INTEGRATION OF MISSION TRAJECTORY MANAGEMENT FUNCTIONS INTO CLEAN SKY TECHNOLOGY EVALUATION PROCESS

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ABSTRACT

Clean Sky European Project is about to develop and demonstrate a large set of innovative technologies, covering all segments of commercial aviation. The Technology Evaluator (TE) of Clean Sky is a dedicated group composed by research centers which assesses the environmental impacts and benefits (noise, fuel burn and gaseous emissions) of the overall Clean Sky ITD output at three aircraft operational levels: single mission, ATM (airport) and ATS (global world fleet). TE assessments shall consider all promising green technologies selected by ITDs, grouped as clusters, forming optimized new aircraft solutions prepared under responsibility of manufacturers in Clean Sky's ITDs.
For large aircraft segment, the link between ITD and the TE is managed by Airbus through WP2.3 of SFWA ITD. In order to provide to the TE representative evaluation of future aircrafts equipped with Clean Sky technologies (including open rotors capabilities in operational conditions), it was deemed essential for WP2.3 to develop a concurrent European industry process able to translate innovative technologies into simplified conceptual aircraft models for technology evaluation. In this process, Airbus specifies the conceptual aircraft relevant to evaluate Clean Sky technologies, collects and converts the technologies into this conceptual aircraft to evaluate the performance, the noise and the local emission gains induced by the ITD technologies. To manage interface complexity and to protect industrial property, the Clean Sky large aircraft conceptual platforms are included and delivered to the TE, for operational evaluation, through an integrated and innovative calculation tool, developed by Airbus for TE needs, called PANEM.
This article will focus on the specificities of the integration into PANEM of Mission Technology Management (MTM) functions, such as Adaptive Increase Glide Slope (A-IGS), Multi-Criteria Departure Procedure (MCDP) or Multi Step Cruise (MSC) and will present noise impact improvement from a selection of Clean sky Technologies.

1 INTRODUCTION TO TE PROGRAM

The Technology Evaluator (TE) of Clean Sky is a dedicated group composed by Research Centers which aims at monitoring the environmental impacts and benefits in terms of noise and gaseous emissions of the overall Clean Sky Integrated Technology Demonstrators (ITDs) output towards Clean Sky environmental goals and the ACARE targets.
TE assessments shall consider the promising green technologies developed, matured, demonstrated and selected under responsibility of manufacturers in Clean Sky's ITDs, grouped as coherent clusters, forming

optimized future aircraft solutions. The TE approach aims at demonstrating the impact of Clean Sky's research and technology outputs in the overall aviation system. So, the comparisons are performed by the TE at three aircraft operational levels: At a single flight ('mission'), at the level of illustrative airports and across the global air transport system.
The 2020 fleet and traffic simulation scenarios have been elaborated by the TE considering the fleet development since the 2000 baseline situation and Clean Sky future aircraft replacing all existing aircraft in the relevant fleet segments. Simulation scenarios with the Clean Sky configurations are compared to the aviation state-of-the-art of the year 2000 (ACARE's baseline).
The TE's ability to build realistic simulation scenarios with future Clean Sky technology benefits relies on the representativeness of the considered performance and design options selected for these conceptual aircraft. Thus, the technology evaluation can only be performed thanks to close collaboration between ITDs and research establishments involved in Clean Sky TE. For large aircraft segment, the interface between Clean Sky ITD and the TE is managed by Airbus through WP2.3 of SFWA ITD.

Several Clean Sky technologies compatible with Airbus large aircraft platforms are developed within SGO ITD (System for Green Operations), SFWA ITD (Smart Fixed Wing Aircraft) and SAGE ITD (Sustainable and Green Aircraft). The numerous interfaces between those ITD and the TE are managed by Airbus through WP2.3 of SFWA.
In order to manage this interface complexity, but also to protect industrial property and to comply with Technology Evaluator requirements, the Clean Sky Airbus conceptual aircraft are designed, computed, included and delivered to the TE, through an integrated and innovative calculation tool, developed by Airbus for TE needs, called PANEM.
PANEM is fully integrated into the Clean Sky TE and ITDs process as detailed on Figure 1.

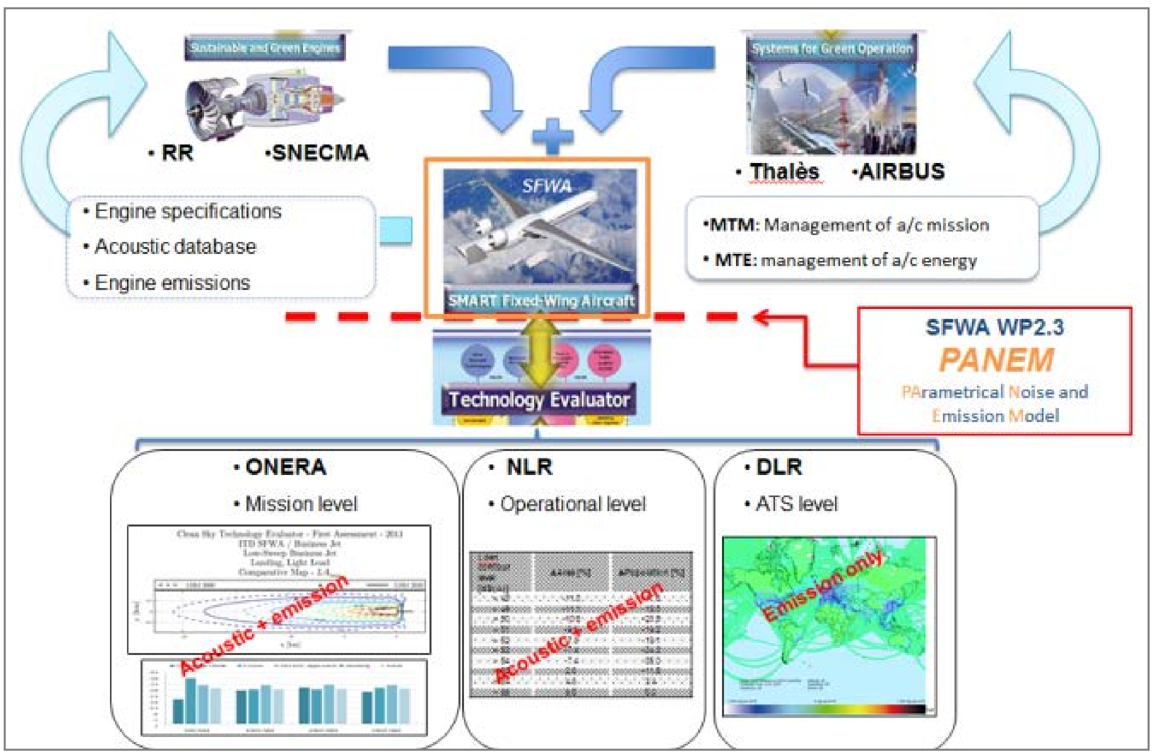

Figure 1: PANEM integration in Clean Sky process (ITD and TE)

After a quick description of the general process put in place to integrate Clean Sky Innovative Technologies into simplified conceptual aircraft models, the article will focus on the integration into PANEM of Mission Technology Management functions (namely Adaptive Increase Glide Slope (A-IGS), Multi-Criteria Departure Procedure (MCDP) and Multi Step Cruise (MSC)). Finally, an assessment of noise impact improvement from a selection of Clean Sky technologies will be presented.

2 PANEM TOOL

PANEM is a computation tool, specially developed by Airbus to comply with the requirements of Clean Sky TE, gathering an aircraft performance calculation module, similar to the one integrated in the operational Flight Management System of Airbus aircraft, a noise computation module, based on the operational noise computation tool of Airbus Acoustic Department and a gaseous emission computation module based on the Boeing Fuel Flow II method.

- ***Aircraft performance computation***

PANEM performance module has been developed by Airbus performance specialists, to match the specific needs of environmental studies (acoustic and emission computations) and has been adapted to cover Clean Sky open rotor engine applications. It computes specific performance values, based on aircraft aerodynamic data. PANEM performance module reproduces the behavior of the Flight Management System (FMS) of Airbus aircraft in operation and computes an operational 4D trajectory including X, Y, Z and time evolutions. Turns as well as the vertical profiles of the trajectories are modelled.
Output file of PANEM aircraft performance module is an operational trajectory containing aircraft position (X, Y, Z in meters), Mach number, aircraft speed (knots), ground distance (Nautical Miles), time (minutes) and fuel burn (kg, cumulated on the trajectory).
PANEM trajectory computation starts (take-off) at 35ft altitude and ends (landing) at 50ft altitude. Taxiing phases are covered separately by Airbus with tables of data directly provided to the TE.
The user inputs are the type of aircraft and the type of mission he wants to compute (in terms of mission length, runway definition, weather condition of wind and temperature and constrains).

- ***Aircraft noise computation***

PANEM acoustic module is based on Airbus in-house operational noise computation tool that has been enhanced to include Clean Sky open rotor engine applications.
PANEM acoustic module computes Sound Exposure Levels (SEL, dBA) for each reception time of the trajectory assessed by the performance module.

Indeed, for each emission angle (usually from 10° to 160° by 5°), the noise module of PANEM considers corresponding trajectory point and calculates, for a defined microphone position, the noise emitted at this point by the knowledge of corresponding parameters (Mach, engine rating, thrust, incidence, slat and flap configuration, landing gear position) and interpolation in the total aircraft noise database. Noise received is obtained by adding in-flight effects (propagation effects, ground effect…) to the noise emitted (see Figure 6).
In accordance with the TE, Sound Exposure Levels are computed on a pre-defined grid of microphones (20km by 40km with a microphone every 200m). By summing PANEM single-event computations, the TE has the capability to assess noise airport fleet studies.

- ***NOx computation***

PANEM gaseous emission tool computes, on a complete mission, for each time, X, Y and Z position, the CO_2 (kg, averaged on segments) and the NO_x (kg, averaged on segments) emissions.
The Boeing Fuel Flow Method II is using engines LTO cycle databases (NO_x emission indexes vs. engine fuel flow in reference conditions) to computes NO_x emissions emitted on the different part of the trajectory. CO_2 emissions are calculated regarding the fuel burned computed by the performance module.

To make the tool exportable within Clean Sky program and to ease the use of the tool by the TE, the three computation modules have been interfaced and integrated into a single program called PANEM. Indeed, data computed by the performance module are used by the acoustic and the emission modules to compute TE environmental indicators (noise and gaseous emission for a given aircraft and a given mission).
The performance and the noise computation modules have been enhanced to evaluate Clean Sky specific future technologies, such as open rotor engine capacity in operations or Adaptive Increase Glide Slope approach.

Figure 2 hereafter shows PANEM integration into Airbus overall aircraft design process.

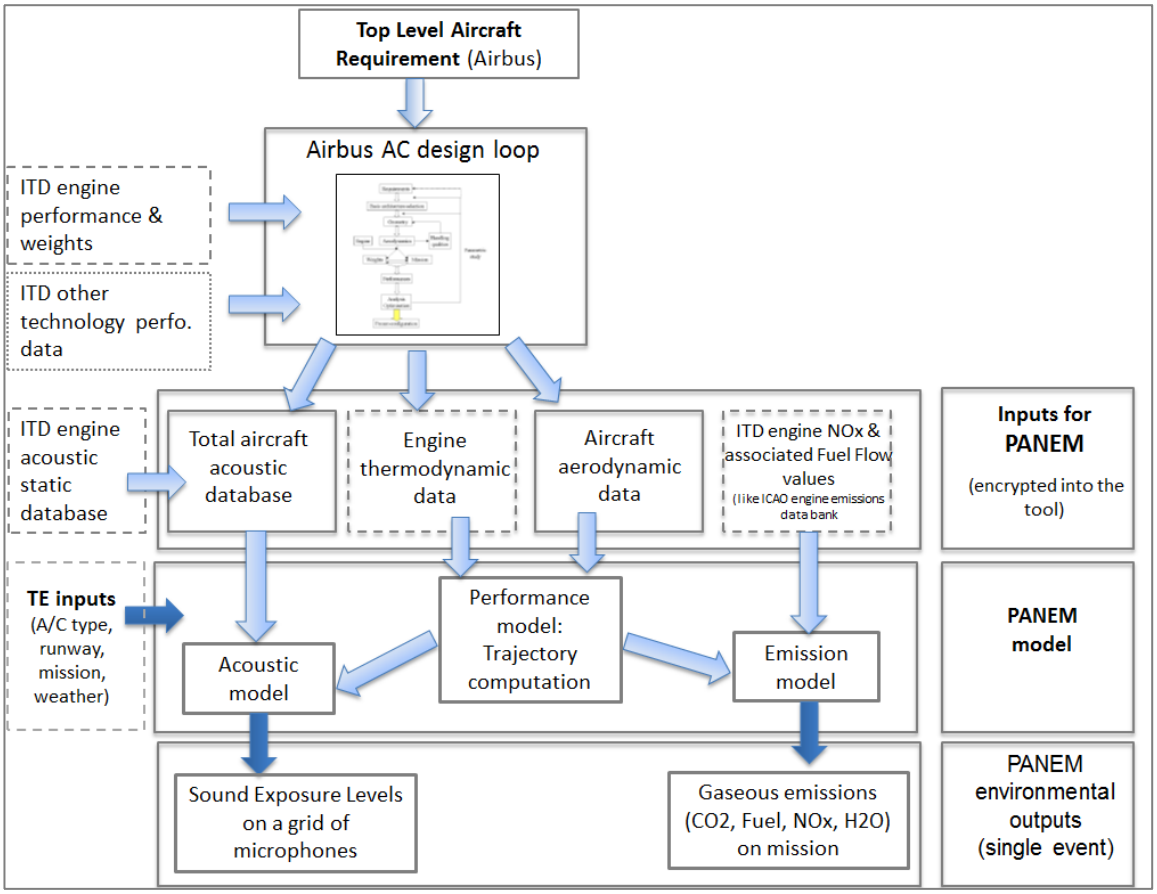

Figure 2: PANEM integration in Airbus aircraft design process

Inputs of PANEM are, in addition to the user inputs (runway, aircraft type, mission, weather), four databases which are computed, encrypted and integrated into PANEM by Airbus and engine manufacturer (aerodynamic data, engines data, aircraft noise databases and emission indices). Those databases are based on Airbus knowledge of the future aircraft and on performance of Clean Sky technologies provided by ITD:

- ***Aerodynamic data*** (polar, flight envelope…) are computed by Airbus Future Project Office after (aircraft optimization).

- ***Thermodynamic engine database*** (Thrust, altitude, Mach and engine thermodynamic data relationship) is provided to Airbus by engine manufacturer. If it is required, a scaling coefficient could be added to the data, in accordance with engine manufacturer. This scaling coefficient role is to perfectly fit together the engine and the aircraft.

- ***NOx emissions indexes*** are provided to Airbus by engine manufacturers under a format agreed between engine manufacturer and Airbus, comparable to certified engines ICAO LTO cycles. (Emission indexes vs. fuel burn in reference conditions)

- ***Total aircraft noise databases*** (Sound Pressure Level in third octave band) are computed by Airbus acoustic specialists, using Airbus noise static to flight transposition tool, engine sea level static noise data, engine thermodynamic cycle and Airbus knowledge of airframe noise. For each aircraft platform (type and specific engine), the noise database is computed, in reference conditions, for several parameters such as several Mach numbers, engine ratings, emission angles, landing gear up and down, and all existing aerodynamic configuration (slats and flats extension angles).
  For the specific case of open rotor engine, the thrust and inflow incidence are added as parameters. Before database computation, open rotor noise data received from engine manufacturer are analyzed by Airbus and compared to previous open rotor wind tunnel measurements. During PANEM static to flight transposition, installation and pylon effects are added to the noise as analyzed during open rotor engine installed tests in wind tunnel.

PANEM computes environment indicators of an aircraft for a single event (one mission, one runway) but the tool has been designed to be interfaced by the TE with external software to simulate for example, the air traffic around an airport in order to enable computing ATM (airport) or ATS (global fleet) studies by summing single event calculations.

3 ITD SGO TECHNOLOGIES INTEGRATION ON PANEM VIRTUAL PLATFORMS

3.1 General process

The first step to translate Clean Sky technologies into simplified conceptual aircraft models is, for Airbus, to define and to specify to the ITDs the most relevant conceptual aircraft for Clean Sky technologies evaluation, taking into account the state of the art of 2025 and the nature of the technologies which have been selected by ITDs.

Airbus has defined two conceptual platforms, one short medium range and one long range to host the Clean Sky technologies designed by ITDs.
Two reference platforms, representative of year 2000 technology state-of-the art have also been defined by Airbus to allow a comparison to ACARE objectives (defined regarding year 2000 reference).
Aircraft specifications, written by Airbus Future Project Office, are gathered in technical reports (see example on Figure 3) and shared with ITD.

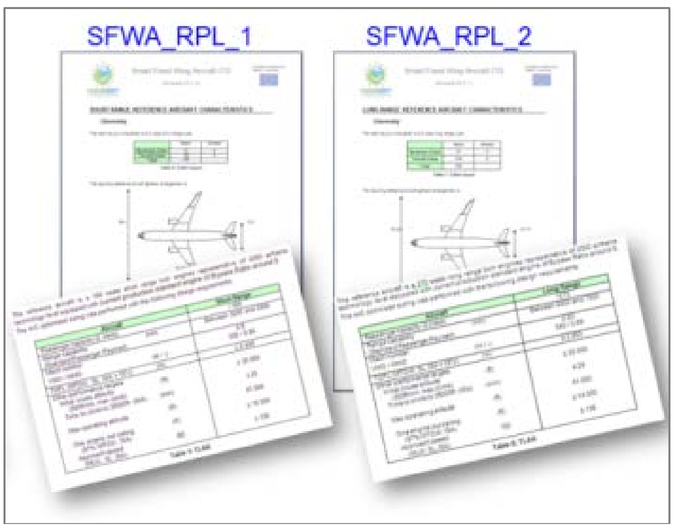

Figure 3: Airbus aircraft specifications documents

Based on these specifications, the performances of Clean Sky technologies (in terms of drag, weight, geometry, fuel, engine thermodynamic, noise or local emission impact), as evaluated by ITDs from calculation or test data, are collected and converted by Airbus as mutually compatible solution-sets into the conceptual aircraft.

For sustainable engines, engine manufacturers involved in Clean Sky provide to SFWA WP2.3, the engine thermodynamic cycle, some acoustic third octave bands data for all noise sources (fan, core, jet, turbine, and propeller), the engine geometry and weights. For laminar wing, SFWA provide technology impact on SFC, weight and drag versus the baseline. For Management of Aircraft Energy, SGO ITD provides also the impact on bleed air. For Management of Trajectory functions, SGO ITD provides SFWA WP2.3 with the optimized trajectory.

ITD technologies allocation on Airbus aircraft platforms is detailed on Figure 4 hereafter.

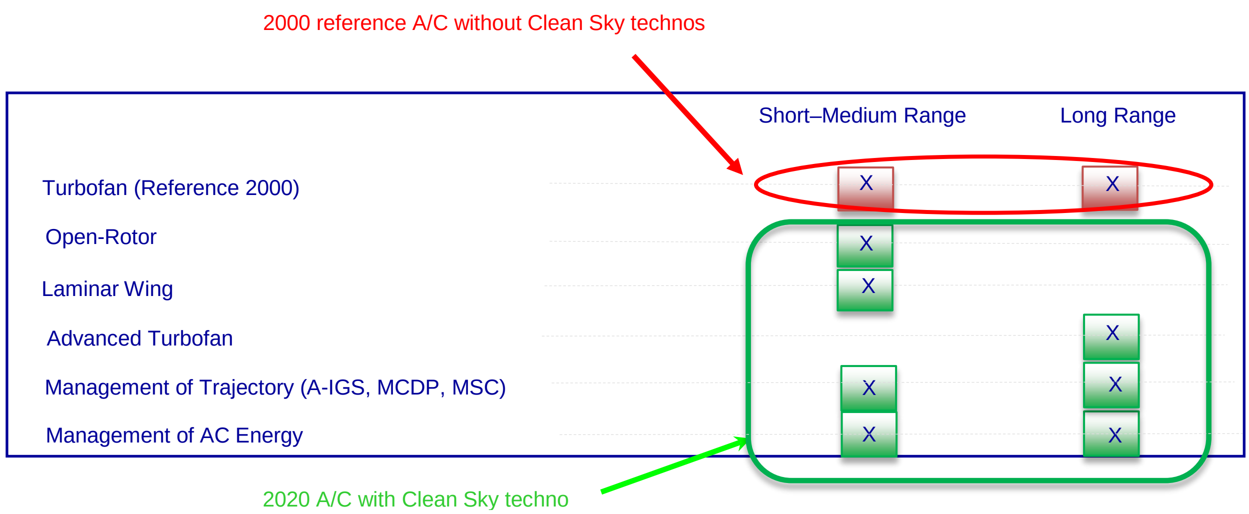

Figure 4: ITD technologies allocation on Airbus aircraft platforms

Collected information is then integrated by Airbus Future Project Office on future aircraft. The engine and the delta in weight, drag, bleed or SFC (Specific Fuel Consumption) induced by Clean Sky technologies are added to Airbus conceptual models. The aircraft performances are then optimized by Airbus Future Project Office for each platform through a design loop.

Clean Sky technology models integrated into PANEM have been continuously improved since the beginning of the project, in accordance to ITD computations, testing and the level of maturity of the technologies.

After this general presentation of PANEM process, next three sections will focus on SGO – Management of Trajectory technologies whose objective is to decrease environmental impact of aircraft in operational conditions.

3.2 Adaptive Increased Glide Slope [A-IGS]

One of the most promising solutions to reduce noise significantly below the final part of the approach (when the aircraft is currently established on the glide slope 10 NM before landing) is to increase final glide slope angles.

Adaptive Increase Glide Slope procedure (A-IGS) concept (see figure 5) consists in taking benefit of aircraft (weight, configuration) and environmental conditions (wind, temperature) to optimize final

approach glide path angle with regards to noise and fuel consumption, in such a way that the vertical speed at flare initiation is in an acceptable nominal range (previously fixed as an operational target).
For instance, from a geometrical effect, taking into account the headwind component and the targeted true vertical speed at flare initiation, the glide path angle would be calculated equal or steeper than the published, avoiding the need for increased thrust.

A-IGS algorithm has been directly integrated into PANEM performance module, and PANEM trajectories now consider this function for final approach calculation for all Airbus aircraft short-medium range and long range platforms.

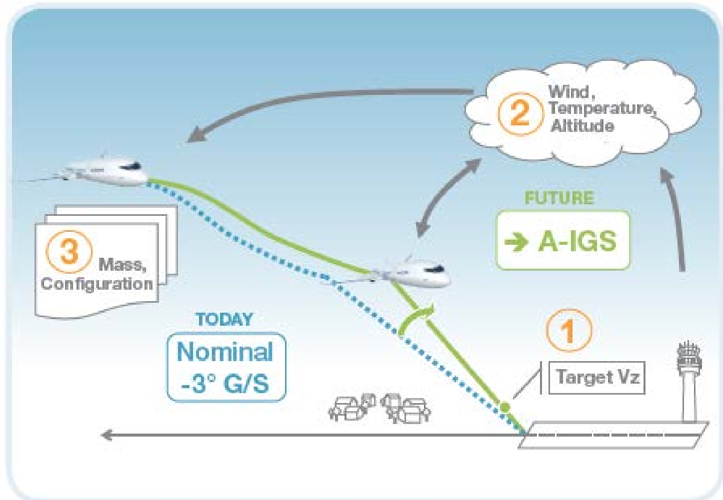

Figure 5 - Adaptive Increased Glide Slope concept

3.3 Multi Criteria Departure Procedure [MCDP]

Multi Criteria Departure Procedure (MCDP) is a new way fully consistent with Noise Abatement Departure Procedures to tailor optimized departure procedures (between 35ft and 10000ft) in order to reduce either noise emission or fuel consumption. Great advantage of this solution is to provide flexibility to operators both in terms of optimization strategy and to airport platforms where they operate. This operational solution provides to pilots during flight preparation the optimized solution to fly, under a full managed way, the best solution depending on day conditions and of course coping with local ATC constraints.

The concept allows tailoring aircraft parameters relative to take-off airborne phase (CAS, reduction altitude, acceleration latitude, power settings) taking into account aircraft conditions (take-off weight, performance) and weather conditions, in order to mitigate environmental impact on a given area.

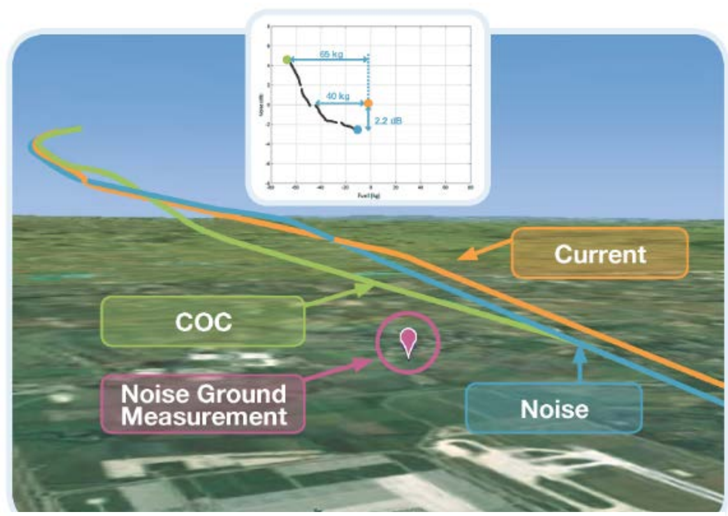

Figure 6 - Multi Criteria Departure Procedure concept

The concept, developed for turbofan application within SGO, has been adapted to open rotor application specificities such as the relationship between engine steering parameter and noise emission.

Full optimisation of departure trajectories cannot be put in PANEM model as the process is too heavy. Thus, based on an agreed scenario between TE, SGO and SFWA, the trajectory optimisation is performed by SGO outside PANEM and a set of optimized trajectory is directly included and encrypted into PANEM input files.

3.4 Multi Step Cruise [MSC]

Multi Step Cruise (MSC) concept objective is to optimise cruise level with regard to fuel consumption and gaseous emissions by taking advantage of environmental conditions.

Taking into account aircraft performance and meteorological conditions (wind and temperature profiles), the function performs a step by step profile computation based on economic altitudes calculations, and delivers a multiple steps altitude profile, associated to the aircraft weight at the end of the trajectory.

The MSC concept is relevant for aircraft missions higher than 4000nm, thus for Long Range aircraft application.

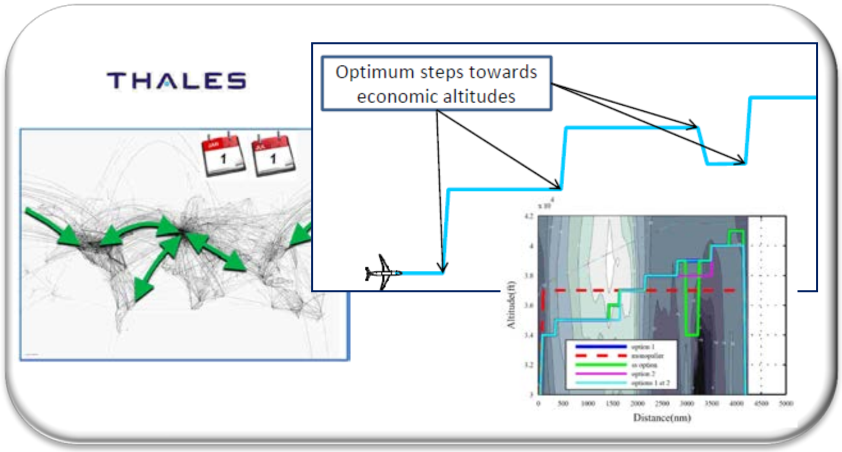

Figure 7 - Multi Step Cruise concept

Like for the MCDP function, the full optimisation of the mission cannot be performed inside PANEM. A set of different scenarios has been agreed with the TE partners, the optimisation has been done by SGO outside PANEM tool and the optimised trajectories have been encrypted afterwards into PANEM input files.

4 NOISE IMPACT IMPROVEMENT FROM CLEAN SKY TECHNOLOGIES

This section finally presents noise reduction achieved thanks to Clean Sky technologies for the Short-Medium range platform at London Heathrow airport.

Technologies integrated into the Clean Sky advanced research Short-Medium range platform are:

- the laminar wing, from SWFA,
- the open rotor engine, from SAGE,
- MCDP and A-IGS functions, from SGO.

PANEM noise computations (75 dBA noise footprints) have been performed at take-off for both the reference platform (without any Clean Sky technology) and the advanced platform. For the advanced aircraft, optimisation of the take-off profile has been performed thanks to MCDP function, in order to minimize the noise measured at Slough location (London Heathrow area). Outside PANEM, and in order to directly evaluate the impact on Clean Sky technologies on populations, the 75 dBA footprints have been translated into population numbers, i.e. the number of people impacted by the 75 dBA footprints.

Figure 8 presents the improvements achieved by Clean Sky technologies on the London Heathrow population impacted by the take-off of a typical Short-Medium range aircraft. Yellow and green lines present respectively the take-off flight profile of the reference aircraft and the advanced aircraft. Yellow bars present the population impacted by reference aircraft (approx. 190,000 people) while the green bars present the population impacted by the 75 dBA footprint of the advanced aircraft (approx.. 90,000 people).

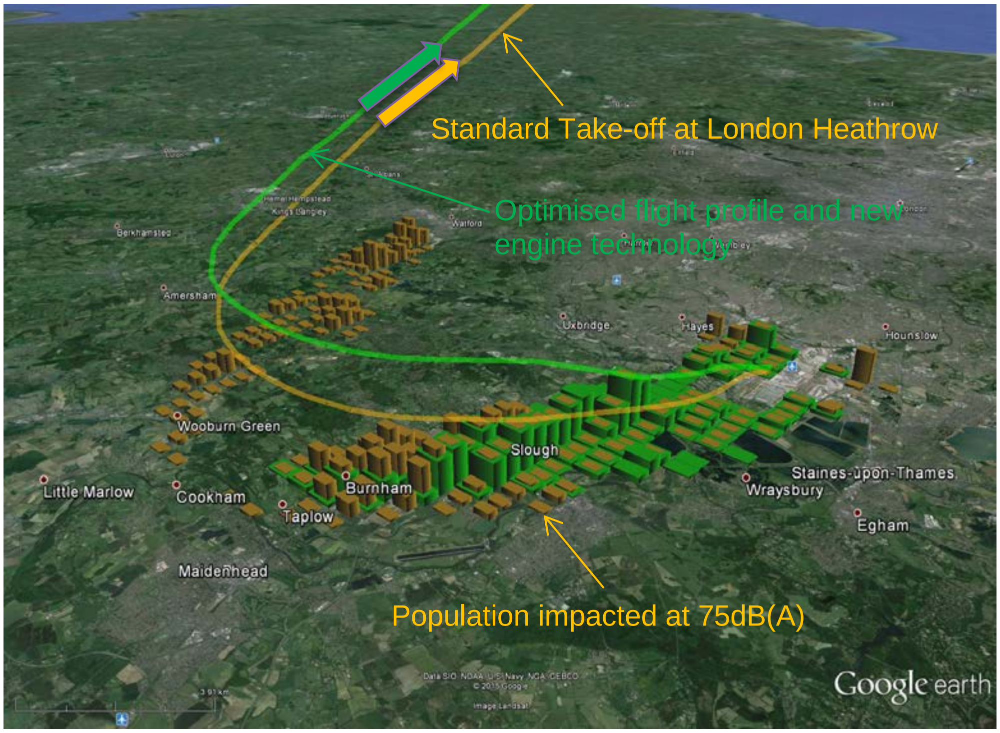

Figure 8 – Population impacted by the 75 dBA footprint at take-off of reference and future aircraft

Figure 9 complements the analysis by presenting the population no more impacted by the 75 dBA footprint of the advanced aircraft at take-off (in comparison with the reference one).

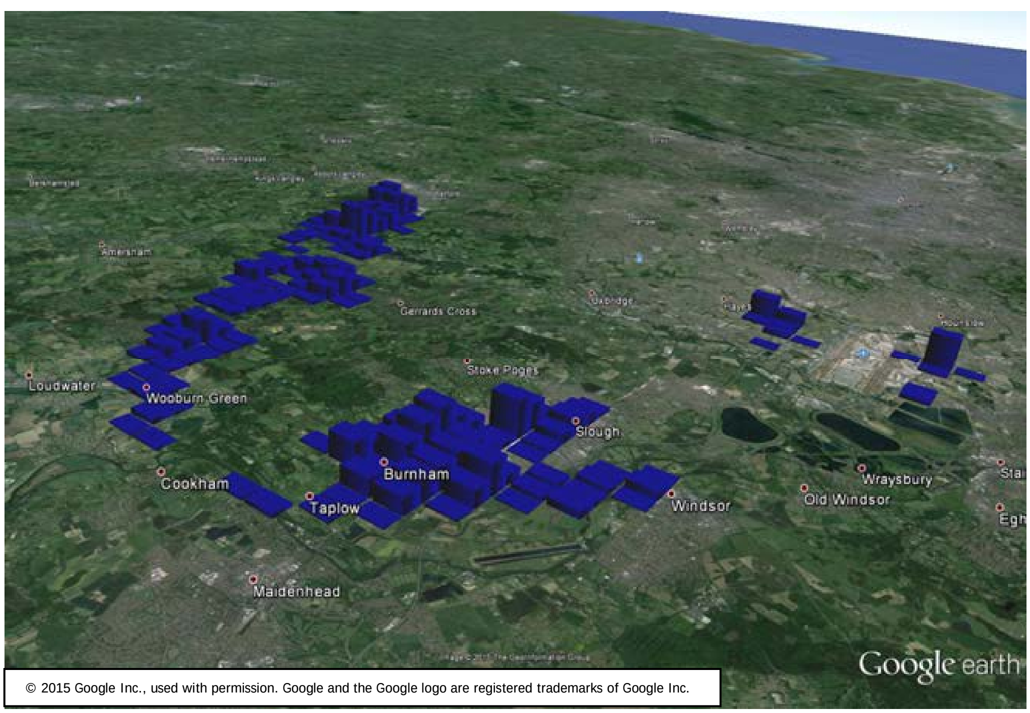

Figure 9 - Population no more impacted by the 75 dBA footprint at take-off of the future aircraft

It is clearly visible that new in-board technologies can lead to a drastic reduction of community's noise impact. There are 50% of people less in the 75dBA footprint area for the Clean Sky Short-Medium Range advanced aircraft at take-off.

5 CONCLUSIONS AND WAY FORWARD

The Technology Evaluator (TE) of Clean Sky, composed by Research Centers, aims at monitoring the environmental benefits in terms of noise and gaseous emissions of the overall Clean Sky ITD output towards Clean Sky environmental goals (ACARE targets).
In order to provide to the TE representative performance of future aircrafts equipped with Clean Sky technologies, to protect industrial confidentiality, and to deal with the complexity and the high technical level of interfaces, Airbus and its partners have been challenged to develop a concurrent European industry process able to translate innovative technologies into simplified conceptual aircraft models.

Clean Sky Airbus conceptual aircraft are computed on the basis of Airbus knowledge and on IDT data, included and delivered to the TE, through an integrated and innovative calculation tool, developed by Airbus for TE needs, called PANEM.

PANEM has been developed by Airbus performance, external noise and emission specialists, to match the specific needs of TE environmental studies (acoustic and emission computations) and to cover Clean Sky open rotor engine applications.
It computes performance, noise and emission of an aircraft for a single event (mission) and has been designed to be interfaced by the TE with other software to compute ATM (airport) and ATS (global fleet) studies to cover the overall aviation system.
Before delivery to the TE, outputs of PANEM are carefully analyzed through a validation process including manufacturers from the ITDs.

Thanks to the huge work done by ITDs and by the TE, PANEM is now able to evaluate efficiently and representatively the environmental benefits of the technologies developed by Clean Sky ITDs.

6 NOMENCLATURE

ACARE	Advisory Council for Aeronautics Research in Europe
A-IGS	Adaptive Increased Glide Slope
ATM	Air Traffic Management
ATS	Air Traffic System
ITD	Integrated Technology Demonstrator
MCDP	Multi Criteria Departure Procedure
MSC	Multi Step Cruise
PANEM	PArametrical Noise and Emission Module
SAGE	Sustainable and Green Engine
SEL	Sound Exposure Level
SFWA	Smart Fixed Wing Aircraft
SGO	System for Green Operations
TE	Technology Evaluator
WP	Work Package

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