CLEAN SKY TECHNOLOGY EVALUATOR – NOISE ASSESSMENT AND EXPERIENCE AT AIRPORT LEVEL

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ABSTRACT

Clean Sky is a European Joint Technology Initiative that aims to develop and mature breakthrough 'clean technologies' for air transport. The Clean Sky goal is to identify, develop and validate key technologies necessary to achieve major steps towards the ACARE environmental targets for 2020.

Cross-positioned within the Clean Sky Programme, the Technology Evaluator (TE) is a dedicated evaluation platform. It has the key role of assessing the environmental impact of the technologies developed in Clean Sky and their level of success towards the ACARE environmental targets. TE assessments consider all promising green technologies selected by Clean Sky's ITDs (Integrated Technology Demonstrator projects in which these technologies are developed); not on a unitary basis, but grouped as clusters, identifying optimised new aircraft solutions named concept aircraft.

The approach in TE is to 'insert' concept aircraft into a number of evaluation scenarios. These concept aircraft are 'flown' (i.e. simulation scenarios are run) and their environmental performance is compared to that of reference technology aircraft. Such comparisons or assessments are performed at three levels: aircraft level (single aircraft flight), airport level (relevant airports to evaluate community impact), and air transport system level (global air transport system, evaluating global fleet).

For the airport level, a dedicated tool suite is developed to efficiently evaluate the Clean Sky environmental benefits, which is part of an overarching TE Information System. This tool suite links state-of-the-art airport models for simulating air traffic and assessing environmental impacts as well as aircraft models developed specifically by ITDs to represent the environmental performance of their concept and reference technology aircraft. On top it includes display facilities to graphically present the (environmental) differences between scenarios (in this case between a scenario without and with aircraft equipped with Clean Sky technologies in the fleet). Its focus is on the prime performance area for airport level: noise; but emissions are addressed as well.

In addition to this tool suite, activities at airport level have been initiated to exploit VCNS (Virtual Community Noise Simulator) for potential support of ITDs in selecting the most promising technologies and for potential dissemination purposes: VCNS enables people to experience the sound and visuals of aircraft flyovers in a virtual reality environment.

With the efforts now under way and the assessment results emerging, the TE airport-level tool suite is demonstrating to be a powerful facility, which, together with VCNS, provides clear opportunities for airport assessments beyond the scope of Clean Sky.

1 INTRODUCTION

Air transport moves over 2.2 billion passengers annually. The associated flights produce 628 billion tonnes of CO_2 [6], making aviation a small but important contributor to climate change as the contribution from aviation represents about 2% of human-induced CO_2 (and 12% of all transport sources). Furthermore these flights make that more than 2.6 billion people in Europe are exposed to significant noise levels (>55 dB L_{dn}) [5]. The challenge facing aviation is to meet the predicted growth in demand for air travel (increasing 4-5% per annum over the next 20 years) but to do so in a way that ensures that the environment (with respect to noise as well as emissions) is protected.

The aviation industry in Europe has long recognised this challenge and in 2001 the Advisory Council for Aeronautical Research and Innovation in Europe (ACARE) established the following targets for 2020 (compared to 2000) [1]:

- Reduce fuel consumption and CO_2 emissions by 50% per passenger kilometre;
- Reduce NO_X emissions by 80%;
- Reduce perceived noise by 50%;
- Make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products.

In the remainder of the text these targets will be referred to as the ACARE 2020 environmental targets.

ACARE has identified the main contributors to achieving these environmental targets. For instance, the predicted contributions to the 50% CO_2 emissions reduction target are:

- Efficient aircraft: 20-25%;
- Efficient engines: 15-20%;
- Improved air traffic management: 5-10%.

Also the noise target has been dealt with in more detail to associate it with representative goals:

- Reduction of 10 dB per operation (for fixed-wing aircraft);
- Limit noise nuisance to 65 dB L_{den} at airport boundaries (provided the appropriate management practices are in place).

The Clean Sky Joint Technology Initiative (JTI), born in 2008 and representing a Public-Private Partnership between the European Commission and the European aeronautical industry, is the most ambitious aeronautical research programme ever launched in Europe. Its mission is to develop breakthrough technologies to significantly increase the environmental performances of airplanes and air transport, resulting in less noisy and more fuel efficient aircraft, hence bringing a key contribution in achieving the ACARE 2020 environmental targets. Moreover, it aims to speed up these technological developments and shorten the time to market for new solutions tested on full-scale demonstrators. The Clean Sky JTI is expected to lead to the earlier introduction of new, greener products that will:

- Increase the competitiveness of the European industry;
- Bring a reduction in emissions, noise, and related impacts;
- Encourage the rest of the world to make greener products.

This paper deals with the environmental evaluation capability within the Clean Sky JTI (called Technology Evaluator) and focuses on the facility assessing the environmental benefits (and in particular noise) for communities in the vicinity of airports.

2 CLEAN SKY JTI PROGRAMME

The greening of aeronautics and air transport calls for a quantum leap in performance through a consistent, coherent and holistic approach focusing on the integration of advanced technologies and validation of results in a multidisciplinary approach leading to full-scale ground and flight demonstrators. Technologies allowing for the step change have to be concurrently developed, integrated and validated to maximise the benefit of technology interaction and cross fertilisation on the whole air transport system.

The Clean Sky JTI Programme, with a budget estimated at € 1.6 billion equally shared between the European Commission and industry, and running from 2008 until 2016, organised these technologies into six main themes called Integrated Technology Demonstrators (ITDs), that cover the broad range of research and technology work:

- Smart Fixed-wing Aircraft (SFWA), which is dedicated to new concepts for large passenger aircraft and business jets, will deliver active wing technologies and new aircraft configuration for breakthrough, new products;
- Green Regional Aircraft (GRA), which is dedicated to new concepts for regional aircraft, will deliver low-weight aircraft using smart structures, as well as low external noise configurations and the integration of technology developed in other ITDs, such as engines, energy management and new system architectures;
- Green Rotorcraft (GRC), which is dedicated to new concepts for rotorcraft, will deliver innovative rotor blades and engine installation for noise reduction, lower airframe drag, integration of high compression engine technology and advanced electrical systems for elimination of noxious hydraulic fluids and fuel consumption reduction;
- Sustainable and Green Engines (SAGE), which is dedicated to new engine concepts, will design and build five engine demonstrators to integrate technologies for low noise and lightweight low pressure systems, high efficiency, low NO_X and low weight cores and novel configurations such as open rotors and intercoolers;
- Systems for Green Operations (SGO), which is dedicated to the management of aircraft energy, trajectory and mission, will focus on all-electrical aircraft equipment and systems architectures, thermal management, capabilities for 'green' trajectories and mission and improved ground operations to give any aircraft the capability to fully exploit the benefits of Single European Sky;
- Eco-Design (ECO) will focus on green design and production, withdrawal, and recycling of aircraft, by optimal use of raw materials and energies thus improving the environmental impact of the whole products life cycle and accelerating compliance with the REACH directive.

New technologies developed within ITDs are evaluated stand-alone inside the ITDs, and, depending on the maturity or technology readiness level that is achieved, these can go from simulations only to ground or flight tests. However, from the beginning it was recognised that successfully monitoring progress towards the ACARE 2020 environmental targets would require a cross-cutting platform in the Clean Sky Programme. The Technology Evaluator (TE) project was born from this need. Figure 1 displays the organisation of the Clean Sky JTI.

Figure 1: Organisation of Clean Sky JTI [Source: Clean Sky JU [4]]

3 CLEAN SKY TE

The main role within the Clean Sky JTI of TE is to assess the environmental impacts of new technologies developed in the ITDs and their level of success towards the ACARE 2020 environmental targets. In addition TE builds and demonstrates an effective information system that enables the Clean Sky community to access results of these environmental assessments and track developments. Finally, upon ITD's request, TE provides support to ITDs to identify interdependencies of impacts, providing input to the selection of most promising 'green' technologies by ITDs.

The TE consortium consists of the ITD leaders (Airbus and Saab from SFWA, AleniaAermacchi and Airbus Defence & Space from GRA, AgustaWestland and Airbus Helicopters from GRC, Rolls-Royce and Snecma from SAGE, Thales and Dassault from SGO, and Liebherr and Fraunhofer from ECO) and the research establishments DLR, ONERA, NLR, CIRA and Cranfield University.

3.1 Approach

The Clean Sky's ITDs identify, develop and validate promising 'green' technologies necessary to achieve major steps towards the ACARE 2020 environmental targets, and monitor their performance and their progress in terms of maturity (or technology readiness level). The TE considers all promising 'green' technologies selected by ITDs; not on a unitary basis, but 'clustered' in coherent and mutually compatible solution sets that define potential future aircraft, named concept aircraft. The approach in TE is based on 'inserting' concept aircraft into a number of evaluation scenarios. These concept aircraft are 'flown' (i.e. simulation scenarios are run) and their environmental performance is compared to the most relevant benchmarks: reference technology aircraft, and most importantly the state-of-the-art aircraft of similar size and role in the year 2000 (ACARE's baseline year). The TE carries out assessments of Clean Sky's 'green' technologies roughly on a yearly basis, with the first one carried out in 2012, following the drumbeat of ITDs' developments of technology integrated into concept aircraft. These yearly results provide insight in the developments in both the environmental performance and the maturity level of Clean Sky technologies.

From the outset the TE was constructed as a 'federated system' of simulation and modelling; and this was a conscious choice. Doing so enabled all contributing 'constituencies' in the evaluation process to work to their strengths. And importantly, it allows proprietary technology and design information to reside with its owners, and this is of great importance in terms of safeguarding competitive know-how. So the TE as a vehicle really pulls together a much broader and more dispersed technology evaluation effort that cross-cuts the whole of Clean Sky. The TE can be thought of as an information hub. Throughout the Clean Sky Programme's duration, all of Clean Sky's concept aircraft will pass through this hub; leaving as footprint a valuable picture of the gains in environmental performance that the joint public-private investment in Clean Sky JTI will make possible in aircraft of the future.

Table 1 gives an overview of concept aircraft (fixed-wing), with the main technologies integrated into these aircraft, that have been considered in the 2014 assessment.

Business jet	
Low-sweep business jet	▪ Natural laminar wing ▪ U-tail for noise optimisation ▪ 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 (TP) 90 seats aircraft	▪ Advanced Composite Materials and SHM ▪ Low noise landing Gears and High Efficiency High Lift Devices ▪ Electrical Environmental Control System
Geared Turbofan (GTF) 130 seats aircraft	▪ Advanced Composite Materials and SHM ▪ Natural Laminar Flow Wing ▪ Advanced Geared Turbofan Engine
Large passenger aircraft	
Small-medium range aircraft	▪ Natural laminar flow wing ▪ Contra-rotative open rotor engine
Long range aircraft	▪ Advanced 3-shafts turbofan engine

Table 1: Clean Sky concept aircraft (fixed-wing) with main technologies integrated (2014 assessment)

3.2 Assessment levels

The assessments in TE are conducted at three levels:

- Aircraft level
  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). More information on aircraft-level assessments and results can be found in [3].
- Airport level
  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 in the relevant seat classes. 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 (CO_2 and NO_X).

- Air transport system (ATS) level
  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 classes 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.

The three assessment levels together comprehensively demonstrate the Clean Sky progress towards the ACARE 2020 environmental targets. Aircraft level could be considered as the most direct aircraft-to-aircraft comparison for a single flight, whereas airport and ATS level address more 'complex' impacts for communities and regions.

The TE's ability to build reliably simulation scenarios of future Clean Sky technology benefits hinges on 'capturing' the performance technologies selected and design options exercised in the concept aircraft. A key challenge for TE was to carry out an independent assessment of the innovative concept aircraft designed in Clean Sky's ITDs, while maintaining strict industrial confidentiality. Thanks to the close cooperation between the TE and ITDs, TE can perform its assessments while fully respecting the confidentiality of industrial data and models.

4 CLEAN SKY TE – NOISE ASSESSMENT AT AIRPORT LEVEL

The airport environment represents a key aggregate-level evaluation. As is known, to a very large extent, noise nuisance and increasingly local air-quality issues are contained within the wider airport surroundings. Taking stock of the range of impacts that future aircraft could have therefore requires addressing the highly interdependent and complex system-of-systems nature of (major) airport operations. The TE addresses this by inserting concept aircraft into airport-level traffic forecasts and assesses the gains made possible. Importantly, for a realistic evaluation of air traffic at and around airports, day-to-day airport and air traffic control operations related to, for instance, arrivals and departures, aircraft separations, and runway and taxiway usage, need to be accommodated in the underlying models and built into the evaluation. The impact of flight procedures on airport capacity is investigated in order to validate that their application is realistic and the connected potential of emission and noise reduction is feasible.

4.1 Approach

The airport-level assessment aims to quantify the environmental benefits of Clean Sky technology for the full range of European airports. Its approach can be sketched as follows. Airport categories have been defined, and illustrative airports have been selected for each category. These illustrative airports are modelled, including their operations to ensure a realistic airport (simulation) environment. Within this environment air traffic at and around the airport is simulated. Based on this simulated air traffic CO_2 and NO_X emissions in the vicinity of the airport are calculated, using (amongst others) aircraft data and models provided by ITDs. Noise levels are calculated as well for the simulated air traffic, once again making use of (amongst others) the data and models from the ITDs, leading to an expected noise contour in the airport surroundings and ultimately the population impacted.

Next, this simulation approach for fixed-wing aircraft is elaborated further, focusing on noise assessments as noise is regarded as the prime environmental indicator at airport level. In this approach the airport traffic scenarios, the data and models, and the models workflow are addressed.

4.1.1 Airport traffic scenarios

In an airport-level assessment two scenarios with year 2020 aircraft traffic are considered for each of the illustrative airports. Both year 2020 airport traffic scenarios are based on the fleet and traffic development since ACARE's baseline year 2000. The first year 2020 airport traffic scenario contains no concept aircraft (but reference technology aircraft) and the second one contains concept aircraft, which replace all reference technology aircraft in the relevant seat classes in the first scenario. Thus a 100% replacement rate is assumed to highlight the full environmental potential of concept aircraft.

4.1.2 Data and models

In the airport-level assessment the following models are used:

- Airport simulator
  To simulate aircraft traffic at and around an airport an airport simulator (AirTOp) is used. The simulator model is fed with three classes of data. The first class is airport data like airport layout, airport routes and procedures, and airport and air traffic control operations. The second class is flight schedule data; for example, per flight the aircraft type and reference time of arrival/departure. The third class of data concerns aircraft performance characteristics in order to represent the aircraft technical capabilities realistically (e.g. with respect to speed, climb/descend rates, and acceleration/deceleration) in the simulation. For concept aircraft and their reference technology counterpart these latter data are provided by ITDs.
  The airport simulator generates a realistic traffic output, including metrics with respect to airport capacity, to indicate the feasibility of the connected potential of noise (and emissions) reductions, and for each flight a 4-dimensional (4D) trajectory.
- Noise models
  The trajectory output of the airport simulator is used to calculate the noise contribution per flight in sound exposure level at the points in a pre-specified grid around the airport. Depending on the aircraft type one out of two types of noise models is used:
  - TE model
    If the flight concerns an existing aircraft, the noise contribution of the associated aircraft is calculated by an NLR noise model, which is fully compliant with the Doc.29 methodology and which processes the 4D trajectory of this aircraft.
  - ITD model
    If the flight does not concern an existing aircraft, it is a reference technology or concept aircraft. In that case the aircraft model from the associated ITD uses the 4D trajectory of this aircraft to calculate the noise contribution of the flight.

  The noise results (i.e. noise levels in grid points) per flight are aggregated over all flights in order to calculate L_{den} levels. From these levels noise contours for specific levels (usually 48-65 dB L_{den}) and, by using the population density database from the European Environmental Agency (EEA), the population exposed to each of these levels can be determined.
- Emissions models
  The calculation process of pollutants emitted (CO_2 and NO_X) is analogous to the one for noise: instead of an NLR noise model and ITD noise models, an NLR emissions model and ITD emissions models are applied.

4.1.3 Simulation framework

To efficiently and effectively perform the airport-level assessments, the models listed in the preceding subsection have become part of a dedicated tool suite. This tool suite smartly connects the models for simulating airport traffic and for calculating aircraft noise and emissions, and it includes pre- and post-processing tools to convert data formats, to exchange data between models and to aggregate data from individual flights and models. The web-based tool suite is built on the system developed in the SPADE Programme (see, e.g. [7]). More specifically, it provides user guidance to perform what-if analyses (e.g. what are the environmental effects of the introduction of Clean Sky technology into an airport fleet?), and consists of three main building blocks: input, output, and computational components.

The input component provides a graphical user interface to specify the assessment at hand in a menu-driven way, i.e. pre-structured, tool-independent, and assessment-oriented. For instance, it enables the specification of an assessment (such as the selection of the airport, the airport traffic scenario or flight schedule, and the metrics of interest) in a user-friendly and intuitive way.

The computational component constitutes the core of the integrated tool suite. Based on the specified assessment, it activates the relevant models and takes care of the conversion of data, the exchange of data between the models, and the aggregation of data from individual flights and models. Furthermore, it also encapsulates the data bases of the models as well as of the tool suite.

The output component provides graphical user-interface elements to display the results of an assessment with respect to, for instance, noise and emissions. Moreover, it includes facilities to graphically present the (environmental) differences between scenarios; think, for example, of the differences in noise contours for a certain noise level between a scenario without and with aircraft equipped with Clean Sky technologies, with the noise contours superimposed on a geographical map (like Google maps). Figure 2 shows an example.

Further, the airport-level tool suite is part of an overarching TE Information System (Figure 3). This Information System is designed to be a unique tool to 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. A more extensive description of the TE Information System can be found in [2].

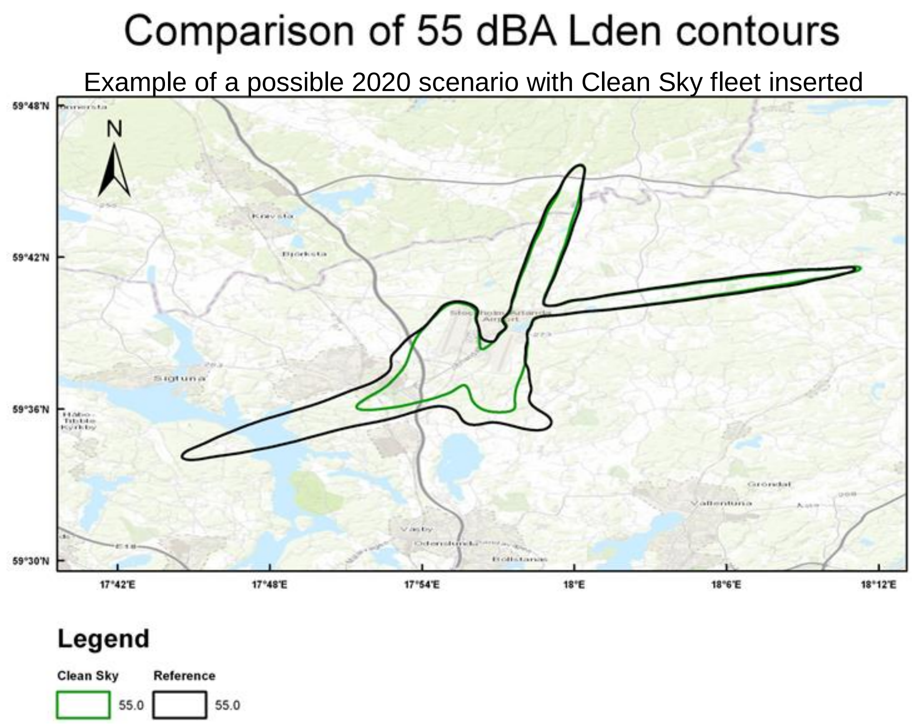

Figure 2: Clean Sky's airport-level tool suite: Comparison of noise contours for certain noise level between two scenarios (provisional result 2012 assessment)

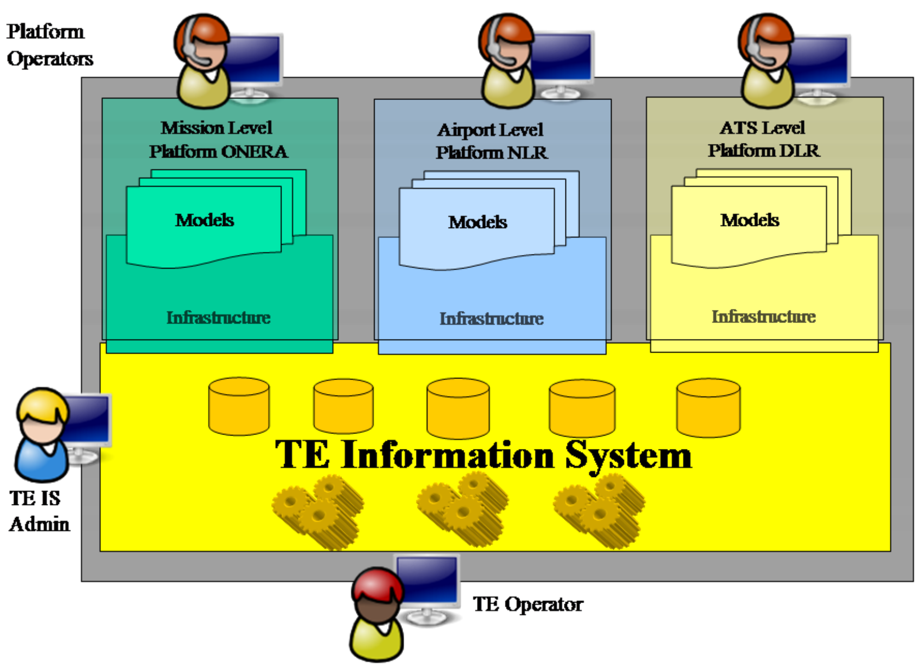

Figure 3: Clean Sky's TE Information System: It consists of three platforms (one for each assessment level) residing in different locations; each platform offers an interface for storing / retrieving data in the underlying TE data storage

4.1.4 Virtual Community Noise Simulator

Within Clean Sky several initiatives are directed towards obtaining quieter aircraft flyovers by adapting innovative noise reduction technology to the aircraft or by implementing noise abatement procedures. Noise results of these approaches are not always best assessed on paper, especially when communicating with stakeholders. Therefore, activities are initiated at airport level to exploit the NLR's Virtual Community Noise Simulator (VCNS).

By means of the VCNS quick simulations of noise generated by aircraft flyovers can be performed, which adds to the impact of a noise result. The flyover noise is coupled in real-time to a virtual environment in which the test person is submersed. As a result the experience (both audible and visual effects) of the flyover noise as perceived, is simulated realistically, under varying atmospheric conditions, as if the person is in the 'real' world standing on the ground (see Figure 4).

These simulations with VCNS can be based on either recordings or so-called auralisations. Recordings determine the authenticity of the simulation, and fixes atmospheric conditions and the aircraft trajectory. Digital processing techniques can be used to circumvent these restrictions. Auralisations are transformations of an aircraft noise prediction, without a recording, into an audio signal.

NLR's VCNS can be used to assess the actual audible impact on the ground of novel aircraft, low noise technology and noise abatement procedures emerging from Clean Sky, compared to today's or reference technology aircraft. It offers new ways to actually listen to and experience future aircraft scenarios in a virtual reality environment, rather than studying deduced aircraft noise contours. As such it provides clear opportunities to evaluate Clean Sky technologies (including effects of atmospheric conditions) to support the selection of the most promising aircraft designs, as well as opportunities to demonstrate the expected noise benefits of these technologies to industry, European Commission, communities and other stakeholders.

Figure 4: Experiencing noise of flyover with NLR's Virtual Community Noise Simulator

5 CONCLUSION

Clean Sky's TE is a key ingredient 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 airport-level assessments.

With the efforts well under way and the assessment results emerging, the TE airport-level tool suite is demonstrating to be a powerful facility to efficiently and effectively perform assessments and to present assessment results. Furthermore, activities at airport level have been initiated to exploit VCNS for potential evaluation and even dissemination purposes: VCNS simulates aircraft flyovers in a virtual environment to enable people to experience the sound and visuals for aircraft flyovers as if they are in the 'real' world standing on the ground.

Both the airport-level tool suite and VCNS provide clear opportunities for comprehensive airport assessments, even beyond the scope of Clean Sky.

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

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NOMENCLATURE

ACARE	Advisory Council for Aeronautical Research and Innovation in Europe
CAEP	Committee on Aviation Environmental Protection
ECO	Eco-design
EEA	European Environmental Agency
GRA	Green Regional Aircraft
GRC	Green Rotorcraft
ICAO	International Civil Aviation Organisation
ITD	Integrated Technology Demonstrator
JTI	Joint Technology Initiative
JU	Joint Undertaking
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SAGE	Sustainable and Green Engines
SFWA	Smart-fixed Wing Aircraft
SGO	Systems for Green Operations
SHM	Structural Health Monitoring
TE	Technology Evaluator
VCNS	Virtual Community Noise Simulator