus on pre-competitive technology demonstration, targeting a highly regulated aviation market characterized by extraordinary long life cycles, Clean Sky 2 achievements will become noticeable within the global fleet only after 2035, the earliest entry into service being 2030 for the most mature mainliner aircraft concepts.

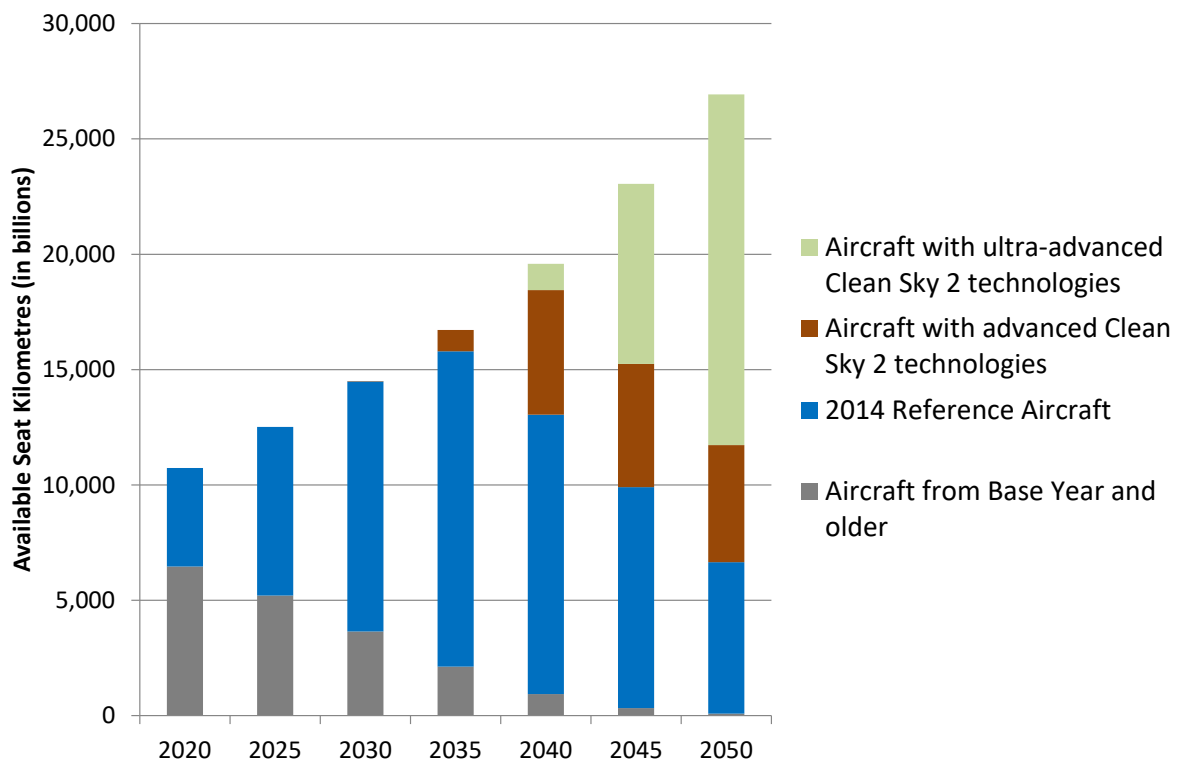


Figure 64 - Evolution of fleet replacement by CS2 aircraft up to 2050.

However, according to the present forecast, approximately **75%** of global available seat kilometres (ASK) will be operated with aircraft expected to carry CS2 technologies in 2050, while 25% of global ASKs will still be operated by aircraft with 2014 SoA technologies, not yet retired. “Legacy aircraft” currently operational (more than half of today’s fleet) will gradually be retired over the next 25 years until complete extinction from the fleet by around 2045.

For the retirement of aircraft, the coefficients used by ICAO CAEP/11 have been applied. The issue of extremely long life cycles, a main characteristic of the aviation sector, has already been addressed in section 4.2.1 (Overall Assumptions and Airport Capacity Constraints).

Several conclusions may be drawn at this stage based on the fleet replacement forecast of Figure 64.



Considering the long development times of a new aircraft as a commercial product (between 5 to 10 years), their extremely long service life, and the inertia in production rates increase (despite some substantial ramp-up in recent years), it is crucial to target the earliest entry into service date for the next generation of aircraft.

Historically, the time between two aircraft generations has been typically 15 to 20 years. The difference of entry-into-service of 5 years between the advanced (2030+) and ultra-advanced (2035+) Clean Sky concept aircraft is therefore artificial and stems from initial assumptions about the time to reach sufficient maturity or readiness of some “ultra-advanced” technologies at TRL6, at least 5 years before market entry.

This underlines the urgent need to accelerate the technology maturation process by promoting and supporting research investments, in order to “skip a generation”. To this end, not only advanced technologies but possibly also ultra-advanced technologies should be applied simultaneously onto the next aircraft generation by 2030, if not, by 2035 at the latest.

Still, a number of Clean Sky concept aircraft already have a short-term EIS (2025+), but in market segments which have less impact on the global share of CO<sub>2</sub> produced across the global fleet (Commuter and Regional segments).

### 5.3.2 Towards Larger Aircraft

Until 2050, an important shift is expected towards aircraft with a higher number of average seats in terms of ASK, today operated through long range aircraft. This is shown in Figure 65 where a clear trend appears towards more flights with widebody aircraft.

The trend of employing larger aircraft has existed already in the past, but is expected to accelerate in the future because of capacity constraints at major airports. Between 1990 and 2019 the average number of seats per flight has increased from 99 to 144, i.e. by 1.3% per year. This trend is apparent over recent years when considering the growing success of the A320 and A321 versions versus the smaller A319 or even A318 with similar range.

Figure 65 shows the fleet evolution by seat class in terms of number of flights, starting from historical data (2014), forecasts for 2020 and 2035, followed by the scenarios (constrained) up to 2045 and 2050. The results show a strong increase in the SAT seat class (19 pax) up to 4 million flights, a strong decrease in the lower end regional segment (<50 seats), a stagnation for the mid-regional range (50-85 seats) around 2 million flights, and an increase again for the regional upper end (86-100 seats). The strongest decrease is observed for the low end SMR segment (126-175 seats) with a clear shift towards larger seat classes above 175 seats.

Figure 66 shows a similar trend and how this translates into the number of aircraft required to absorb these flight volumes per seat class in 2050.

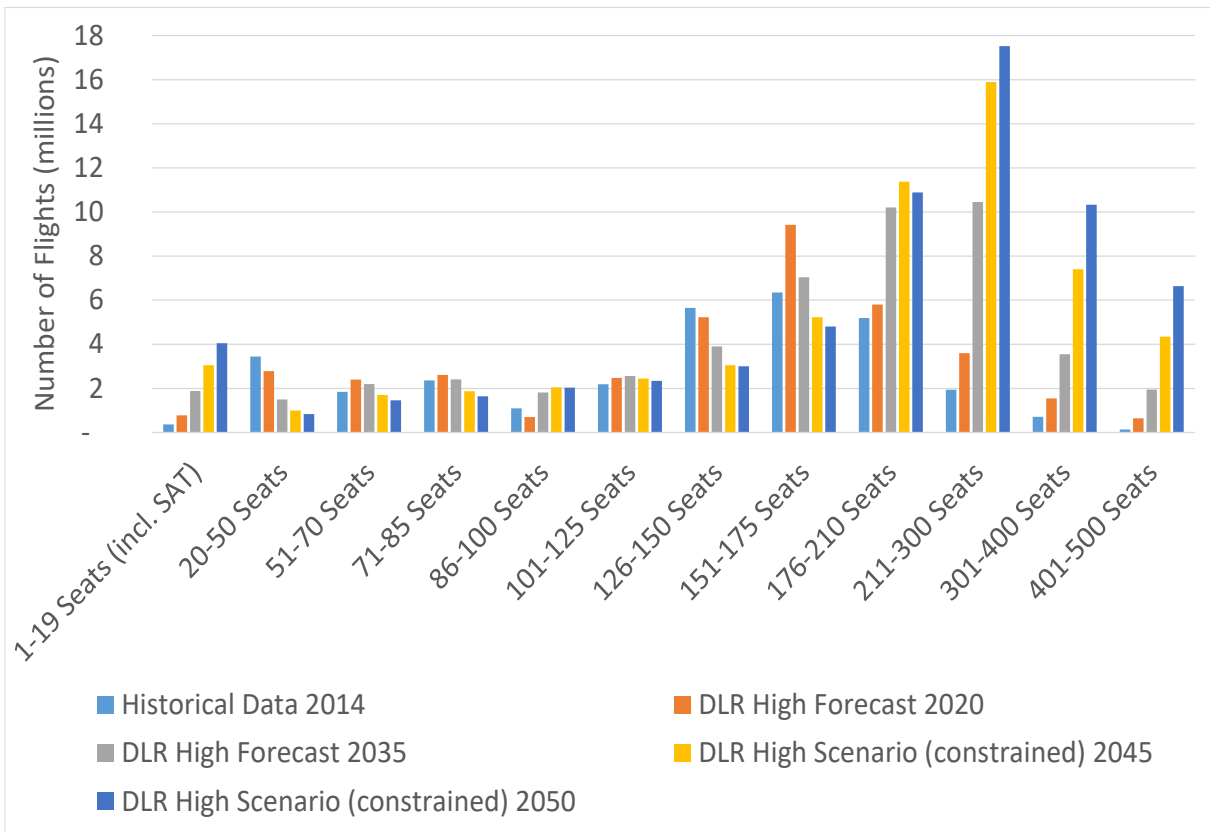


Figure 65 - Fleet evolution in terms of number of flights by seat class up to 2050.

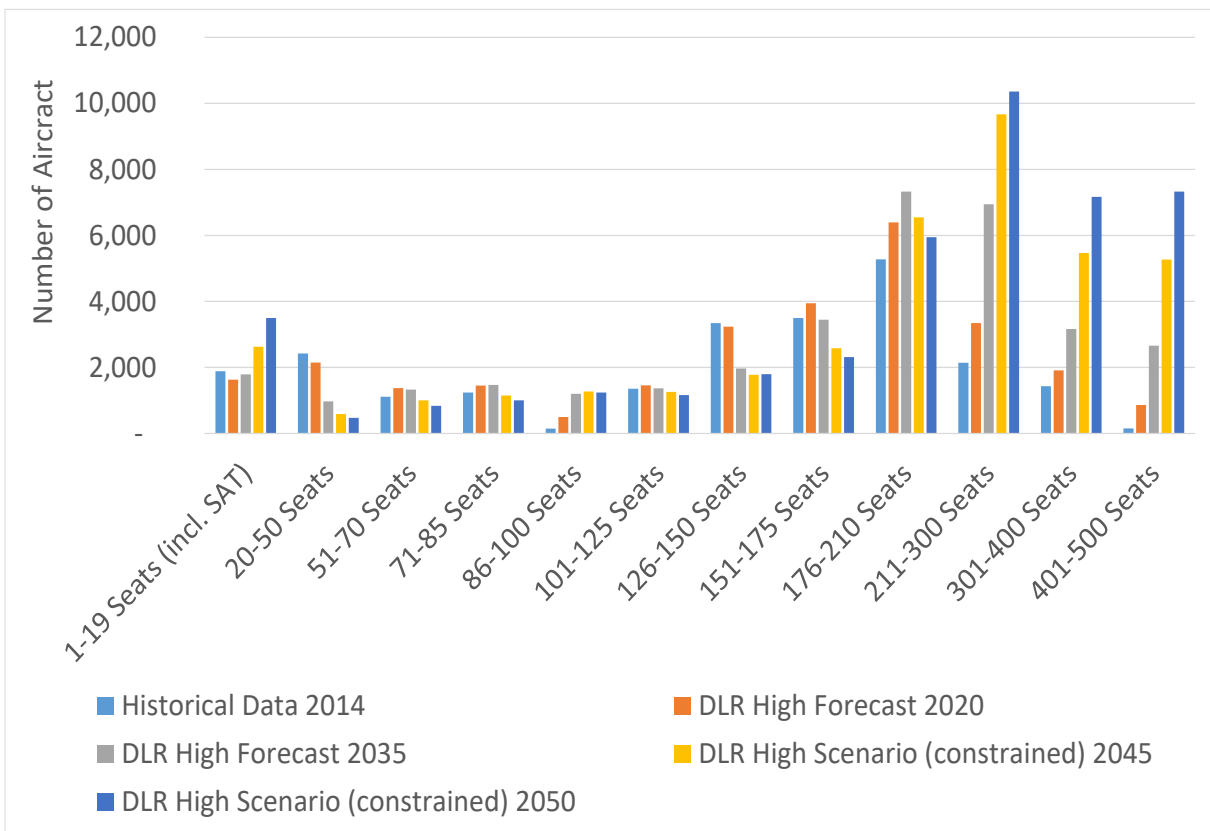
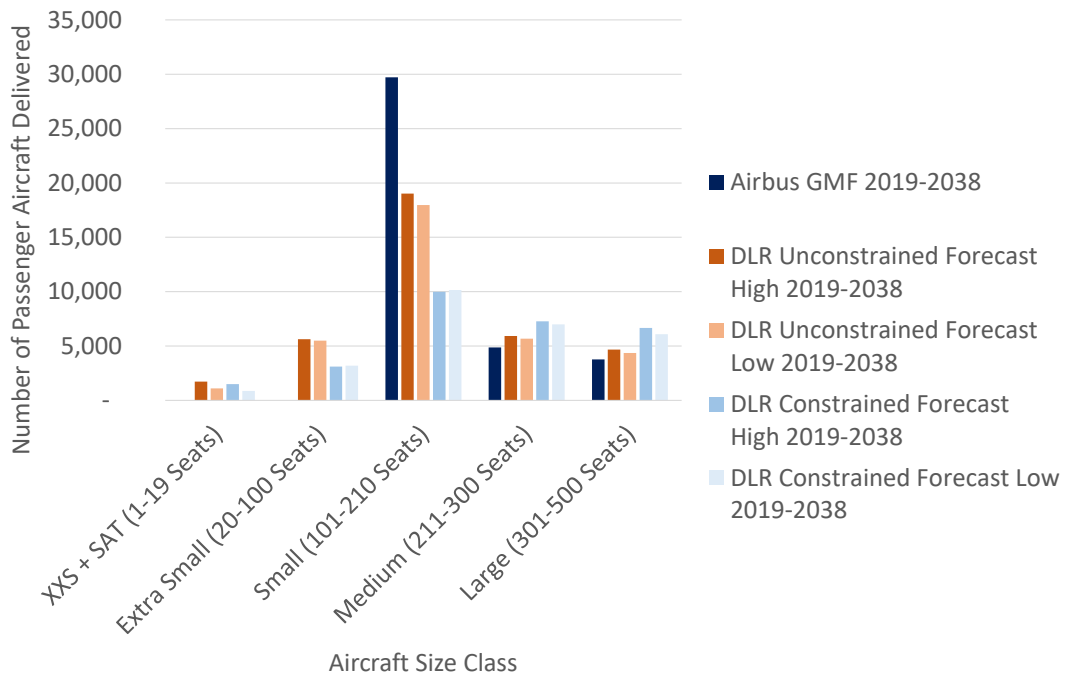


Figure 66 - Fleet evolution in terms of number of aircraft by seat class up to 2050.

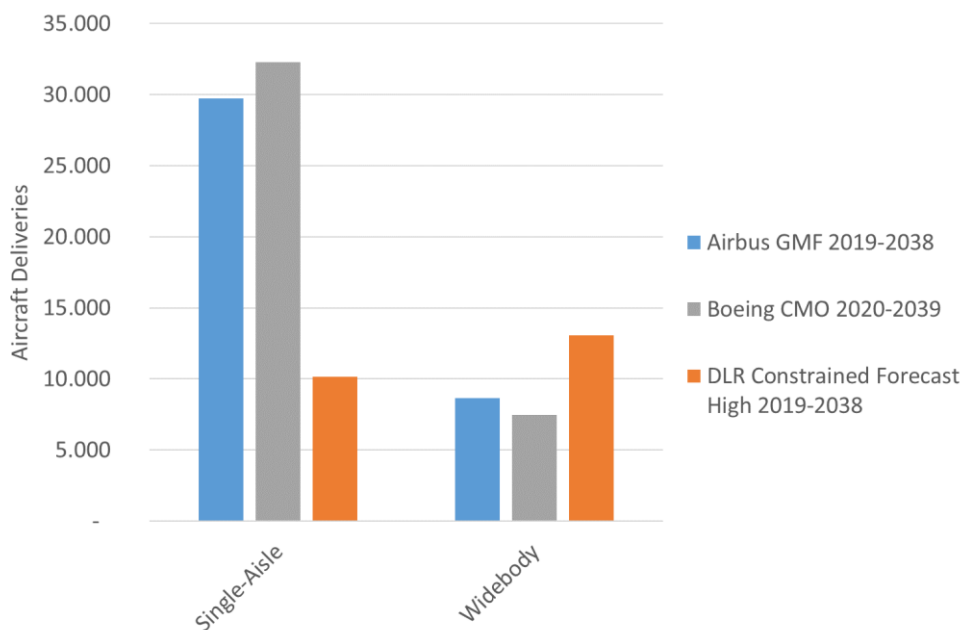


In order to compare with existing forecasts, for example, the Airbus Global Market Forecast 2019-2038, the DLR data has been extracted for year 2038, both for the constrained and unconstrained scenarios (High and Low).

Focusing on the constrained scenarios (High or Low), the present study foresees only about 10,000 new deliveries in the Small seat class (101-210 seats) instead of 30,000 to the benefit of the Medium and Large seat classes which increase respectively by 30 and 50%.



**Figure 67 – Comparison of DLR forecasts (constrained and unconstrained) on aircraft deliveries by 2038 to the Airbus GMF (Global Market Forecast) 2019-2038.**



**Figure 68 – Comparison of Narrowbody (Single-Aisle) and Widebody (Twin-Aisle) aircraft deliveries estimates.**



As a simplified conclusion at the level of narrowbody and widebody aircraft deliveries (Figure 68), and comparing to the most recent existing industry forecasts (e.g. the Airbus Global Market Forecast 2019-2038 or the Boeing Commercial Market Outlook 2020-2039), the expected deliveries in widebody aircraft in general (twin-aisle) are exceeding 13,000 units compared to about 8,000 units as seen by industry.

The overall number of aircraft to be delivered (including all categories) remains in-line with the observation made earlier, i.e. about 30% lower flight volumes for a constrained forecast result in about 10,000 to 12,000 less aircraft deliveries.

For the SAT market, about 1,500 aircraft would need to be delivered, and about 3,500 for the Regional market by 2038 so as to satisfy the demand in both of these seat classes.

### 5.3.3 Towards Shorter Range

The question then arises as to the range over which this much higher number of large aircraft will be flown.

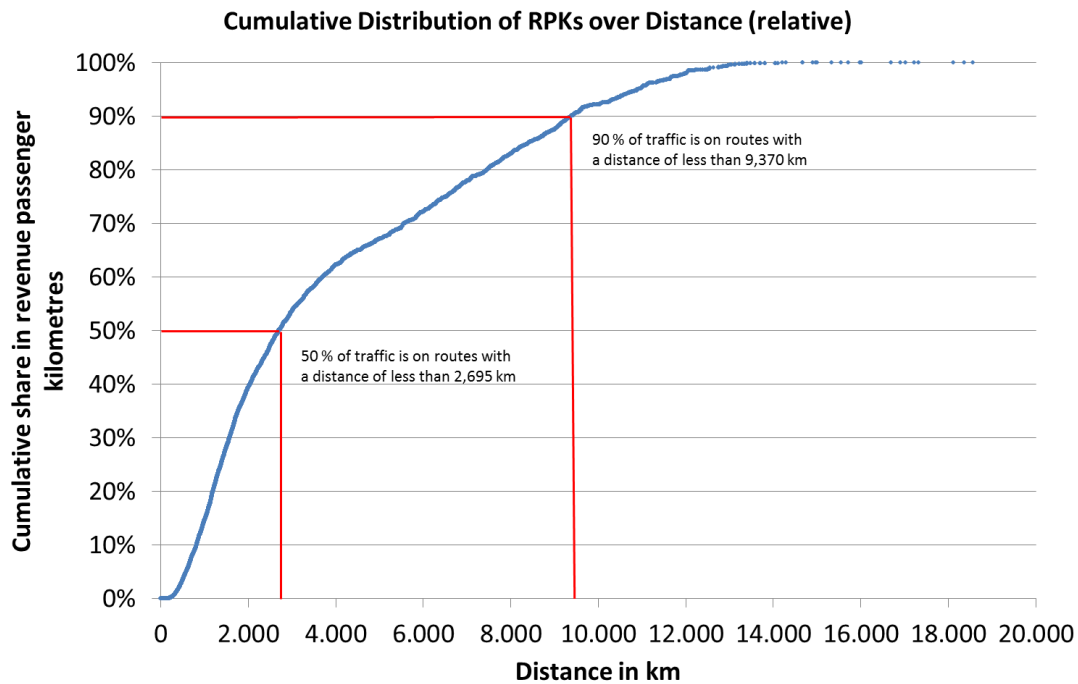


Figure 69 – Cumulative distribution of RPKs versus distance flown (Sabre Market Intelligence).

Already today, a considerable number of aircraft are used on shorter mission distances than the actual aircraft design range, at the expense of more energy inefficiency versus the benefit of airline flexibility. Figure 69 shows that 50% of traffic is on routes with a distance of less than 2,695km (~<1500 nm).

This is confirmed by Figure 70 which shows the distribution of flights versus distance flown per aircraft seat class (in 2020). Figure 71 shows what is the corresponding distribution in terms of share of CO<sub>2</sub> generated by the current air traffic.



Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000			
Commuter	0-19												0,08%	2,0%	0,03%
Extra-Small	20-100												4,3%	23,1%	3,6%
Small	101-210												37,3%	58,9%	41,9%
Medium	211-300												25,6%	10,3%	24,5%
Large	>300												32,7%	5,6%	29,9%
CO2		17%	22%	12%	8%	5%	5%	6%	5%	5%	5%	9%	Share of total in 2020		
Flights		55%	28%	9%	3%	1%	1%	1%	1%	0%	0%	1%			
Passenger-km		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%			

Share of total flights

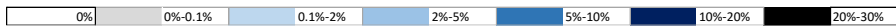


Figure 70 – Distribution of flights versus flight distance per aircraft seat classes in 2020.

Figure 70 confirms the statement already made based on Figure 69, but indicates in which seat classes most of the flights are occurring. 54% of passenger-km (RPKs) are generated over flights below 3000 km, which in turn, generate 51% of the global fleet CO<sub>2</sub> emissions. This traffic share is covered by 92% of the flights. While 23% of the flights are in the Regional seat class (20-100 seats), the vast majority (56%) is in the Short-Range seat class (101-210), 8% in the Medium-Range seat class (211-300).

Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000			
Commuter	0-19												0,08%	2,0%	0,03%
Extra-Small	20-100												4,3%	23,9%	3,6%
Small	101-210												37,3%	58,3%	41,9%
Medium	211-300												25,6%	10,2%	24,5%
Large	>300												32,7%	5,6%	29,9%
CO2		17%	22%	12%	8%	5%	5%	6%	5%	5%	5%	9%	Share of total in 2020		
Flights		55%	28%	9%	3%	1%	1%	1%	1%	0%	0%	1%			
Passenger-km		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%			

Share of total CO<sub>2</sub> emissions:

Figure 71 - Share of CO<sub>2</sub> emissions per aircraft seat-class and flight distance (range flown) in 2020.

Looking at the CO<sub>2</sub> generated by the current fleet (Figure 71), and considering aircraft size or market segment, roughly 63% of today’s kerosene consumption – which directly correlates with CO<sub>2</sub> emissions – thus comes from flights operated with Small- and Medium-range aircraft (a/c with 101-210 seats



(37,3%) and a/c with 211-300 seats (25,6%), respectively). These two aircraft categories account for about 70% (68,5%) of the flights over any distance.

Less than 5% of emissions are caused by Regional (fewer than 100 seats) and Commuter (<19 PAX) aircraft, which are serving about 26% of today’s flights. The remainder of emissions (~33%) stems from Long-Range aircraft (over 300 seats), which are serving just over 5% of the flights.

Regarding flight ranges, 9% of emissions come from flights above 10,000 kilometers, but these only make up around 1% of the total number of flights. By contrast, flights spanning less than 3,000 kilometres account for more than 51% of total aviation CO<sub>2</sub> emissions and 92% of all flights, regardless of aircraft size, as seen in Figure 70.

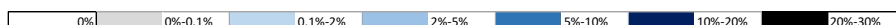
**This data indicates that, today, the main focus on decarbonizing aviation should be on short-range aircraft flying less than 2,000 to 3,000 kilometers.**

In order to answer our question as to the range over which the larger capacity aircraft will be flown in 2050, it is necessary to look at the same distributions in Figure 72 (Flight distribution in 2050) and Figure 73 (CO<sub>2</sub> distribution in 2050).

Comparing to Figure 70, the relative share of flights has significantly changed towards more flights in the Medium and Large seat classes below 3000 km, even below 2000 km. The share of flights in 2020 (below 3000 km), with a vast majority (56%) in the Short-Range seat class (101-210), 8% in the Medium-Range seat class (211-300) and 3% in the Long-Range class (>300 seats) has now evolved by 2050 towards a share of 33% in the Short-Range seat class (101-210), 26% in the Medium-Range seat class (211-300) and 20% in the Long-Range class (>300 seats).

Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km	
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000				
Commuter	0-19													0,04%	1,5%	0,01%
Extra-Small	20-100													1,1%	9,6%	0,8%
Small	101-210													11,7%	33,7%	12,3%
Medium	211-300													26,8%	28,1%	22,0%
Large	>300													60,3%	27,2%	64,8%
<b>CO2</b>		19%	26%	14%	8%	4%	5%	5%	4%	4%	4%	4%	6%	<b>Share of total in 2050</b>		
<b>Flights</b>		54%	28%	8%	3%	1%	1%	1%	1%	1%	1%	1%	1%			
<b>Passenger-km</b>		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	5%	8%			

Share of total flights



**Figure 72 - Distribution of flights versus flight distance per aircraft seat classes in 2050.**



Aircraft Class	Seats	Flight Distance (km)											CO2	Flights	Passenger-km	
		0-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10000	>10000				
Commuter	0-19												0,04%	1,5%	0,01%	
Extra-Small	20-100												1,1%	9,6%	0,8%	
Small	101-210												11,7%	33,7%	12,3%	
Medium	211-300												26,8%	28,1%	22,0%	
Large	>300												60,3%	27,2%	64,8%	
<b>CO2</b>		19%	26%	14%	8%	4%	5%	5%	4%	4%	4%	6%	<b>Share of total in 2050</b>			
<b>Flights</b>		54%	28%	8%	3%	1%	1%	1%	1%	1%	1%	1%				
<b>Passenger-km</b>		15%	25%	14%	9%	5%	5%	6%	5%	5%	5%	8%				
Share of total CO2 emissions:			0%		0%-0.1%		0.1%-2%		2%-5%		5%-10%		10%-15%			

**Figure 73 – Share of CO<sub>2</sub> emissions, flights and passenger-km per aircraft seat-class and flight distance (range flown) in 2050.**

The overall distribution across all distances flown has not changed significantly however. This may be explained by the fact that traffic growth grows in a similar way in each distance segment. There is a very similar growth of short-haul and long-haul demand occurring in parallel. However, the growth does differ by region, as e.g. growth rates in the EU are much smaller than in India or China, where many more routes <1000km may play a compensating role.

Regarding the share of CO<sub>2</sub> generated by the traffic in 2050, the flights spanning less than 3,000 kilometers (regardless of aircraft size) now account for almost 60% of total aviation CO<sub>2</sub> emissions, a 10% increase versus 2020, still covering more than 90% of all flights. This increase occurs despite the assumption that 75% of the fleet has been replaced by new CS2 concept aircraft with a -20 to -30% CO<sub>2</sub> reduction improvement in performance.

On the long-range flights, over 10,000 kilometers, the percentage of global share of emissions has decreased to 6%, a 3 % decrease versus 2020, to be attributed to only a moderate or no increase of the number of flights on these routes, and to the performance improvement assumed for the long range CS2 concepts (as far as these aircraft have been renewed).

The share of CO<sub>2</sub> emissions from Short- and Medium-range aircraft (flights with 101-210 seats (11,7%) and flights with 211-300 seats (26,8%), respectively) is reduced to less than 40% versus more than 60% in 2020. This 20% decrease in CO<sub>2</sub> emissions is caused by a reduction of the number of flights in that same category by 10%, which is almost entirely transposed to the large aircraft category which now accounts for more than 25% of the flights versus 5% in 2020. The long-range flights over 10,000 km remaining practically unchanged, it is clearly visible that this increase is predominantly affecting the short-haul traffic below 3,000 km, now, even up to 4,000 km for the largest aircraft.

In 2050, 55% of the CO<sub>2</sub> emissions will come from the Medium and Large aircraft categories on short-medium haul flights (<4000km). These two aircraft categories would account for about 55% of the



flights, instead of 15% in 2020.

The share of CO<sub>2</sub> emissions caused by Regional (fewer than 100 seats) and Commuter (<19 PAX) flights has decreased from 5% to about only 1%, as these aircraft are projected to serve only 10% of the flights in 2050 versus 25% of today's flights.

The 2050 data therefore strengthens the conclusion that **the main focus on decarbonizing aviation should be on short-range aircraft flying less than or about 4,000 kilometers, however with much larger passenger capacity, well over 300, even over 400 passengers in the cabin.** This type of aircraft does not exist today.

Therefore, in order to avoid the energy inefficiency of flying aircraft with a large design range on short distance routes and in order to improve passenger mobility, one recommendation may be issued from this work, i.e. **to introduce an additional aircraft concept with optimized design range for the average shorter range routes (~ 4,000 km) with much larger passenger capacity** to satisfy the actual mobility demand and operational missions in 2050. This would provide some additional emissions reduction potential, probably of the order of 10-15% versus the currently available aircraft, which are either too small or able to fly too far.

This raises another question as to what would be the optimum aircraft according to the routes to be flown (especially if those routes would be "climate optimized") and what would be the optimum fleet and optimum network.

It is therefore worthwhile to mention two other currently running Clean Sky 2 projects which are addressing these issues. GLOWOPT<sup>29</sup> will provide the design of an optimized aircraft in terms of flight speed, altitude and route, which in turn will have resulted from an optimization of a climate function defined to minimize climate impact in general (including not only the effects of CO<sub>2</sub> and NO<sub>x</sub>, but also water emissions and contrails, particulates, soot, etc.). REiVON<sup>30</sup> will run studies as to what would be an optimum fleet with an optimum network, including parameters like flight frequencies at airports, among others.

This is also where policy makers and new regulations may have a role to play in order to accelerate the required changes to make aviation climate neutral by 2050, as addressed also in the project GLIMPSE2050<sup>31</sup>.

In conclusion, combining the considerations on aircraft size, airport constraint (no new airports), the fact that a typical mission is much shorter than the design mission, the present study points out the need for an aircraft with a regional/short range (2000-4000 km) and features for speed and eco-impact, that is larger than today's aircraft but operable from existing airports with existing runway limitations.

---

<sup>29</sup> GLOWOPT, "Global-Warming-Optimized Aircraft Design", <https://cordis.europa.eu/project/id/865300>

<sup>30</sup> REiVON, "Reduction of the Environmental Impact of aviation via Optimisation of aircraft size/range and flight Network", <https://cordis.europa.eu/project/id/101007659>

<sup>31</sup> GLIMPSE2050, "Global Impact Assessment of Regulations and Policies for Sustainable Aviation by 2050", <https://cordis.europa.eu/project/id/865118>



#### 5.3.4 CO<sub>2</sub> and NO<sub>x</sub> impact at fleet level

Currently, the highest improvements in aircraft energy efficiency are obtained for the regional (> 30% CO<sub>2</sub> and >60% NO<sub>x</sub>) and SMR++ concepts (>25% CO<sub>2</sub> reduction). Regional aircraft today occupy less than 5% of the fleet and these aircraft types are predicted to occupy a smaller share of the fleet in the future to the benefit of larger aircraft, here modelled by the LR+ concept, which currently can achieve a more modest improvement of 13% CO<sub>2</sub> reduction.

By applying the performance improvements of the SPD aircraft models (see Table 15), an overall reduction of **CO<sub>2</sub> and NO<sub>x</sub> emissions of about 15% and 31.0% per seat kilometre** can be expected for the year 2050 high fleet scenario (including the CS2 aircraft concepts) as compared to a 2050 global traffic scenario incorporating only 2014 reference technology. **This corresponds to global emissions savings of 250 Megatons of CO<sub>2</sub> and 2.7 Megatons of NO<sub>x</sub>.**

For the 2050 low scenario these values are slightly lower (about 14% CO<sub>2</sub> and 29.0% NO<sub>x</sub>) because the share of Clean Sky technology aircraft in terms of ASK is slightly smaller, about 70% compared to the high scenario with 75%.

These conclusions are globally in-line with the recently published ATAG report Waypoint 2050. Several scenarios are presented in the ATAG report and the Clean Sky 2 TE first assessment forecasts and scenarios are comparable. The ATAG traffic forecasts of this study are in the 'central' range of around 3.0% per annum compound growth but the study does not indicate which percentage of fleet replacement is achieved by 2050 considering aircraft retirement rates and if airport capacity constraints were considered. Another wave of new aircraft joining and starting to replace the fleet around 2030-2035 is assumed.

The ATAG baseline scenario (Figure 74) estimates a -13% reduction of CO<sub>2</sub> emissions by 2050 thanks to technology improvements (T2) considered conservative or evolutionary (i.e., assuming no- to little-risk by shifting to unconventional platforms) and therefore show a continuation of the current rate of improvement (the next generation of 'tube-and-wing').

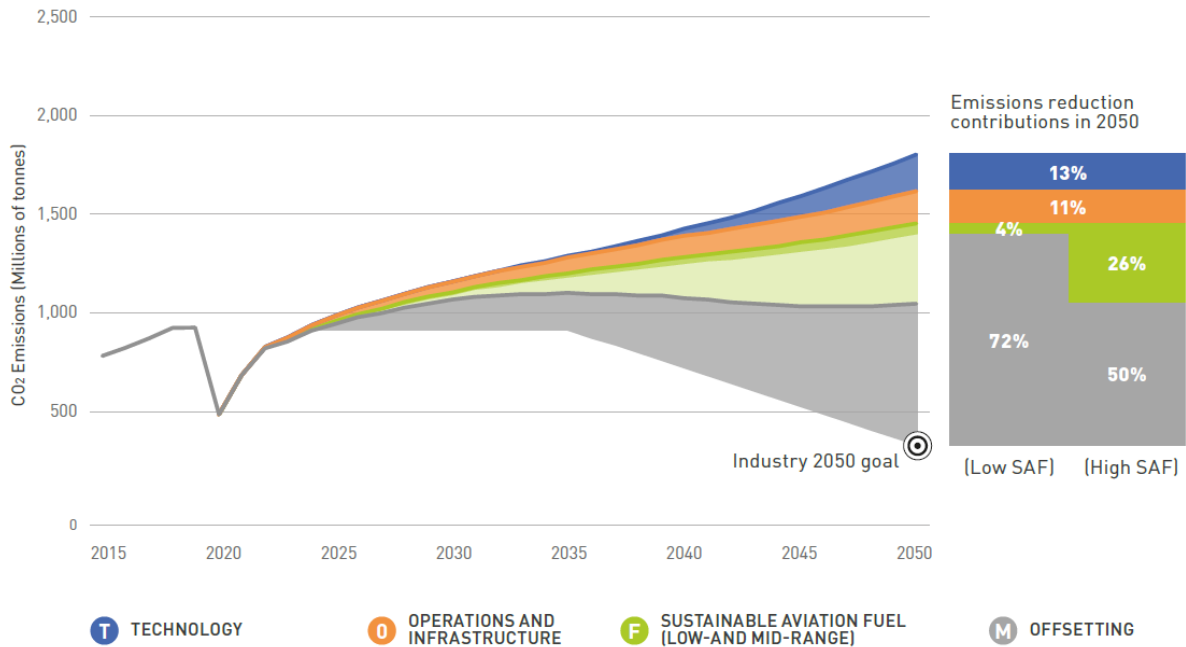
A more advanced scenario (scenario 2) with more ambitious technology improvements (T3 - New airframe configurations with substantial aerodynamics performance, strut-braced wings, blended-wind body and open rotor configurations) estimates a -15% reduction of CO<sub>2</sub> by 2050 (Figure 75).

The Clean Sky 2 aircraft concepts which have been presented in detail in the present report already include ambitious technology improvements such as open rotor configurations (SMR++ and Innovative Regional TP 130) or advanced aerodynamic technologies such as natural of hybrid laminar flow (NLF and HLFC), morphing wings, composite materials, etc.

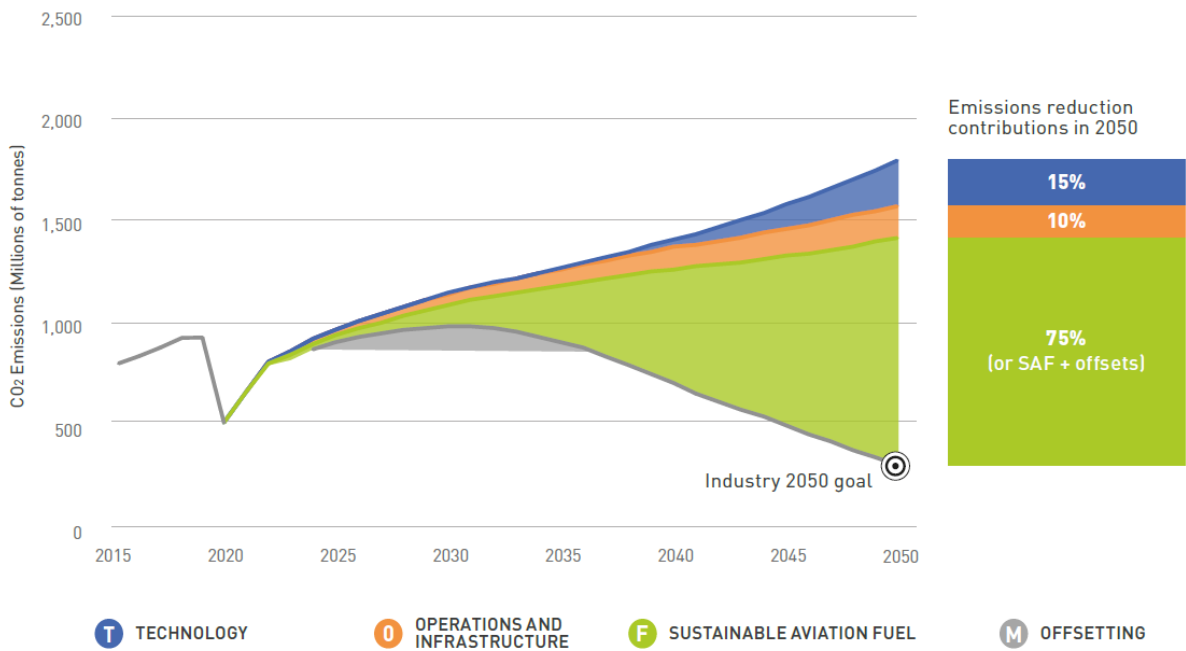
As already stated earlier, if all concepts would achieve the -20% to -30% CO<sub>2</sub> reduction target, and a 100% fleet replacement could be achieved by 2050, only then, a -20% to -30% reduction could be achieved at global fleet level by 2050.



This underlines once more **the urgent need to accelerate the technology maturation process by promoting and supporting research investments, in order to “skip a generation”**. To this end, not only advanced technologies but possibly also ultra-advanced technologies should be integrated simultaneously onto the next aircraft generation by 2030, if not, by 2035 at the latest.



**Figure 74 – Evolution of CO2 emissions by 2050, baseline scenario 0 with T2 Technology Developments - ATAG Waypoint 2050 Report, 2020.**



**Figure 75 – Evolution of CO2 emissions by 2050, scenario 2 with T3 Technology Developments - ATAG Waypoint 2050 Report, 2020.**



## 6 Societal Impact

### 6.1 Connectivity and Mobility

Before COVID-19, more than 93% of air travellers within Europe used direct flights for their trip from origin to destination. Less than 7% of travellers use a transfer connection for their itinerary. This means that additional direct flights with mainliner / regional aircraft are likely to add only a small contribution to improvements in connectivity.

A strong contribution is likely to come from vehicles providing passenger services connecting areas which so far, have had no or only limited direct access to commercial air transport.

Fast rotorcraft or small air transport vehicles (typically 19 seat commuter aircraft), which can be operated from heliports or small airfields can increase substantially the number of people who have easy access to air transport. On average, *only 10.2%* of the European population can be reached with conventional transport modes (car and scheduled aviation) within four hours from each NUTS3-region<sup>32</sup>.

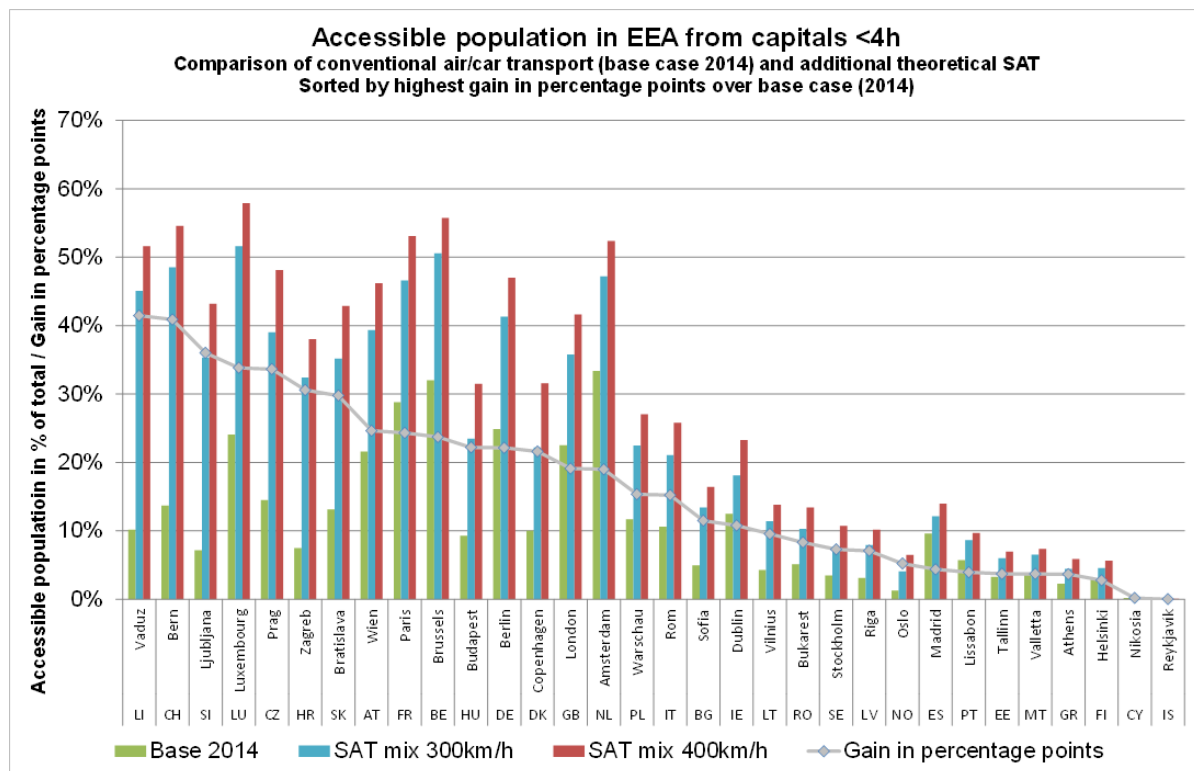


Figure 76 - Percentage increase of accessible population per country.

With the introduction of SAT commuter aircraft (800km range, 300km/h cruise speed), ***the percentage of population accessible within 4 hours can be substantially increased to 29.9%, or to 36.6% if cruise speed is increased to 400km/h***, see Figure 76.

<sup>32</sup> NUTS3-region: Nomenclature of Territorial Units for Statistics or NUTS is a geocode standard for referencing the subdivisions of countries for statistical purposes.



However, the benefits for individual NUTS3 regions differ considerably – regions which are already today well connected to air transport, can benefit less from SAT, while centrally located NUTS3 regions, e.g. in Switzerland or Southern Germany, that have no immediate access to airports with commercial operations, have the highest potential. Vaduz (Lichtenstein) or Bern (CH) achieve percentage gains over 40% in terms of connectivity.

The SAT 19-seat concept aircraft has been designed with a degree of versatility which allows it to be used for a single mission of 800 nm or for two consecutive missions of 300 nm, however without refuelling.

Figure 77 gives an idea of the radius of action which may be covered by such type of aircraft within central Europe in a range of 500 to 1000 nautical miles. Several other Clean Sky concept aircraft provide an attractive solution to the mobility objective in this sort of range: the NGCTR with 24 pax (<1000 nm), the Regional Multi-Mission TP 70 pax (1000 nm) and the Regional Advanced TP 90 pax (1200 nm). The Regional Innovative TP 130 pax also answers this mobility objective over a slightly higher range (1600 nm = ~ 3000 km).

**Connectivity**

Most of Europe can be covered with flights below 1000 nautical miles, (approximately 1800 km) out of Brussels Airport.

Regarding Rotorcraft, in the oil and gas domain time benefits between about 23% and 36% could be achieved leading to a more than 30% increase in transport capacity if all 100% of the OAG fleet was replaced by Clean Sky vehicles.

In general, for both vehicles (RACER and NGCTR), the mission time is reduced by 30%-40% and both vehicles perform better at longer distance flown.



Figure 77 - European cities within a range of 500NM-1000NM (926km-1852km) from BRU (Brussels).



## 6.2 Macroeconomic Effect

The projection indicates strong positive growth in aviation-related employment in Europe and the world as well as a significant increase in gross value added created by aviation. Based on the movements forecast and an economic input-output model using data from the World Input-Output Database<sup>33</sup>, the economic effects of civil aviation, which are supported by CS2, are estimated.

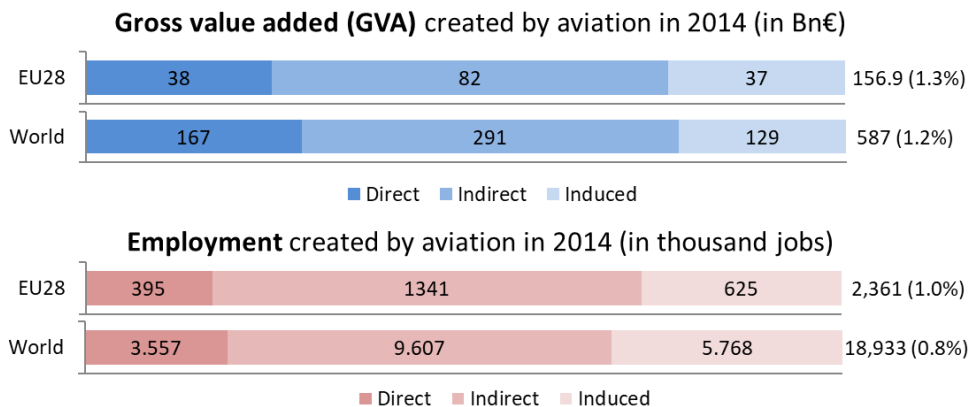


Figure 78 – Gross Value Added (GVA) and Employment created by aviation in 2014.

Gross Value Added (GVA) and employment effects include:

- *Direct effects* that arise from the economic activity within the air transport industry (i.e. the airlines)
- *Indirect effects* that result from the economic activity of upstream suppliers (e.g. aircraft manufacturers, airports)
- *Induced effects* that arise from labour income generated either directly or indirectly by air transport, which is spent on private consumption

In the EU28, aviation is responsible for an above-average share of total GVA and total employment compared to the rest of the world.

Aviation-related employment in the EU-28<sup>34</sup> amounts to an estimated 4.0 to 4.7 million (low vs. high scenario) direct, indirect, and induced jobs in 2050, compared to 2.4 million jobs in 2014.

Global aviation-related employment is expected to more than double between 2014 and 2050, with an increase of between 110 and 135%.

Employment growth is particularly strong in emerging economies due to strong air traffic growth in these countries.

The direct, indirect, and induced real gross value added created by aviation would reach € 267 to € 304 billion in the EU-28 by 2050, compared to 157 € billion in 2014.

<sup>33</sup> Cf. <http://www.wiod.org/home>.

<sup>34</sup> UK has left during the elaboration of this report



Global aviation-related GVA is expected to rise by about 80 to 105% between 2014 and 2050.

### Employment created by aviation between 2014 and 2050 (in thousand jobs)

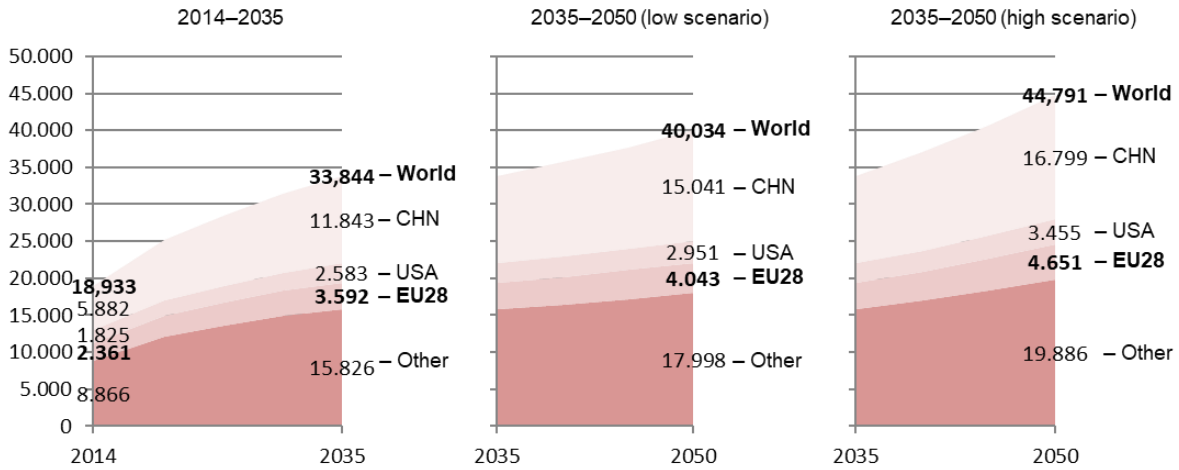


Figure 79 – Employment created by aviation between 2014 and 2050.

Although a significant driver is the strong air traffic growth in emerging economies such as China, India, and Indonesia, the EU28 and the US will see both their employment and GVA from aviation roughly double by 2050 versus 2014, maintaining therefore a significant share of the world’s global aviation-related employment and GVA

### Gross value added (GVA) by Aviation between 2014 and 2050 (in Bn€)

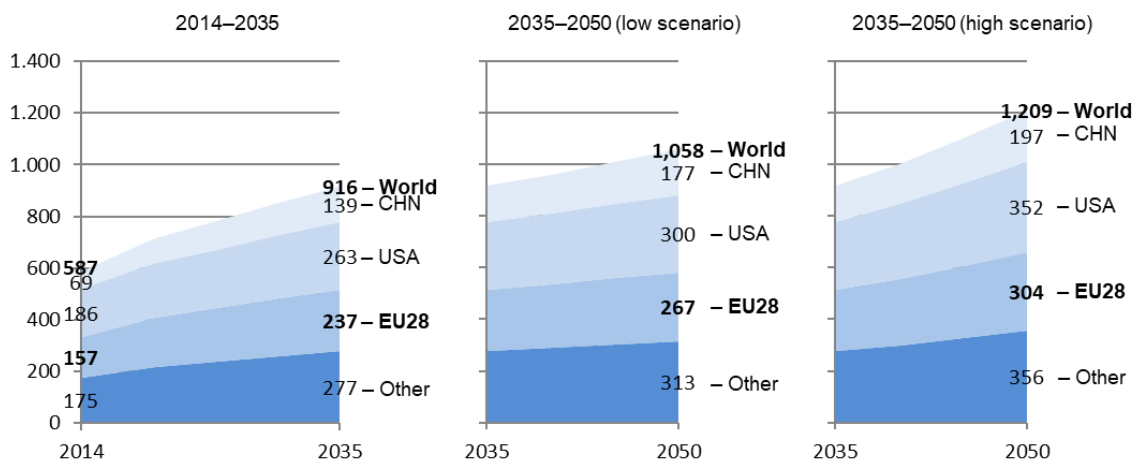


Figure 80 – Gross Value Added (GVA) by aviation between 2014 and 2050.



### 6.3 Competitiveness and Societal Impact

Competitiveness has not yet been covered in this first assessment but will be addressed via a specific Call for Tender by the CS2JU to be included into the second assessment.

Appropriate competitiveness indicators have already been identified and a first glimpse at the promotion of collaboration in the aeronautics sector through Clean Sky 2 indicated similar levels to those achieved in Clean Sky 1. The Call for tender shall also consider the impact of COVID-19 on the competitiveness of the aeronautics sector.

As a result of this first assessment, all stakeholders acknowledge that Clean Sky 2 contributes positively to the improvement of the technical know-how, competitiveness and job creation in the EU industry.

The structure of Clean Sky 2 enables all actors in the aviation space to collaborate and share ideas easily. Researchers can learn what the industry's needs are, and SMEs can gain access to much bigger industrial giants and their facilities. In turn, industry benefits from the innovative potential of SMEs and the deep specialised knowledge of the research centres.

**Clean Sky has successfully established a robust innovation network and quality supply chain in the aviation sector, motivated to drive cleaner, greener aviation forward.**

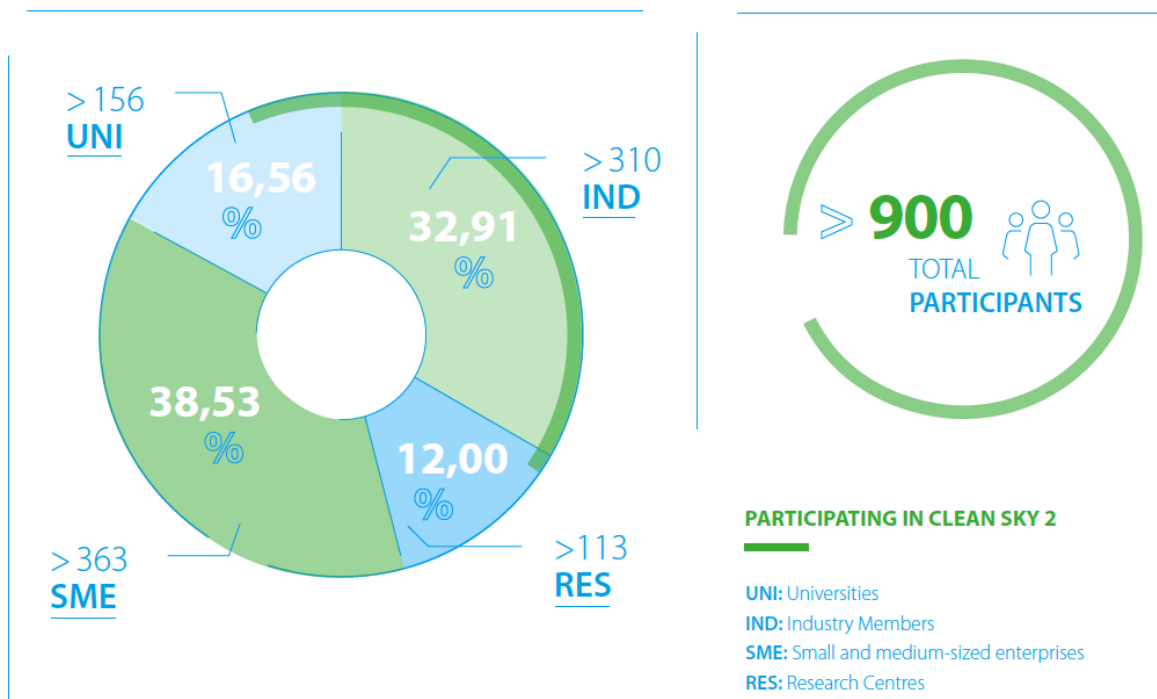


Figure 81 - Total number of participants and relative share of SMEs, UNIs, RES and IND in the Clean Sky 2 programme (status after CfP11).

By the end of 2020, four Calls for Core Partners and eleven Calls for Proposals have been launched and evaluated. Through these call mechanisms, the €4 Bn Public-Private Partnership Programme has



achieved an unprecedented level of participation in the programme. More than 1750 participants / 940 entities have been involved in more than 550 granted projects with broad geographical spread and widening of aeronautics sector.

Many newcomers from other sectors (e.g. automotive) joined the programme providing key innovation impetus and statistics show a large SME participation with a high percentage of SMEs being first-time EU programme participants as well.

This involves more than 5000 scientists and engineers around Europe working on Clean Sky 2 projects.



The country distribution and number of participating organisations per country is indicated in Figure 82 and 83 respectively.



**COUNTRY DISTRIBUTION**

The figures indicate the number of Clean Sky participating organisations per country. Participating organisations are counted once in the map. They may however participate in multiple projects. Therefore, in the participation chart, the number of participations takes into account all projects where they were involved.

900 entities across 30 countries

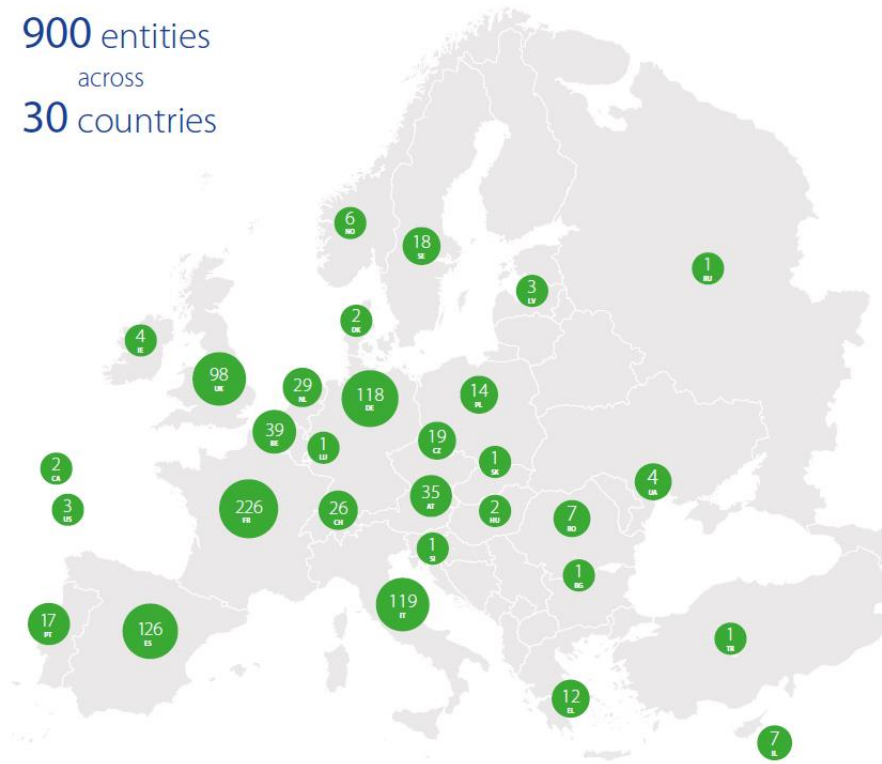
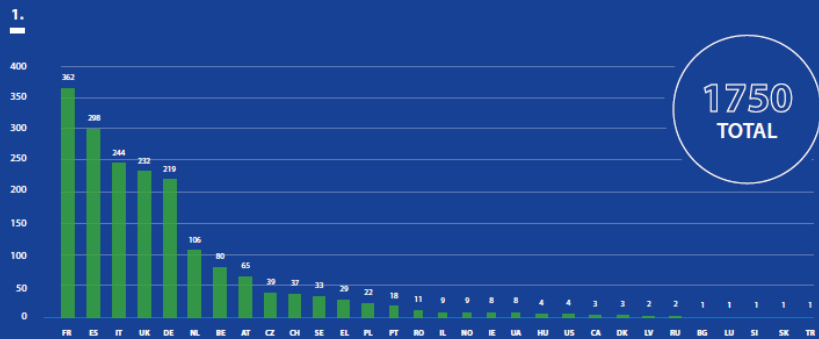


Figure 82 – Number of Clean Sky participating organizations per country.

**NUMBER OF PARTICIPATIONS**

This graph shows the number of times that a country has taken part in a Clean Sky 2 project - referred to as participations. The data displayed here includes Calls for Core Partners 1-4 and Calls for Proposals 01-11.



**NUMBER OF MEMBERS AND PARTNERS**

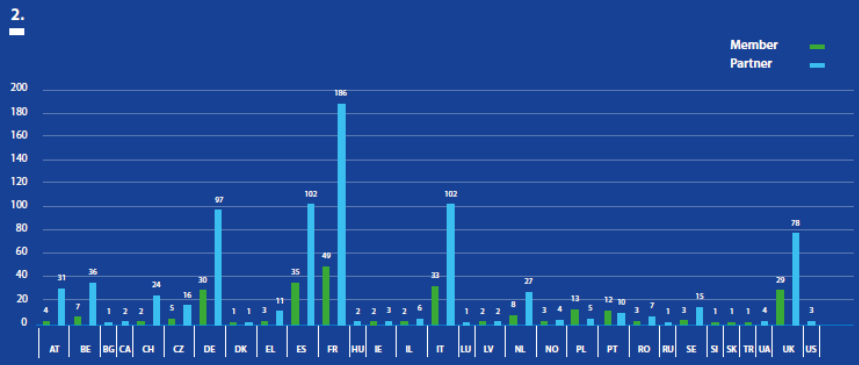


Figure 83 – Number of participations and number of members and partners in the Clean Sky 2 programme per country.



## 7 Impact of COVID-19

The assessments at Airport and ATS level are based on the forecasts and scenarios, as they reflect the expected market diffusion before the COVID-19 crisis. The latest information on the potential impact on aviation have left increasing doubts that the COVID-19 crisis will have the same impact on aviation growth as earlier crises, where forecasted aviation growth rates have been reached again after 5-7 years.

The potential impacts on demand, movements and fleet are listed below:

- **Demand** (short term lower, mid-term unclear, long term old growth rates possible)
  - Business travelers: many branches are affected by lockdowns and cancellation of on-site events/meetings; reduction of travel budget; sustainable, structural change towards videoconferences and teleworking?
  - Private travelers: recovery is more likely, provided that entry bans are lifted, but many people may be affected by reduced workdays or even unemployment with lower income and reduced travel budget, which may have negative impacts on demand volumes.
  - However, no data is currently available regarding the amount of travel budget decrease and impact on destinations.
- **Movements and Network** (short term lower, mid-term unclear, long term old growth rates expected)
  - Reduced number of movements and decreasing network size caused by lower demand
  - Reduced number of movements and decreasing network size caused by lower travel options (short and medium term)
  - Airline market concentration will probably increase (due to bankruptcies, mergers, and selective state aids)
  - Impact on network unclear but this year and previous crises have shown that airlines tend to concentrate on key (hub) airports and routes (less impact on country and continent level and for primary airports, high impact on intercontinental level and for secondary/regional airports);
  - Recovery of international flights depends on bilateral agreements between states regarding entry bans
- **Fleet**
  - Short term: airlines will continue to use the most efficient aircraft and cancel orders
  - Recovery phase will see stored aircraft getting back to service, but the effect on aircraft use patterns and on routes is unclear
  - Manufacturers will suffer from order stops/cancellations and may not be able to develop new aircraft

In conclusion, COVID-19 will lead to reductions in demand, movements and fleet, which will certainly alter the results at Airport and Fleet level in the second global assessment. At mission level, the aircraft concept performance is expected to be further improved thanks to additional technology insertions but may have to be applied to a different fleet structure and to smaller flights and passenger volumes.



Finally, in terms of impact on the aeronautical industry, to mitigate the COVID effect and effects of any similar case in the future, the aviation industry will need to tackle a whole set of new technologies which are quite different from the current CS2 targets and climate neutrality. Customers may simply no longer want to travel using public transport means which are potentially unsafe for health.





updated Open Rotor model, in particular to integrate a low NO<sub>x</sub> combustion model. Similarly, the LR+ concept will receive an updated Ultrafan® model (ENG WP5-6). The short-range business/regional turboprop (ENG ITD WP3) recently and successfully ground tested by SAFRAN HE is also a candidate to re-engine the regional turboprop concept models.

#### New/Updated Reference Vehicles

Based on the difficulties related to the choice of an appropriate reference vehicle (in particular for the rotorcraft concepts), a potential revision of the reference vehicle or the creation of a generic compound helicopter or tilt-rotor is envisaged.

The business jet reference aircraft (currently SoA Y2000) will be updated to a generic business jet aircraft SoA Y2014. This will lead to a decrease of performance gains of about 10%, which is estimated to be regained almost totally by additional technology insertions (see Section 5.1.1.9 Low Sweep Business Jet Aircraft Concept.).

#### New Engine and Aircraft Models

In terms of new aircraft concepts, a number of new models are envisaged.

- The SAT concept studies have been extended already to hybrid/electric system architectures. This work is ongoing under ENG ITD WP8 by GE Avio based on the MAESTRO engine programme and integrated under the SAT Transverse Activity. The serial-hybrid architecture has already been down-selected and the current estimates foresee further improvement from -21% to -27% CO<sub>2</sub> reductions.
- The Regional aircraft models will be complemented by an additional concept: a GTF (geared Turbofan) regional airliner currently being investigated under the project ADORNO<sup>35</sup> to exploit advances in GTF technology from MTU in ENG ITD WP4. This project is currently ongoing and should be concluded by end 2022.
- The SMR+ concept studies will continue by investigating other configurations, but with passenger capacity increased to 250 following updated sizing rules. Trade-off assessment will continue with a Rear End option already implemented and a high-wing configuration with VPF (Variable Pitch Fan) engine. More technologies from the SYS ITD are to be integrated (to exploit further weight gains).



Figure 85 – Evolution of SMR+ concept as a high-wing configuration with VPF engines.

---

<sup>35</sup> ADORNO, “Aircraft Design and nOise RatiNg for regiOnal aircraft”, <https://cordis.europa.eu/project/id/821043>



- The Long Range concept LR+ will undergo further studies as well and will be complemented by an Ultra-Advanced Long Range concept (LR++) to complete the mapping of the fleet.
- As a result of the shift towards larger capacity aircraft and average shorter range (<3000 km) for a majority of flights, and in order to satisfy the actual mobility demand and operational missions in 2050, one recommendation of this study is ***to introduce an additional aircraft concept***: a wide-body short-range concept (with updated sizing rules), often called “people mover” in the aeronautical community. The final specifications of this concept as to the passenger capacity (between 300 to 500 pax) and the design range (up to 3000 or 4000 km) will be the focus of a parametric study as to define the optimum concept fleetwise.

In terms of new engine model or engine updates,

- The SMR++ CROR engine model is currently being updated for inclusion of the low NO<sub>x</sub> combustor model, and an overall updated CROR engine model (including revised emission and noise performance) will be delivered for aircraft integration.

#### [New/alternative assumptions for forecast and scenarios](#)

Forecasts and scenarios will be updated with new or alternative assumptions, in particular regarding the effect of the current COVID-19 crisis. Recovery scenarios will be considered and their impact at airport and fleet level by 2050 will be evaluated.

Updated forecasts for all vehicle models (mainliner/regional, rotorcraft, bizjet, SAT) will be performed with improved modelling for SAT (better consideration of other transport modes regarding travel time advantages and costs) and for mainliner (improved fleet modelling considering the diffusion of new components into the fleet). Work is also ongoing under the currently running project TeDiMo<sup>36</sup> addressing in particular the technology diffusion models.

The potential for emission reductions external to Clean Sky - stemming from policies, alternative fuels and new propulsion systems will be assessed. These factors are currently addressed in ongoing projects such as GLIMPSE2050<sup>37</sup> (policies), TRANSCEND<sup>38</sup> (alternative fuels and new propulsion systems, including Hydrogen). Potentially new emissions caused by air taxis (urban mobility solutions) and supersonic aircraft are addressed as well in the ongoing OASyS<sup>39</sup> project.

Finally, consideration of SESAR improvements regarding global flight efficiencies and benefits from air traffic management and operational measures will be addressed.

---

<sup>36</sup> TeDiMo, „Technology Diffusion Model“, <https://cordis.europa.eu/project/id/821354>

<sup>37</sup> GLIMPSE2050, „Global Impact Assessment of Regulations and Policies for Sustainable Aviation by 2050“, <https://cordis.europa.eu/project/id/865118>

<sup>38</sup> TRANSCEND, „Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains“, <https://cordis.europa.eu/project/id/864089>

<sup>39</sup> OASyS, „Overall Air Transport System Vehicle Scenarios“, <https://cordis.europa.eu/project/id/864521>



### Updated Socio-Economic Impact

Based on the above assumptions regarding the recovery after the pandemic, the socio-economic assessment will be updated and complemented by additional impacts, addressing catalytic effects, competitiveness and additionality of Clean Sky 2.

In terms of connectivity impacts of Fast Rotorcraft, the assessment will be completed at EU-wide level.

### Updated Environmental Impact

The achievement of the objectives is currently assessed versus the targets set by the Regulation, i.e. in terms of CO<sub>2</sub>, NO<sub>x</sub>, and Noise. However, it is well known that the non-CO<sub>2</sub> effects are at least as important as the CO<sub>2</sub> effects, although there is a general agreement among the scientific community that the level of understanding of these global warming mechanisms is low.

The assessment of the benefits of the technology progress from Clean Sky may be extended to a more general climate impact assessment rather than CO<sub>2</sub> effects only. The airport assessment may also be enlarged to include local air quality impacts, subject to the provision of required information on other kinds of emissions like SO<sub>x</sub>, H<sub>2</sub>O, VOC and particles.

This last point deserves a note of attention. The current engine models, hence aircraft models do not provide this additional emission data. Models are currently being updated to provide numbers in terms of particulate emissions following the recent update of the CAEP regulation. The subsequent update of the aircraft models will then have to be performed, but the fact that this data (particulate emissions, but also water, SO<sub>x</sub>, VOC, etc.) should be made available as well for the existing fleet and legacy aircraft is an issue. An appropriate modelling approach may alleviate this problem, but the extension of the assessment to a climate impact assessment may be compromised or simply impossible if none of these two conditions are fulfilled.



## 9 Conclusions

The scope of this first Global Assessment of the Clean Sky 2 programme covers two major aspects: the **environmental impact assessment** of the technologies developed under CS2 research and the **socio-economic impact assessment** of the programme. This work has been performed by the German Aerospace Center (DLR) based on the inputs from all SPDs within the framework of the Technology Evaluator as a transversal activity.

The environmental impact assessment covers the achieved results to date in terms of CO<sub>2</sub>, NO<sub>x</sub> and Noise reductions based on a number of aircraft concept models received from the various SPDs. These models have been used to estimate performance improvements versus a reference aircraft (SoA year 2014) at mission level, at airport level (including noise footprint) and at fleet level (Air Transport System) in a forecast up to 2035, followed by two scenarios (high and low) up to 2050.

The study uses a forecasting model based on various economic growth assumptions, technology diffusion models and fleet replacement rates. It introduces an important novelty, as compared to other models dealing with air transport: **airport capacity constraints**. Due to insufficient adjustment of infrastructure to air transport, demand growth is endogenized and its effects on fleet mix evolution is captured. Comparisons are provided with the results of other models (such as ICAO and Airbus). To strengthen the credibility of this forecast, DLR has performed the same calculations without this assumption (i.e. an unconstrained forecast) for comparison. A constrained forecast is likely to show **an overall reduction of 30% in terms of flight volumes** to be expected by 2050 versus an unconstrained forecast, with direct consequences on aircraft in service, hence deliveries.

Attention will be devoted in the continuation of the programme to further testing the robustness of this model and to extend it to new scenarios, including the recent effect of the COVID-19 pandemic on aviation, too recent to be considered in this study.

At mission level, a high-level description is provided of the nine proposed fixed-wing concept aircraft according to the market segments (commuter, regional, small, medium and long range) and two fast rotorcraft concept vehicles with their respective links to the IADPs and ITDs, together with their chosen reference vehicle for comparison.

The results are presented based on detailed descriptions of the concepts and their technology insertions. They underline the fact that **substantial progress has already been achieved and that the programme is well on track**. Most of the concepts achieve their target or even exceed it. However, this is a snapshot of the results at programme mid-term. This means more progress is to be expected over the second part of the programme through further maturation of the technologies and updates of the models as well as inclusion of additional technologies not yet considered today, while not yet mature enough at the time the first models were defined. Those mission level performance results are the basis for the airport and fleet level calculations.

Thanks to the progress in noise reduction technologies, the airport level assessment also shows substantial improvements. Noise impacts were estimated by comparing the noise performance of future airport traffic scenarios with and without CS2 technologies in the year 2050 for a set of



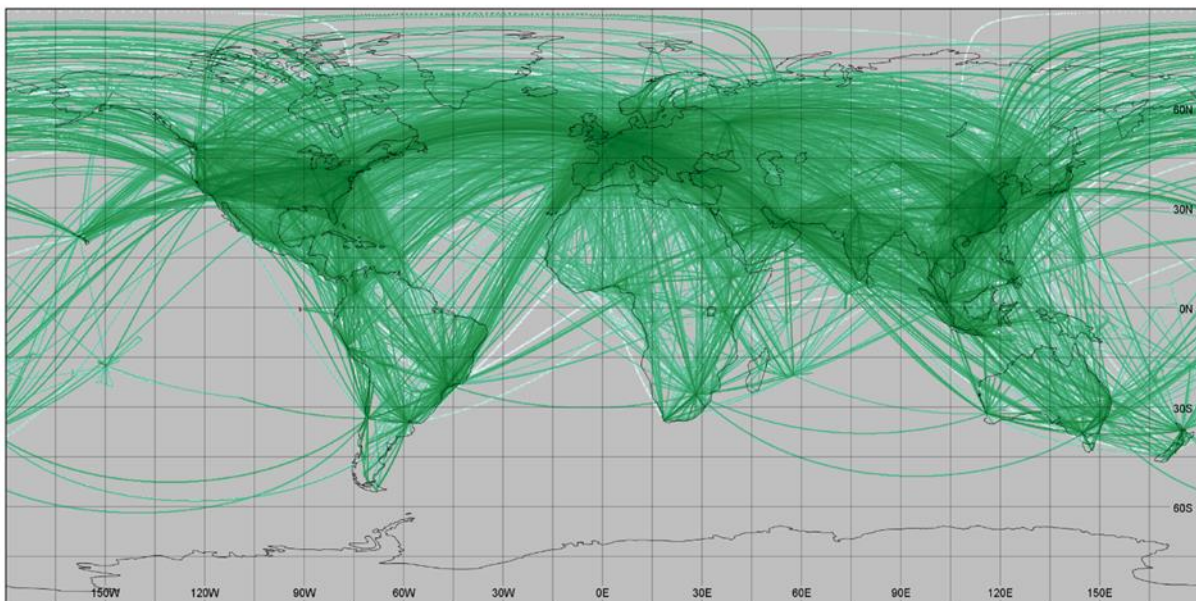
representative airports. The reductions for 2050 in surface area of Lden contours for relevant noise levels (60-65 dB(A)) are about 10-15% and point out **significant reductions of population exposed and population highly annoyed in the range of 10-25%**.

In 2050, **reductions of CO<sub>2</sub> emissions will amount to about 8-13.5% for the European airports considered, while the associated NO<sub>x</sub> reductions will be in the range 6.5-10.5%**.

At fleet level (Air Traffic System), according to the present forecast, approximately **75% of global available seat kilometres (ASK) will be operated with aircraft expected to carry CS2 technologies in 2050**, while 25% of global ASKs will still be operated by aircraft with 2014 reference technologies, not yet retired.

By applying the performance improvements of the SPD aircraft models, **an overall reduction of CO<sub>2</sub> and NO<sub>x</sub> emissions of about 15% and 31.0% per seat kilometre can be expected for the year 2050** high fleet scenario as compared to a 2050 global traffic scenario incorporating only 2014 reference technology.

2050 Clean Sky high scenario traffic network

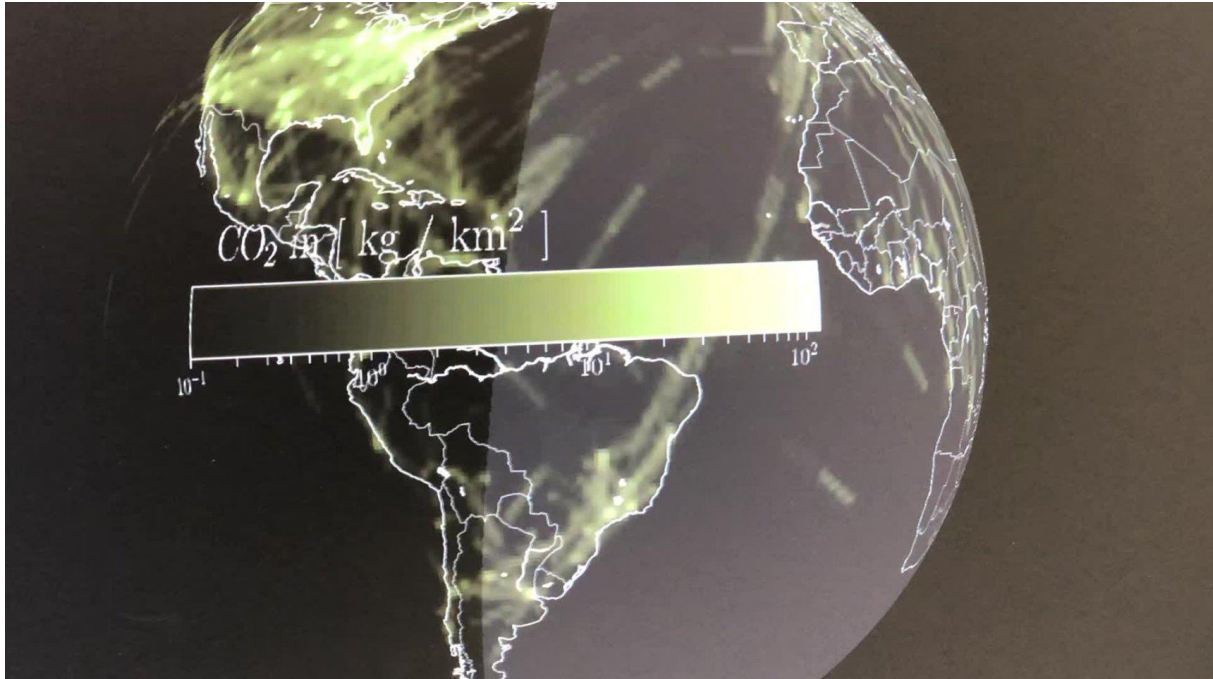


As for fleet evolution, in the case of mainliners, the model predicts **a major shift towards larger aircraft (301-500 seats) mainly to be used to fly short range (<3000km)**. It is thus expected that the discrepancy between design range and operational use will considerably increase in importance. The implications of this result for the environmental impact of CS2 and the regulatory implications will be further explored in view of the second Assessment.

Funded by the EU's Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness by delivering innovative solutions for the aviation sector. The socio-economic impact assessment of this study covers societal aspects like e.g. mobility, connectivity, and economic aspects such as employment, GDP growth and competitiveness.



Clean Sky's long-term vision is to enable the EU aviation sector to reach complete climate neutrality by 2050. Achieving such an ambitious goal requires sector-wide cooperation, and Clean Sky engages SMEs, universities, research centres and the aviation industry to continue to deliver ground-breaking results.



© Clean Sky 2 Joint Undertaking, 2021.

Postal address :

**TO56 - 4/02, B-1049 Brussels**

Visiting address :

**Av. de la Toison d'Or, 56, B-1060 Brussels**

[www.cleansky.eu](http://www.cleansky.eu)