CLEAN SKY TECHNOLOGY EVALUATOR – AIR TRANSPORT SYSTEM ASSESSMENTS

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ABSTRACT

The Clean Sky program is made up of 6 Integrated Technology Demonstrators (ITD) and the Technology Evaluator (TE). The ITDs are [2]:

- Smart Fixed Wing Aircraft (SFWA) addressing large aircraft technologies
- Green Regional Aircraft (GRA) addressing regional aircraft technologies
- Green Rotorcraft (GRC) addressing rotorcraft technologies
- Sustainable And Green Engines (SAGE) addressing engine technologies
- Systems for Green Operations (SGO) addressing aircraft systems
- Eco-Design (ED) addressing aircraft life cycle assessment

The Technology Evaluator is a simulation network that assesses the performance of the technologies developed in the ITDs and clustered at concept aircraft level. TE assessments are done in order to evaluate emissions or noise improvements of Clean Sky aircrafts and fleets.

From the beginning it was recognized that successfully monitoring progress towards the ACARE environmental goals (noise and emissions) would require a crosscutting evaluation platform in the Clean Sky Program. The TE was born from this need, and its composition reflects the need to pool know-how and simulation/modelling capability that exists among industry, the research establishments and academia.

In order to determine noise or emissions improvements the approach in the TE is to 'insert' Clean Sky conceptual aircraft into a number of evaluation scenarios. In essence: the technologies developed, matured and demonstrated in the Clean Sky ITDs are 'clustered' in coherent and mutually compatible solution-sets that define a potential future aircraft. These conceptual aircraft are 'flown' (i.e. simulation scenarios are run) and the Clean Sky configurations are compared to the most relevant benchmarks: most importantly the state-of-the-art of aircraft of similar size and role in the year 2000 (ACARE's baseline year). The comparisons are performed at a single flight, or 'mission'; at the level of illustrative airports; and finally across the global air transport system. So the TE approach aims to demonstrate the environmental impact in the overall aviation system of Clean Sky's (research and technology) output by illuminating the 'pathway' from technologies to aircraft and air transport system (ATS) performance.

This paper gives an overview on the whole TE process and presents in more details the ATS level assessments, i.e. showing the Clean Sky technologies environmental impacts through global or regional aircraft fleet scenarios.

1. INTRODUCTION: TECHNOLOGY EVALUATION IN CLEAN SKY

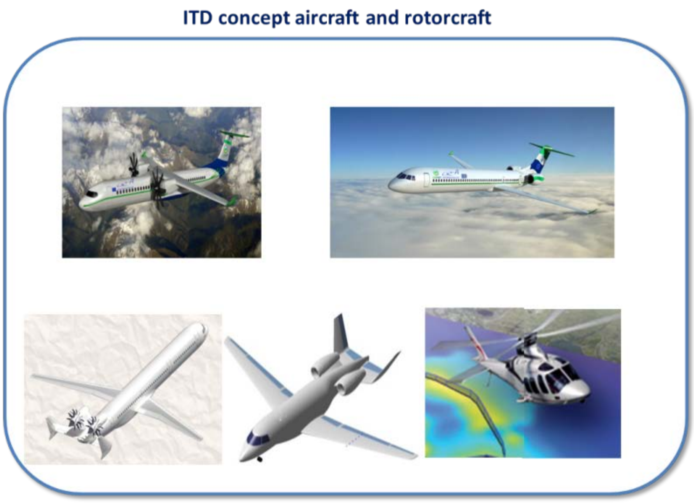
A specificity of Clean Sky is to have put in place two complementary means for evaluating the aircraft and rotorcraft technologies which are developed in the programme.

The first one is, as usual, to evaluate the new technology stand alone, in comparison to the "old one" using specific criteria such as weight saving, maintenance or production improvement, overall aircraft system simplification, noise reduction capacities, etc.. These technology specific evaluations are performed inside the Clean Sky's ITDs (Integrated Technology Demonstrators), and according to the Technology Readiness Level (TRL) which is achieved, can go from simulations only to ground or flight tests.

The second one is a global evaluation of the environmental benefits (emissions and noise reduction) of the overall Clean Sky program. To this aim, key technologies are clustered into aircraft or rotorcraft simulation models in order to figure out what would be the performances of these Clean Sky aircrafts/rotorcrafts when equipped with Clean Sky technologies.

This second kind of evaluation is done by a specific Clean Sky sub-project: the Clean Sky Technology Evaluator, the principles and results of which are described in the following in general and in more detail at Air Transport System level.

The figure besides shows artist views of some Clean Sky aircrafts/rotorcrafts that are evaluated by the Technology Evaluator. The complete list, including the main Clean Sky technologies that they integrate, is given in Table 1.



Business jet	
Low-sweep business jet	▪ Natural laminar wing ▪ U-tail for noise optimization ▪ 2020 entry-into-service technology engines
High-sweep business jet	▪ Natural laminar flow wing ▪ Innovative 3-engine afterbody (2020 entry-into-service technology engines)
Regional aircraft	
Turboprop – 90 seats	▪ Advanced Composite Materials and SHM

	▪ Low Noise Landing Gear and high efficiency high lift devices ▪ Electrical Environmental Control System
Geared turbofan – 130 seats	▪ Advanced Composite Materials and SHM ▪ Natural Laminar Flow Wing ▪ Advanced Geared Turbofan
Large passenger aircraft	
Small-medium range aircraft	▪ Natural laminar flow wing ▪ Contra-rotative open rotor engine
Long range aircraft	▪ Advanced 3-shafts turbofan engine
Helicopters	
Single Engine Light	▪ SEL specific low drag, low noise and more Electrical technologies ▪ Advanced engine
Twin Engine Light	▪ TEL specific low drag, low noise and more Electrical technologies ▪ Advanced engine
Twin Engine Medium	▪ TEM specific low drag, low noise and more Electrical technologies ▪ Advanced engine
Twin Engine Heavy	▪ TEH specific low drag, low noise and more Electrical technologies ▪ Advanced engine
High Compression Engine	▪ HCE specific low drag, low noise and more Electrical technologies ▪ Advanced engine

Table 1: Clean Sky aircraft and rotorcraft with their main advanced technologies

2. TECHNOLOGY EVALUATOR METHODOLOGY

In order to forecast the environmental improvement when Clean Sky aircrafts/rotorcrafts are flying, the Clean Sky aircraft/rotorcraft models simulate flights in specific scenarios. It is then possible to compare the noise and emissions of these Clean Sky aircrafts/rotorcrafts with their reference counterparts of aircraft/rotorcraft which include technologies of the year 2000.

These scenarios have been designed at 3 levels: A single aircraft/rotorcraft flight or "aircraft level "; all aircraft/rotorcraft movements at and nearby an airport or heliport, the "airport level" and the fleet of aircraft and rotorcraft all around the world or "Air Transport System, ATS level". The three levels are described hereafter in general and a more detailed view on the ATS level assessments is given.

The evaluation results of these levels are generated by dedicated simulation platforms and capitalized in the Technology Evaluator Information System based on a web-service platform which is available for all Technology Evaluator members.

2.1. ACARE objectives

Three evaluation or assessment levels (see chapters 2.2; 2.3; 2.4 and 3) were defined in order to be able to assess as much as possible the Clean Sky contribution towards the ACARE environmental objectives. These ACARE objectives were set in 2000 by an aeronautical representative stakeholder group to define the improvements which should be aimed at to be reached by 2020, considering the more and more demanding environmental constraints. These objectives are summarized in Figure 1. The TE assessments are performed in order to determine the contribution of the Clean Sky technologies to reach the ACARE goals. It must be noted that ACARE goals were defined for mission and airport level but not for the ATS level.

ACARE objectives

- **CO_2 emissions reduced by 50% compared to similar and relevant 'Year 2000 aircraft'**
- **NO_X emissions reduced by 80% compared similarly**
- **A halving of perceived noise compared to 2000 level performance**

Figure 1: the ACARE environmental objectives [1]

2.2. Aircraft level assessments

At aircraft level the environmental evaluation of a single flight by a concept aircraft and its reference technology aircraft along the same reference trajectory is performed. The main environmental indicators considered are noise on ground, fuel burn and emissions (CO_2 and NO_X).

2.3. Airport level assessments

At airport level the environmental impact on local communities around an airport is assessed by comparing a year 2020 airport traffic scenario with reference technology aircraft with the same traffic scenario but in which concept aircraft replace their reference technology counterpart. The purpose of this replacement approach is to evaluate the full potential of environmental benefits of Clean Sky technologies. The main metrics at airport level are noise on the ground, population impacted by certain noise levels, and emissions (NO_X).

2.4. ATS (Air Transport System) level assessments

At ATS level the environmental impact of Clean Sky technologies is quantified at global or world-wide scale by comparing a year 2020 fleet scenario with reference technology aircraft with one in which all reference technology aircraft in the relevant seat categories have been replaced by their conceptual counterpart. Similar as for the airport level, this replacement scheme aims to address the full environmental potential of Clean Sky technologies. Fuel burn and emissions (CO_2 and NO_X) are the main indicators of interest at ATS level.

For future ATS activities it is also foreseen to provide the overall reduction of noise exposed persons in Europe when Clean Sky technologies will be implemented, taking the results of all major airports in Europe.

3. ATS LEVEL ASSESSMENTS

3.1. Approach and scenarios

The ATS or global assessments (see Figure 2) are based on 2020 fleet traffic forecasts taking into account the traffic growth from 2000 to 2020. The reference time period chosen was the month September as this is a representative month for the whole yearly traffic. These September 2020 global fleet traffic scenarios were then compared with either 2020 Clean Sky technology or 2000 reference technology aircraft inserted into the fleet. The comparison of these fleets allowed the calculation of the Clean Sky environmental benefits or "delta´s" in terms of CO2 and NOx reduction in absolute and relative values.

Some assumptions are done for the insertion of Clean Sky aircraft in the 2020 fleet. In order to show the full potential of the Clean Sky technologies a 100% insertion rate is assumed. This aircraft insertion is of course not a realistic replacement scenario but shows the maximum achievable environmental delta at fleet level through Clean Sky 2020 technology aircraft.

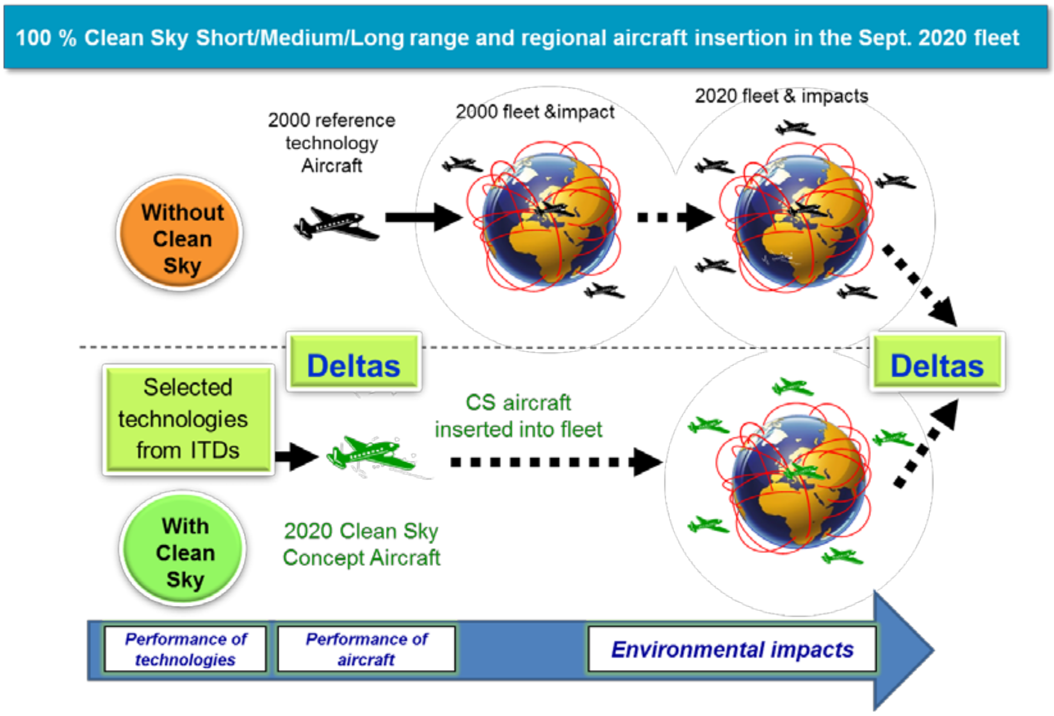


Figure 2: ATS level assessments methodology

Global fleet assessments were performed for different kinds of fleets: Global aircraft fleet with Mainliner and regional aircrafts, Global business jet fleets [4] and Global rotorcraft fleets.

These fleets were analysed separately because different markets and business cases lie behind them. The mainliner and regional aircraft fleet is based on scheduled flight plans and focuses on the transportation of people with affordable prizes. The business jet market is based essentially on non-scheduled flights for mainly VIP transportation at high prizes. The rotorcraft market is driven by different rotorcraft mission types (Emergency and Medical Services, Police, Passenger Transport, Search And Rescue, Oil & Gas, Civil utility) from which the passenger transportation represents a minor part.

The example is given for the mainliner and regional aircraft fleet where Clean Sky aircraft were replaced in the 75 to 350 seat categories fleet segment (see Table 2) i.e. for which Clean Sky aircraft models are available. For the commuter and Very Large Aircraft segment of the fleet no replacement was done as no Clean Sky aircraft models are yet available here. As already mentioned before the emission outputs of these aircrafts where then calculated with DLR internal models.

fleet segment	Seat category
Commuter	25
	50
Regional	75
	105
Short / Medium range	125
	150
	175
Long Range	250
	300
	350
Very large Ac	400
	450
	500

Table 2: seat category structure of the global mainliner´s and regional aircraft fleet

3.2. Data, models and results

In order to perform an ATS assessment fleet emission inventories have been calculated for September 2020 fleet traffic scenarios using the following models (see Figure 3) and data inputs[1]:

- Year 2020 fleet and traffic forecast:
  Based on manufacturers inputs and taking the year 2000 fleet traffic as start point a September 2020 fleet and traffic forecast was performed providing for each flown airport pair information on name of the airports, distance between these airport pairs, geographical coordinates of the airports, aircraft type used, number of flights flown per airport pair and arrival/departure time

- Fleet Emission inventory calculation
  Emission performance calculation per airport pair for the whole fleet was done:
  - For existing aircrafts through DLR internal models [3]. For the Clean Sky application these comprised mainly the Commuter and Very Large Aircraft segments of the fleet. But the DLR models allow also the calculation of emission outputs for all currently existing aircraft types in the fleet.
  - For Clean Sky aircrafts through ITD aircraft models: these comprised 2020 Clean Sky and 2000 reference technology aircraft models.
- Additionally the geographical distribution of the fleet emission output data on the globe was done to make visualisations and to allow the analysis of the distribution of the global fleet emission data in space and time. This can be interesting for example when analysing the flight altitudes and the corresponding emission amounts.

After comparing the 2020 Clean Sky to the 2020 reference fleet scenario the environmental delta in terms of fuel, CO_2 and NO_x reduction was calculated (see Figure 2). Although not done in Clean Sky 1 aircraft fleet emission inventories can be used in a further step to make simulations on aviation climate impact.

Further, the ATS level tool suite composed of the above described models and data inputs is part of an overarching TE Information System. This Information System is designed to be a unique tool to

[1] The example is given for a mainliners and regional fleet use case

collect and harmonise the tremendous amount of data generated by the TE assessments of all Clean Sky aircraft at the three levels. It enables the Clean Sky community to access results of TE assessments and track developments. More specifically for ATS use cases it is possible to calculate user generated scenarios and their corresponding fleet emission inventory outputs in real time through a web service application.

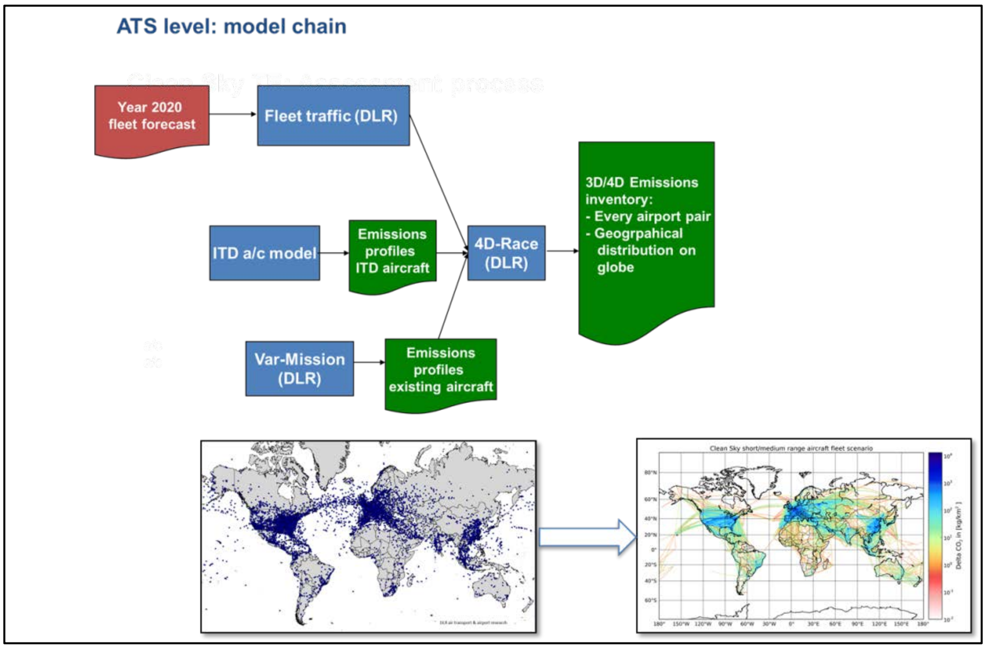


Figure 3: ATS level model chain

Figure 3 shows the ATS level model and data input chain. The chain consists basically of two steps that is to first model the traffic scenarios and secondly to calculate the fleet emission inventory output. Figure 4 shows the example of a 2020 fleet scenario with Clean Sky Short and medium range aircraft equipped with Open rotor engine and natural laminar wing technologies and the associated CO2 reduction effect. The picture shows the environmental delta effect for CO_2 in kg/km^2. The natural laminar wing and the open rotor engine are technologies that have been developed in the SFWA[2] and SAGE[3] ITD[4]. For future assessments it is also foreseen to integrate SGO[5] technologies in the concept aircraft models, i.e. mission trajectory management optimization for departure, cruise and approach segments of the flight.

[2] Smart Fixed Wing Aircraft ITD
[3] Sustainable and green engines
[4] Integrated Technology Demonstrator
[5] Systems for Green Operations

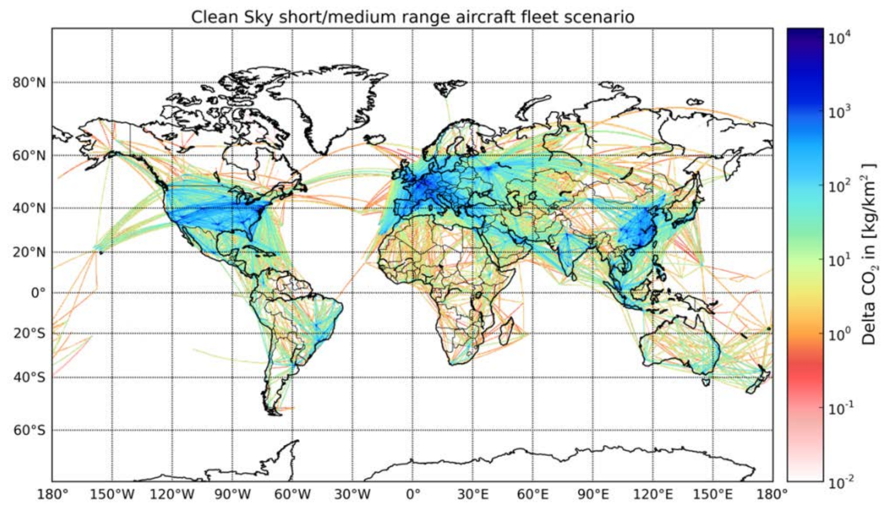


Figure 4: Clean Sky short/medium range aircraft fleet scenario and its associated CO2 delta

The 2014 assessment result showed that the whole aircraft fleet (see Figure 5) emission reduction effect due to 2020 Clean Sky aircraft technologies integration in Short, Medium, Long range and regional aircrafts in the fleet leads to about 20% of CO_2 savings for the September 2020 time period. The Clean Sky short and medium range aircraft fleet segment represents with about 55% the largest contribution to this overall CO_2 reduction (see Figure 4).

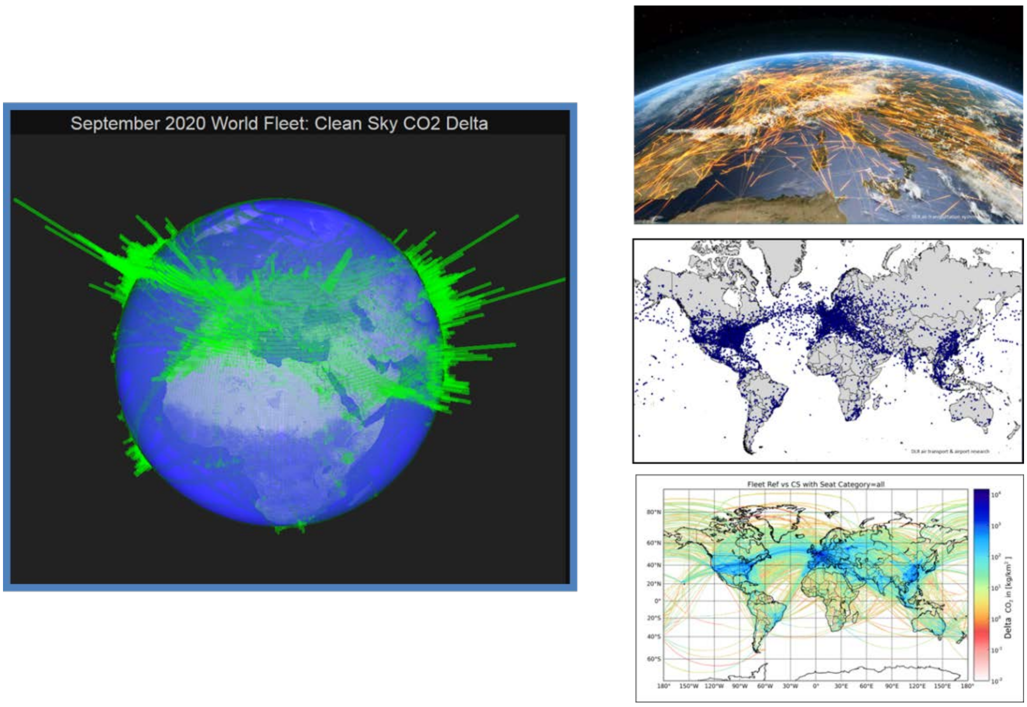


Figure 5: Overall September 2020 aircraft fleet Clean Sky environmental benefit for CO2

4. CONCLUSION

Clean Sky's TE is a key element in the overall Clean Sky Programme approach, comprehensively evaluating Clean Sky environmental benefits at three interrelated levels: aircraft, airport and ATS. The present paper focuses on ATS level assessments.

The ATS level tool suite is a powerful means to calculate emission inventories for global fleet traffic scenarios for Clean Sky applications. These scenarios based on manufacturers and TE forecasts vary according to the market drivers of the respective air vehicle covered, i.e. mainliner´s and regional aircraft fleet, business jet fleet and different rotorcraft fleets.

Future developments will cover amongst others more automation in the tool suite.

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Information about the Clean Sky Programme, including annual reports, can be found on the website www.cleansky.eu.

REFERENCES

[1] www.acare4europe.com
[2] www.cleansky.eu
[3] M. Schaefer (2012), development of a forecast model for global air traffic emissions
[4] Ascend Worldwide Limited, ASCEND Online Fleets, Online Database for business jets (2014)

NOMENCLATURE

ACARE	Advisory Council for Aeronautical Research and Innovation in Europe
ED	Eco-design
GRA	Green Regional Aircraft
GRC	Green Rotorcraft
ITD	Integrated Technology Demonstrator
JTI	Joint Technology Initiative
JU	Joint Undertaking
SAGE	Sustainable and Green Engines
SFWA	Smart-fixed Wing Aircraft
SGO	Systems for Green Operations
TE	Technology Evaluator
TRL	Technology Readiness level