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1. Final publishable summary report

1.1. Executive summary of the OPENAIR project

As part of the European 7th Framework Program, OPENAIR started on 1st April 2009 as a program on aircraft noise reduction with a total budget of 30 million Euros, 60% funded by the European Commission. The project objective was to deliver a 2.5 dB noise reduction at TRL5 for both engine- and airframe noise sources, beyond the SILENCE(R) achievements. To do so, OPENAIR focused on validation of so-called “Generation 2 technologies”, such as electronically assisted solutions, designs exploiting improved Computational Aero-Acoustics and new affordable absorbing materials. Incorporated in the work were trade-off studies on engine cycles, turbomachinery- and nacelle aerodynamics and acoustic liner design. Solutions included active/flow control control techniques with parallel studies on mechanical integration and manufacturing.

The engine noise technologies focused on both the turbomachinery design by creating a low noise signature at the source as well as optimizing the attenuation/re-direction of the sound through innovative nacelle configurations:

Among the technologies validated by OPENAIR are MDO Outlet Guide Vanes (OGVs) and acoustically lined OGVs as well as an active noise control OGV system, with loudspeakers in the stator vanes that showed capability of both forward- and rearward radiated fan noise control.

A “Folded Cavity” inlet liner performed well thanks to a large space that is folded behind the conventional liner. The highly curved bypass duct technology proved beneficial through improved noise attenuation characteristics thanks to adapted duct shape.

Many configurations of supplementary liner area in the bypass duct were tested, both “splitters”, who fully cover the duct height, as well as so-called “fins”, who protrude halfway into the duct.

For changing the directivity of the rearward radiated fan noise the Scarfed nozzle technology proved successful and the “Microjet” technology reduced jet noise by blowing air at the nozzle exit.

Under the Airframe Noise sub-project, technologies were developed that focused on the main landing gear and on wing slats and flaps:

A low noise landing gear design grouped all efforts to design landing gear components to a low noise configuration. Among these, the aft placed deceleration plate worked well in reducing the velocity upstream in the gear structure and thereby reducing noise.

In the adaptive slat concept, a morphing trailing edge of the slat that could fully close the gap between the wing and the slat enabled quiet operation. On the flaps, porous flap side edges performed well during large scale wind tunnel testing.

In September 2014, the OPENAIR project with their 47 partner strong consortium ended after 5.5 years of fruitful collaboration. Working on noise reduction technologies for both engine- and airframe related noise sources, a total of 15 technologies were validated to TRL4/5 through large scale testing on fan rigs, jet noise facilities and wind tunnels. The technology evaluation of OPENAIR showed through an airport impact study that the combined benefit of these technologies could bring an average of 2.3 dB reduction per operation.

1.2. Summary of OPENAIR project context and objectives

The aerospace industry has significantly grown over the years as more and more people are using air transport to travel for business or pleasure. These growing numbers of airplanes have put pressure on the public acceptance with respect to its environmental impact and in particular the noise aspects.

Although enormous noise reductions have been achieved in the past, continued improvement of the noise climate is required to mitigate annoyance as much as possible. Therefore, in the year 2000, a “group of personalities” had formulated a number of challenging goals for the aerospace industry, including several environmental goals. For “noise” an objective for 2020 was set to reduce noise caused by aircraft by half. ACARE (the Advisory Council for Aeronautics Research in Europe) then translated this
objective in a 10 dB reduction per aircraft operation (departure or arrival). This objective is now known as one of the ACARE noise objectives for 2020.

Around the same time, in 2001, a major review undertaken within the ICAO Committee for Aviation Environmental Protection (CAEP), led to the implementation of the more stringent Chapter 4 noise limits, effective as of January 2006. As another significant outcome of the process, recommendations were made in favour of a “Balanced Approach” encompassing four elements: reduction of noise at the source, land-use planning, noise abatement procedures and aircraft operating restrictions. This concept implies the elaboration and implementation of a process meant to help the assessment and resolution of noise problems at airports in the most cost-effective manner. The “reduction of noise at the source” element of the Balanced Approach has been the key objective of the OPENAIR project.

In the late 90’s, several aircraft noise projects made significant progress under the coordination of the X-Noise network. Projects like RAIN (airframe noise), RANTACC (Nacelle acoustics) and RESOUND (turbomachinery noise) delivered results up to TRL3. For a next step, to achieve TRL5-7, these projects and several others were combined into a follow-up project called SILENCER that ran from 2001 to 2007. While SILENCER delivered about 10 fully matured “Generation 1” technologies, it also performed some work on more advanced methods and techniques. These so-called “Generation 2” technologies were based on continuously improved Computational Aeroacoustics as well as electronically assisted solutions. The OPENAIR project, has continued this work started in SILENCE(R), while incorporating a multi-disciplinary design approach. For the more unconventional technology solutions in the project, intensive engine and aircraft integration studies were set up to be followed by large scale fabrication there where new materials or new manufacturing methods were needed.

Progress towards the noise objective up to now has been achieved thanks to many projects that have been completed since the year 2000. A large contribution came from the SILENCE(R) project that proved a 5 dB reduction, based on 10 new noise technologies, combined with the application of improved noise abatement procedures. OPENAIR aimed to achieve another 2,5 dB reduction based on a new set of technologies that could provide a step change in source noise reduction. This step change is pictured in Figure 1, where the “generation 2” technologies from OPENAIR, together with results from new engine – and aircraft architectures are foreseen to complete the gap to the achievement of the ACARE noise goal. OPENAIR plans to validate these technologies up to TRL5.

![Figure 1: Steps to ACARE Noise goal](image)

Besides these quantitative objectives, OPENAIR also aimed to verify the practical applicability of its technologies over a range of products ranging from business- to long range aircraft as well as future aircraft configurations.
1.3. Main Scientific & Technical results from OPENAIR

More than 50 technology developments have taken place in OPENAIR, all executed around a number of key technologies identified at project start. From this set, 15 technologies have achieved TRL4/5 through large scale testing in wind tunnels and dedicated engine fan- or exhaust rigs.

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Figure 2: 15 OPENAIR technologies matured to TRL4/5

Part of the 50 technology developments were organized as risk-reduction, back-up or long term solution related to the key technologies. A total of 144 low TRL ideas were collected before project start in an “innovative concepts” database from which the project selected 19 for inclusion in OPENAIR. This approach was perceived as very successful for OPENAIR and other related projects and will be proposed for best-practice in the future. A selection of the examined technologies is described in the sections below.

1.3.1 Engine Noise Technologies

The engine noise reduction was covered in the 2 of OPENAIR sub-projects and includes both engine source noise reduction techniques as well as noise suppression techniques among which nacelle modifications. Under the Integrated Propulsion System Design sub-project, the following technologies were developed:

1.3.1.1 MDO Outlet Guide Vanes (OGVs) and Lined OGVs

Both the Multi-Disciplinary Optimized (MDO) OGVs and the Lined OGVs have been designed with a large reduction of the number of vanes (~10) compared to the traditional configuration (~40). This allowed design space for (thin) special shapes as explored under the MDO OGV design, or (thicker) designs that allow internal space for acoustic liners as seen for the lined OGVs. Design objectives balance aero performance and acoustic design. Both broadband- and tonal noise sources were lowered while leaving the aero performance unchanged. All designs were tested on the large scale AneCom Aerotest UFFA fan rig with engine style representative fan.

Figure 3: Lined- and MDO OGVs
1.3.1.2 Intake Technologies

Various new inlet liner concepts, based on recent advancements in Computational Aero Acoustic (CAA), have been developed and tested on a fan rig. Among the configurations tested are a “Folded Cavity Liner” which has a geometry that allows low frequencies to be damped through a large space that is folded behind the conventional liner. In this way lower nacelle thickness can be used compared to conventional designs. A “Segmented Liner” has also been tested on the large scale AneCom Aerotest UFFA fan rig where the first 25% of the inlet lining (measured from the fan face) was configured as a conventional deep liner. Forward fan noise reductions have been achieved, besides a significant reduction of the buzz-saw noise, which is an annoying noise source also audible in the cabin.

![Figure 4: Folded-cavity liner impedance model and fan rig liner design](image)

1.3.1.3 Highly Curved Bypass duct

The highly curved bypass duct seeks to push out the duct earlier to a higher radius. As the duct cross sectional area is conserved this results in a reduced height duct with a greater liner area per unit length. Reduced height ducts are more effective at noise absorption. These attributes allow a shorter nacelle to be used giving significant reductions in weight and drag.

![Figure 5: Highly Curved Bypass duct configuration in Anecom Aerotest UFFA fan rig](image)

1.3.1.4 Acoustically lined splitters

Many configurations of supplementary liner area in the bypass duct were designed and several were tested on the large scale AneCom Aerotest UFFA fan rig. Bringing extra structures in this area come with new challenges, but may provide a solution to the acoustic area loss when shorter nacelles are desired in the future. OPENAIR has tested both “splitters”, who fully cover the height between the inner and the outer wall, as well as so-called “fins”, who protrude from the outer wall up to halfway the duct height.
1.3.1.5 Negatively Scarfed Nozzles

The scarfed nozzle have been designed for the secondary nozzle of both short- and long cowl nacelles. The scarfed shape is changing the directivity of the rearward radiated fan noise to higher angles and provides a global reduction on the total engine noise. The test vehicle in the QinetiQ large scale exhaust Noise Test Facility was equipped with a hot air primary jet stream and water cooled speakers in the secondary duct for fan noise simulation.

1.3.1.6 Innovative active/adaptative technologies

Several innovative active/adaptative technologies were investigated for engine noise reduction. For fan noise concern, the potential of advance concepts on sensors, actuators and active lining were evaluated. The principles were verified in simulations and lab tests.

Jet noise concepts based on fluidic injection, mechanical actuators, resonant cavities, or plasma actuators were also investigated during lab scale test campaigns. According to the Jet noise reduction achieved, the fluidic microjets were selected to the large scale tests campaign.

A 3D adaptive chevron with shape memory alloy wires (SMA) has been successfully demonstrated. The feasibility of controlling the position using a PID controller has been notably proven.
1.3.1.7 Active Stator

Following a successful start of the research efforts on this active noise control technology in the SILENCE(R) project, OPENAIR followed up with improved actuators, sensors and algorithms. Objectives were extended to include also rearward fan noise control, besides the already demonstrated forward fan noise control. The new system has been validated in the RACE fan rig. Integration aspects of this technology have been largely matured through full scale demonstrator OGVs.

1.3.1.8 Active Nozzle

Under the Active Nozzle jet noise technology activity, various active flow/noise control concepts have been explored before selecting one for large scale testing at the CEPRA19 facility in France. The validated concept concerned the “Microjet” technology based turbulences caused by air blowing at the nozzle exit. Extensive integration studies have been performed on the air supply through the nacelle to the primary and secondary nozzle.
1.3.2 Airframe Noise Technologies

Under the airframe noise sub-project, technologies were developed that focus on the main landing gear and on wing slats and flaps:

1.3.2.1 Innovative technologies

Innovative technologies were explored during Openair project in order to address disruptive solutions for airframe noise reduction. Those technologies were investigated during small scale test campaign and the noise reduction potential was assessed. Decision to go to the large scale tests campaign was decided based on the noise reduction achievement and maturity of the technology for full scale test.

**Landing gear innovative technologies:**

- The deceleration plate (DP) is an structure placed downstream of complex gear structures. Strategically placed, these objects will reduce the velocity upstream in the gear structure and thereby reduce noise generation without negative flow displacement effects. Reductions were found in the broadband noise of the landing gear.

![Figure 12: Preliminary landing gear testing at small scale](image)

- The splitter plate is a structure attached to the rear of bluff body gear components. This plate has the function to reduce the noise originating from local flow separation. The noise reduction induced by the splitter plate was assessed during small scale test and only small noise reduction was achieved with the broader plate.

![Figure 13: preliminary landing gear testing with splitter plate](image)
Wing innovative technologies:

- Low-noise trailing edge design were assessed on a NACA0012 airfoil, those technologies are of interest for application. The understanding of the mechanisms and scaling dependence need to be improved prior to large scale test.

![Figure 14: Low noise trailing edge](image)

- Slat hook serrations were proposed for slat noise reduction. Different serration design were tested, the effect on noise reduction was not confirmed for a full scale application.

![Figure 15: preliminary test of slat hook serrations](image)

- Low noise spoiler concepts were studied: fractal spoilers and splitter plate concept. The splitter plate concept provided a significant noise reduction and should be further investigated with more parametric tests including flap setting, length of splitter plate in future projects.

1.3.2.2 Low-noise landing gear

This OPENAIR technology groups all efforts to adapt the detailed design of all landing gear components to a noise and aero optimized configuration. Besides technologies from TIMPAN project (hub caps, brake fairings and mesh fairings), the test gear was equipped with a rectangular torque link in front of the leg, electric dressings and solid covers for drag stay and leg cavity. Tests at full scale at the DNW-LLF facility were carried out on both wing mounted, as body mounted landing gears. A total number of 14 body gear configurations and 15 wing gear configurations were tested at large scale in DNW LLF. The investigation on the deceleration plate as promising noise reduction technology for the wing gear was further investigated at small scale in DLR-AWB.

Amongst all tested configurations, the following ones showed the highest EPNL reductions, and should be considered as low noise configurations:

- For the body-mounted gear:
  - Torque ling mesh fairing.

Also the deceleration plate between wheels with closed dressing cut-out turned out to be an efficient noise reduction technology when considered isolated with respect the baseline condition. Nevertheless, its impact is quite negligible when associated with a torque link mesh fairing, so that it is not worth the associated mass increase.
• For the wing-mounted gear:
  o Low-noise dressing routing;
  o Forward location for cardan pin;
  o Torque link mesh fairing;
  o Door aligned with flow;
  o H-shape side-stay with spring and big side-stay mesh fairings.

The deceleration plate showed significant noise reduction, its optimisation against integration criteria was proposed. The study led to an optimised version of the deceleration plate and significant noise reduction.

Figure 16: Deceleration plate and torque link mesh fairing (TIMPAN)

1.3.2.3 Adaptive slats

In the adaptive slat concept, the trailing edge of the slat is a flexible morphing structure that can fully close the gap between the wing and the slat. In normal operation with low angle of attack, the gap is closed and quiet. When Clmax is required or high angles of attack, the gap opens for maximum aircraft performance.

The adaptive slat (closed gap) provides a broadband noise reduction of up to 5 dB at wing level, equivalent to a full elimination of the slat noise source at the F15-LS high-lift large scale model in the DNW-LLF.

Figure 17: Adaptive Slat geometry and aero performance
1.3.2.4 Low-Noise Slat Settings

In this non-morphing concept, the slat/wing gap/overlap is optimized for aero- (Clmax) and aeroacoustic performance. Modified slat settings with intermediate gap width are suited to reduce slat noise by about 3 dB at F15-LS large scale wing level while producing negligible aerodynamic impact at the operative test angles of attack within the linear region of the lift polar.

![Figure 18: Gap/overlap optimization for wing slat.](image)

1.3.2.5 Porous flap-side edge

Various acoustically porous materials were evaluated for their environmental (certification) requirements before a final selection was manufactured for large scale acoustic testing at the DNW LLF wind-tunnel. The PFSE was identified as effective means to reduce FSE noise without any significant aerodynamic penalty: A 5-dB FSE noise reduction was measured at the F15-LS model. Transposed to flight conditions for a short range aircraft, due to the low-weighted contribution of the FSE to the overall aircraft certification noise levels, the gained effect is negligible if this technology is solely applied. A higher benefit will be obtained with PFSE used in combination with low noise slat technologies. The noise reduction obtained by PFSE at source level makes this technology relevant for application on Aircraft with significant flap noise.

![Figure 19: Porous flap side edge in DNW wind-tunnel](image)

1.3.3 Technology evaluation

All technologies that have successfully matured to TRL5 during the project have been subject to the technology evaluation process. By using performance and noise models, the TE process has evaluated the benefits of the new technology concepts developed in the project with the integrated technologies fitted into “Virtual Platforms” representing current and potential future market segments. See Figure 16.
Depending on the characteristics of engine or airframe in the evaluation matrix, a technology package has been adapted to each virtual platform.

Since 2001, this approach has proven to be a valuable tool for decision making, as it allowed assessment of the environmental benefits of the low noise technologies, in balance with aircraft performance and design constraints over a wide range of typical engine/aircraft configurations. It is also able to determine the maximum noise reduction achievable by a package of low noise technologies on current or future products with minimum weight, performance and industrial risk. In order to identify potential global benefits from the OPENAIR project, the TE process has concluded with an airport impact assessment on a major European airport.

Indeed the environmental impact of OPENAIR Low Noise Technology (LNT) has been assessed on an airport scale using Amsterdam Airport Schiphol (AAS). The current AAS fleet is replaced by the OPENAIR aircraft platforms equipped with advanced turbofans engine (Short-Medium Range (SMR) and Long Range (LR) platforms with EP2 engine) with and without OPENAIR best low noise technologies package.

This allowed assessing the noise benefit brought by the OPENAIR low noise technologies at airport footprint noise level.

Results are expressed in LDEN footprints (Level Day Evening and Night) at 50dB(A), calculated by the Integrated Noise Model (INM) on Figure 17.
These results correspond to a noise reduction brought by the OPENAIR technologies equal to:
- 2.3 dB at LDEN contour level, per average operation
- 49% reduction of noise impacted people

Both results are based on the average reduction resulting from 45, 50, 55, 60 and 65 Lden footprint analysis.

This shows that the potential noise reduction brought by OPENAIR technologies allows a significant progress further to previous technology programs such as SILENCE(R) and VITAL towards the 2020 ACARE objective.

However novel aircraft/engine architectures have to be addressed to fully comply with this objective.
1.4. Potential impact and the main dissemination activities & exploitation of OPENAIR results

The OPENAIR results strongly contribute to the competitiveness of European aircraft-, engine- and system suppliers. The noise performance of products is of increased importance given the public reaction to the ever expanding air transport system. Inhabitants impacted by air transport become more vocal and express their discomfort with the noise environment created by aircraft. Although other pillars of the balanced approach like noise abatement procedures and land use management are also being worked on, the largest progress to the improvement of the noise environment is coming from the “reduction of noise at source” to which OPENAIR has contributed. With 15 technologies matured to TRL4/5, the basis is laid for a final research step to achieve TRL6 through follow-on activities.

Some projects for exploiting the OPENAIR results have already been started, like the AFLONEXT project. Others are being progressed in national or company funded projects. Other opportunities for TRL increase will be pursued in the European Framework program “Horizon 2020”.

Once at TRL6, the OPENAIR solutions will be ready for implementation in new European aircraft, engines and systems like landing gears.

Dissemination of the OPENAIR results will be done through presentations at conferences like Internoise, AIAA/CEAS Aeroacoustics, Aerodays 2015, technology related magazines like Clean Sky’s “Skyline”, and websites of participating companies, as well as the X-Noise website which hosts an OPENAIR page.

1.5. Public website and contact details of the OPENAIR project

1.5.1 Public website

http://openair.xnoise.eu

1.5.2 Contact details

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