“Aircraft Noise Reduction Technologies and Related Environmental Impact”

ARTEM

Project Overview and

Achievements at Month 24

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1. General information and project objectives

"ARTEM" – stands for **A**ircraft noise **R**eduction **T**echnologies and related **E**nvironmental i**M**pact.

ARTEM is a four-year research project, started in December 2017, and is devoted to the development of novel noise reduction technologies for low-noise 2035 and 2050 aircraft configurations.

The project was set up in order to help closing the gap between noise reductions obtained by current technologies - as already applied or being matured in large EC technology projects such as OpenAir and CleanSky - and the long-term goals of ACARE, i.e. a noise reduction of 65% for each aircraft operation in year 2050 compared to the reference year 2000 value.

Therefore, ARTEM takes up innovative ideas and concepts for efficient noise reduction by novel liner concepts and investigates the potential of dissipative surfaces as encountered with the development of meta-materials. The aim is to develop those "Generation 3" noise reduction technologies (NRTs) to a technology readiness level (TRL) of 3 (experimental proof of concept) to 4 (technology validated in lab).

Within the project it is taken into account, that future aircrafts, anticipated to be introduced between 2035 and 2050, might have different configurations than the current tube-and-wing design with underwing–mounting of the engines. For 2035, the tube-and-wing layout could persist while the engine placement might differ, e.g. being semi-buried in the fuselage. For the 2050 time frame, blended wing-body aircrafts with very high bypass ratio (BPR≥16) may power long-range aircrafts, while regional aircrafts might exhibit hybrid propulsion systems or distributed electric propulsion system.

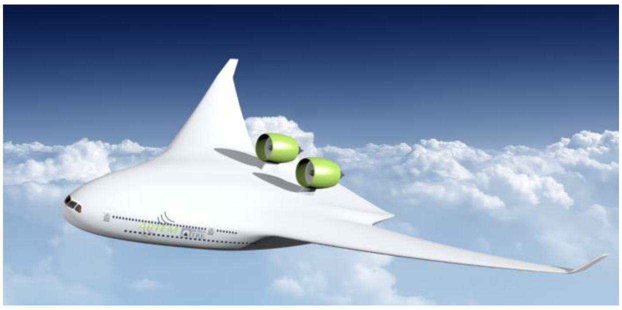



Figure 1: Left: *A possible candidate for 2035 air transport: ONERAs NOVA concept with semi-buried engine (© ONERA, 2015). Right: Initial layout of a blended wing body anticipated for 2050 operation, equipped with generic UHBR engines mounted on pylons on the top of the centerbody (© University RomaTre, 2018).*

The noise signature of the anticipated configurations will be strongly influenced by the interaction of several aircraft components: the interaction of airframe, high-lift-system, and propulsive jet of the engine(s), the interaction of airframe and engine inlet, the interaction of the landing gear with the airframe. These effects – which directly involve the noise generation - will be investigated in the ARTEM framework by dedicated experiments and high-fidelity numerical calculations.

Reduce noise sources, reduce noise propagation, predict the impact of new aircrafts and their noise reduction

The first core topic of ARTEM is the development of innovative technologies for the reduction of aircraft noise at the source. The approach moves beyond the reduction of isolated noise sources as pure fan or landing gear noise and addresses the interaction of various components and sources - which often contributes significantly to the overall noise emission of the aircraft.

Secondly, ARTEM addresses innovative concepts for the efficient damping of engine noise and other sources by the investigation of dissipative surface materials and liners. The development work will mature, and subsequently down select these technologies by comparative testing in a single relevant test setup. Furthermore, noise shielding potential for future aircraft configurations will be investigated.

The noise reduction technologies will be coupled to the modelling of future aircraft configurations as the blended wing body (BWB) and other innovative concepts with integrated engines and distributed electrical propulsion. The impact of those new configurations with low noise technology will be assessed in several ways including industry tools, airport scenario predictions, and auralizations.

Initiated by the Association of European Research Establishments in Aeronautics (EREA), ARTEM follows a holistic approach for noise reduction of future aircrafts and provides enablers for quiet air traffic of the future which is an important part of EREAs Future Sky initiative.

ARTEM brings together the expertise of a large and diverse consortium consisting of twenty-four (24) partners throughout Europe: national research centers for aviation research, universities, small-and medium-sized enterprises (SMEs), and major European aircraft industry companies.

Project Details

Project ID/Grant Agreement:	769350
Funded under:	Smart, Green and Integrated Transport
Start date:	2017-12-01,
End date:	2021-11-30
Total cost:	7.9 M€
EU contribution:	7.5 M€
Coordinated by:	DLR
Call Topic(s):	MG-1-2-2017 “Reducing aviation noise”
Funding scheme:	RIA – Research and Innovation action

2. Activities and Achievements during the period M19-M24

The following paragraphs highlight some activities and achievements of ARTEM partners which have been finished or produced significant results during the stated period.

A Numerical Benchmark Exercise Prepares Noise Reduction Investigations

For a cross-comparison study of different numerical tools and tool chains of three ARTEM partners (ONERA, Technical University of Braunschweig (TUBS) and DLR), the Leisa2 F16 high-lift configuration (Figure 2), jointly specified by ONERA/DLR as the Category 6 problem of the Benchmark for Airframe Noise Computations (BANC) workshop [1], has been selected.

For this configuration a comprehensive experimental database is available from earlier aerodynamic and aeroacoustics measurements conducted in the ONERA F2 and DLR AWB wind tunnel facilities.

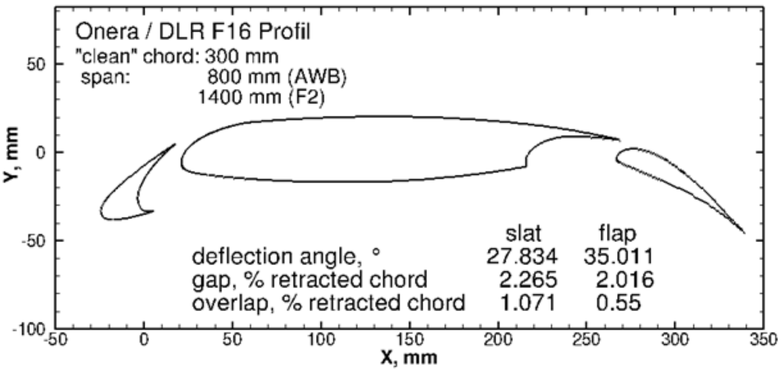


Figure 2: ***F16 reference high-lift airfoil and settings used for the cross-comparison study (© DLR/ONERA2015)***

Different numerical grids and different numerical schemes have been used to calculate the flow field and the pressure distribution around this airfoil configuration for the following conditions:

- U_∞ = 61.5 m/s (M_∞ = 0.18)
- AoA = 6.15°
- Re_∞ = 1.23×10^6.

As can be observed when comparing Figure 3 and Figure 4, the bench mark case is very demanding in terms of accuracy of simulations. The RANS solution of the time averaged flow around the F16 airfoil was computed with the TAU solver of DLR. Initial RANS simulations revealed a strong flow separation on the flap (large blue region on the downstream side of Figure 3) that is not present in wind tunnel measurements. Several RANS simulations were necessary to overcome this problem. It was found that the flap-separation could be significantly reduced for the present simulation case by replacing the standard hybrid unstructured meshes with fully structured meshes. The structured 2-D mesh consists of approx. 1 million grid points and has an extension over 100 chord lengths in all directions (Figure 4).

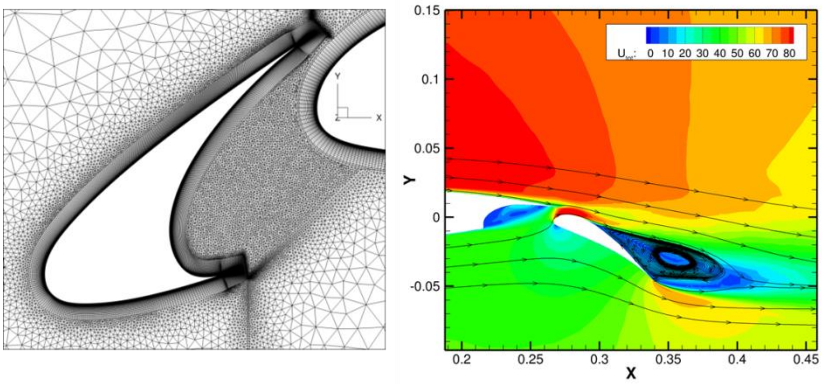


Figure 3: ***TAU simulation with k-ω SST model on unstructured mesh; flap separation present (© DLR 2019).***

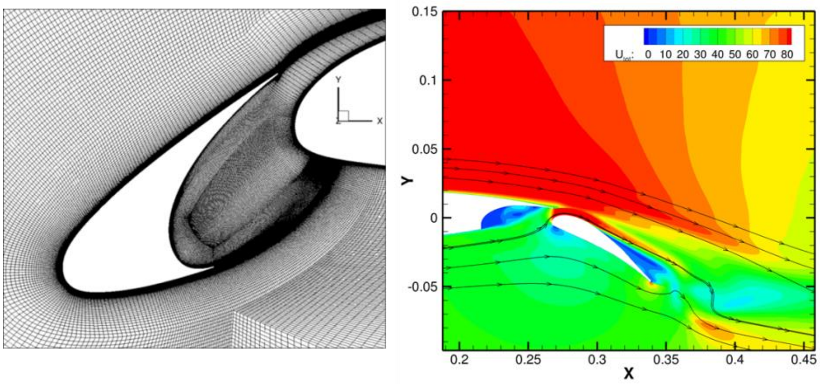


Figure 4: ***TAU simulation with k-ω SST model on structured mesh; flap separation reduced (© DLR 2019).***

The pressure distributions around the high-lift configuration obtained by the different numerical tools are presented in Figure 5. All approaches yield a fairly good agreement of the predicted Cp-distribution with the experimental measurements.

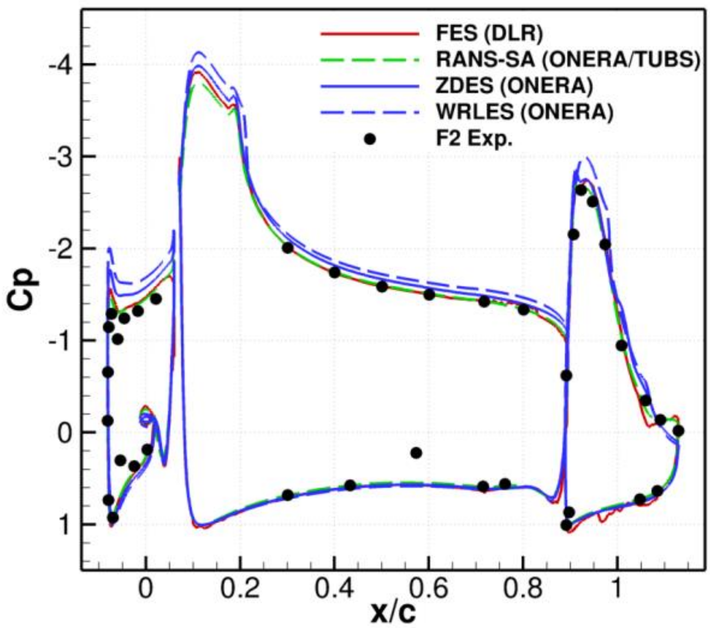


Figure 5: ***Cp-distribution (comparison created by DLR, 2019).***

Results for the power-spectral-densities are shown in Figure 6 for the shear layer stagnation point close to the slat trailing edge. The spectra have been computed using Welch's method, but each partner applying its own tool.

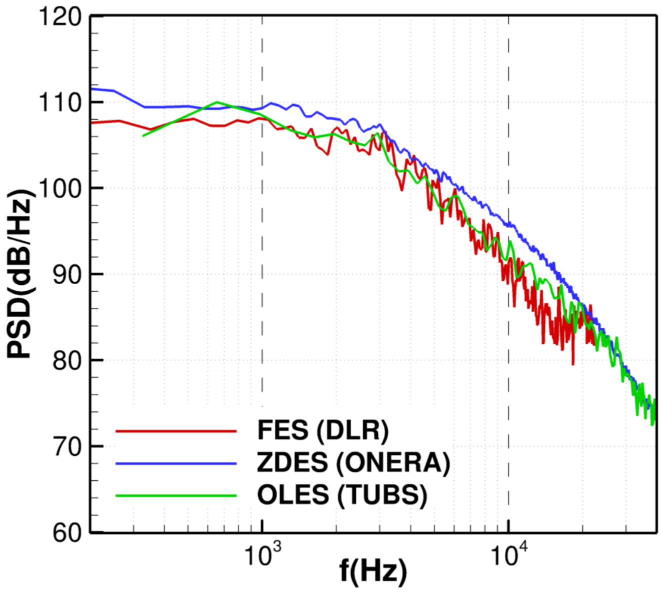


Figure 6: Evaluation of power spectral densities (PSD) in the shear layer stagnation point (SP) as found in the gap between slat and main airfoil from "scale resolving" simulation results *(comparison created by DLR, 2019).*

Very good agreement between all simulations is obtained in terms of spectral shape and level yielding differences of the order of 2dB. This indicates that all methods provide a similar spectral content close to the slat trailing edge, as indicator of properly catching the important slat noise sources.

Id	Org	Method	Mesh	Time integration	Order of method	Max. domain extension in chord units / h x l x b	No. points, entire domain / mio	wall normal resolution „y^+“	time step size $\Delta t \times a_0/c$ / -
1	TUBS	OLES (PIANO)	structured	explicit	4	0.28 x 0.3 x 0.05	44	lower: 2.7 upper: 4.5	2,70E-05
2	ONERA	ZDES (FUNk)	structured	implicit	2	100x100x0.16	65	lower: 0.55 upper: 2.5	2,27E-04
3	ONERA	WRLES	structured	implicit	2	100x100x0.25	2600	lower: 0.95 upper: 1.2	2,27E-04
4	DLR	FES (PIANO)	structured	explicit	4	1.5 x 2.7 x 0.05	15	lower: 21 upper: 41	5,00E-05

Table 1: *Overview about simulation methods.*

Overall, the simulation results reveal a good agreement in terms of the mean-flow trends and the time averaged Cp-distribution. Furthermore, all methods are capable to properly resolve the unsteady flow inside the slat cove which governs the turbulence noise generation at the slat. This is highlighted by the very good agreement between all simulations in terms of spectral shape and level of the wall pressure fluctuations close to the slat trailing edge with differences in level of the order of 2dB.

Major trends of the turbulence production in the slat shear layer are also captured by all methods. However, the simulations of TUBS with relatively coarse near wall resolution, respectively with levels typical for wall-modelled LES in case of DLR, indicate some missing turbulence kinetic energy contributions from the inner slat cove wall and from the turbulent boundary layer on the upper slat side.

The explicit 4th order Runge-Kutta time integration method applied by TUBS and DLR for compressible simulation yields very high simulation times for increased wall resolution. The results indicate that the implicit 2nd–order backward Euler (BDF-2) time integration method applied by ONERA for ZDES is clearly better suited for wall resolved simulation. Based on a time step size defined by the convective flow velocity and resolution parallel to the wall, an one order of magnitude larger time step size can used despite a 5 times larger wall resolution.

However, the very good resolution of the unsteady part of the shear layer for all simulations at least is an indicator that the near-wall turbulence contributions might not have a prominent impact on the main slat noise sources. Furthermore, for the simultaneous proper resolution of acoustics, a 4th order Runge-Kutta method is preferable due to its significantly smaller dissipative and dispersive errors compared to BDF-2.

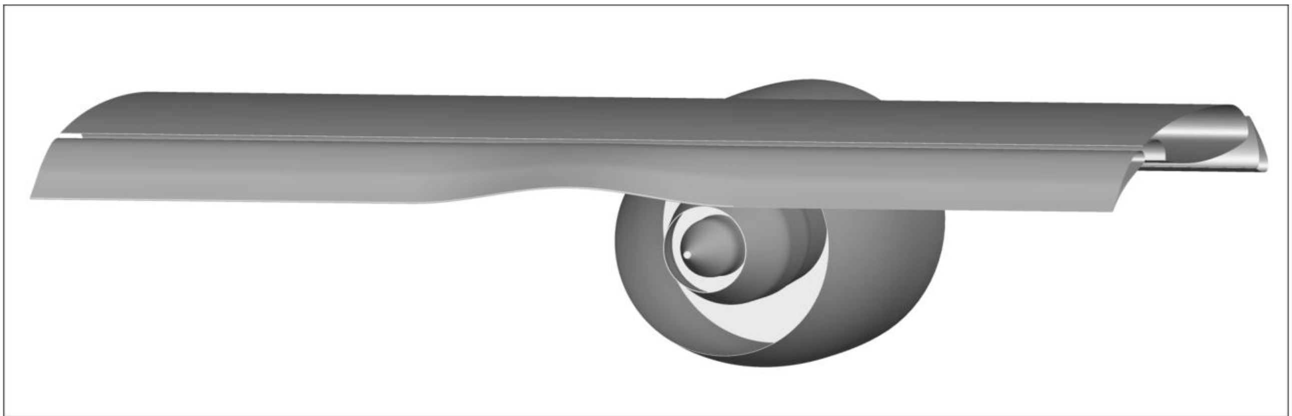


Figure 7: ***Continuous mould line flap trailing edge of F16 wing to mitigate jet-flap installation noise of an UHBR nozzle (© DLR 2019).***

DLR applies in consecutive simulations during the course of the ARTEM project the PIANO code for 3-D simulations with so called "Forced Eddy Simulation" (FES) as a scale-resolving approach to assess two alternative airframe based approaches concerning their potential to reduce jet-flap interaction noise (Figure 7). The latter study involves a combination of a non-swept high-lift wing based on the F16 geometry, combined with ultra-high bypass-ratio (UHBR) nozzle simulator (bypass-ratio 14.67) that has been studied in DLR's acoustic wind tunnel AWB in a national German predecessor project.

Windtunnel Setups for Research on Trailing Edge Noise Reduction

TU Bristol has designed, manufactured and tested two setups, namely the "flat plate" and the "airfoil" setup, both highly instrumented to provide substantial amount of data on trailing edge noise, and trailing edge noise reduction using 3D surface treatments, referred to as "finlets".

The flat plate setup is a simple configuration which allows for a detailed investigation of the underlying physics of noise generation and the effectiveness of passive flow/noise control methods, such as the finlet treatment. In the first round of experiments in the aero-acoustic facility of the University of Bristol, finlets were placed on the surface of the flat plate to study their effects on the surface pressure, velocity and far-field noise. A large amount of data has been collected, which is currently being post-processed.

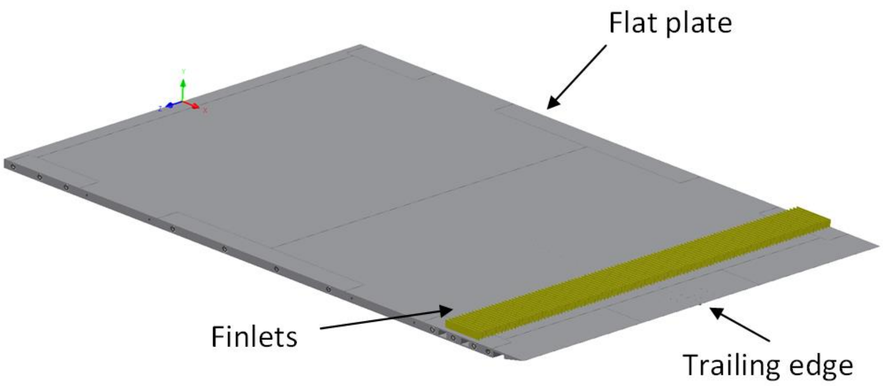


Figure 8: Surface treatment applied on the flat plate setup *(© U Bristol 2019).*

A wide range of finlets have been tried, but a few examples will be provided here for the sake of brevity. The data produced as part of this work will be supplied to the TU Braunschweig for validating the numerical results by an accompanying simulation.

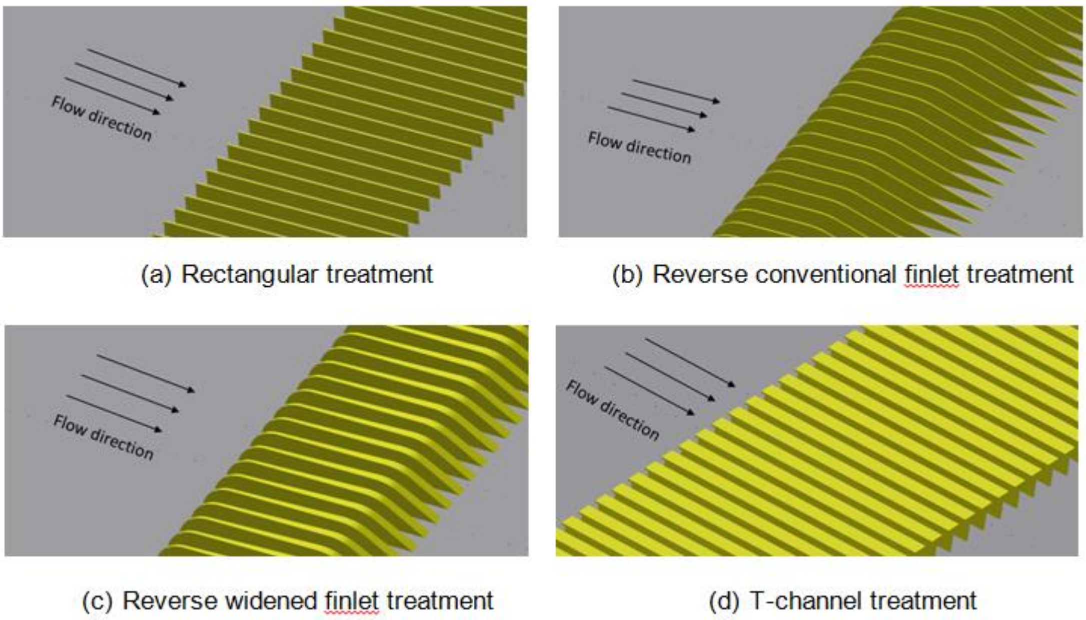
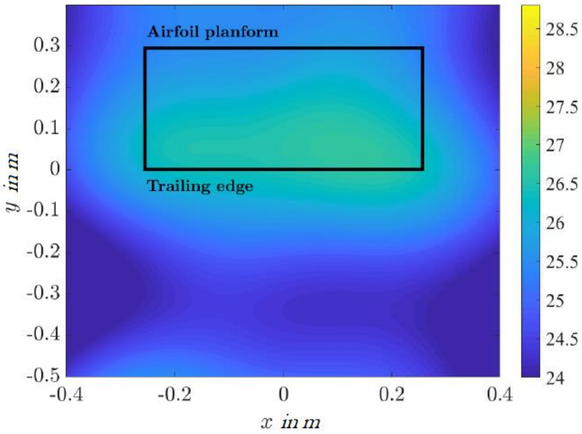


Figure 9: Finlet geometries investigated for their noise reduction potential on the flat plate setup *(© U Bristol 2019).*

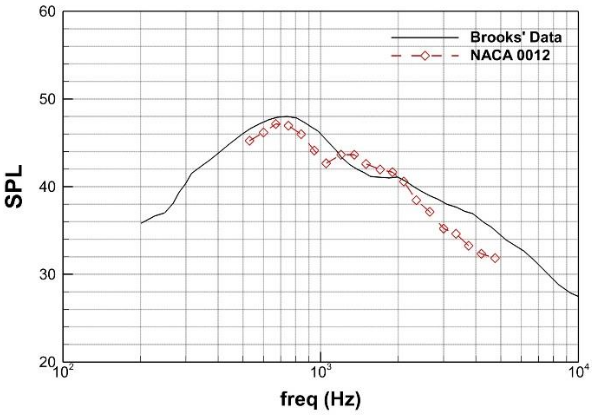
The data evaluated so far have revealed some very interesting results demonstrating the effectiveness of the surface treatments for reducing the unsteady surface pressure acting over the surface near the trailing edge area, promising potential reduction of far-field noise. First far-field noise measurements have been made using the far-field microphone arc. In the second phase of the project a beamforming array will be used in order to assess more detailed the acoustic effects of the finlets.

The flat plate case provided an opportunity to understand the effectiveness of surface treatments for reducing trailing edge noise for a zero-pressure-gradient flow. In order to study their performance for some real-world applications, finlets will also be tested on NACA 0012 airfoil as part of this project. This will enable us to study the aero-acoustic performance of the treatments for the cases involving adverse pressure gradient. Since the NACA 0012 model has been studied extensively in the past, testing this airfoil allows for a cross-check and validation with previously published data.

Some preliminary beamforming results are given in Figure 9. Figure 9(a) shows the beamforming map for a centre frequency of $1780\,Hz$ in 1/6 octave bands as determined using a functional beamforming approach. A comparison of the Sound Pressure Level (SPL) obtained using the beamforming array against the benchmark data from Brooks et al. [2] can be found in Figure 9(b). As can be seen, the beamforming array is able to accurately predict the radiated noise and therefore will be extensively used in the next phases of the project.



(a) Beamforming map



(b) Comparison with data from Brooks [2]

Figure 10: Beamforming results for a NACA0012 at the angle of of attack of 5^0, at a centre frequency of 1780 Hz in 1/6 octave bands *(© U Bristol 2019).*

The data collected as part of this task will be shared with the numerical partners (TUBS) for the validation of the LES simulations planned as part of the ARTEM project.

A Model Setup for the Investigation of Distributed Electrical Propulsion (DEP)

Four ARTEM partners (Pipistrel Vertical Solutions – PVS, VKI, ONERA, INCAS) have worked closely to settle the geometrical and mechanical design of the Distributed Electric Propulsion (DEP) mock-up, and have carried out several numerical activities that contributed to the final design.

The work included a comprehensive aerodynamic study of wing and propeller, carried out by PVS. The study had several objectives. First, CFD results of an isolated propeller were compared with experimental data in order to validate the numerical approach. Furthermore, several operating conditions of an isolated propeller were simulated, to serve as a validation for lower fidelity methods used by VKI and ONERA.

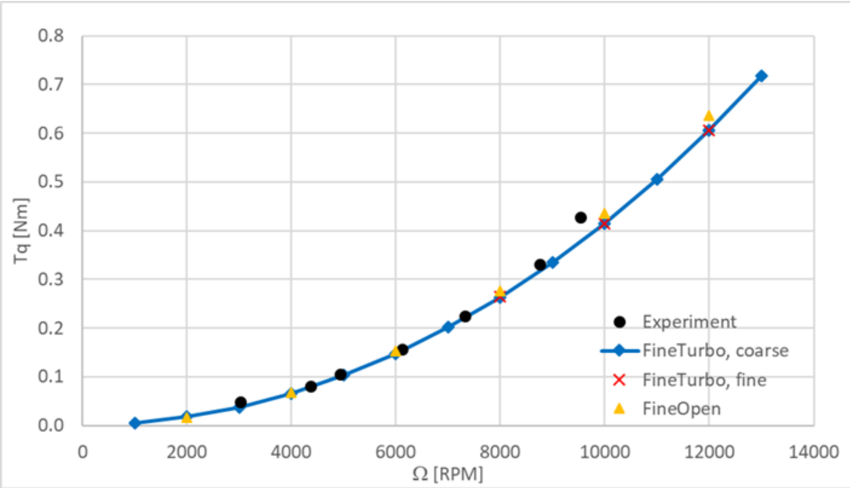


Figure 11: Aerodynamic torque of the 11x7 Master Airscrew propeller at static operating conditions *(© PVS 2019).*

Calculations with NUMECA FINE™/Turbo (respectively FINE™/Open) with $k-\omega$ SST turbulence model, and 2nd order central scheme for integration of all equations were made. They showed very good agreement with experimental values (example depicted in Figure 11).

Another objective was to find the aerodynamically most beneficial propeller positions at take-off condition for both tractor (also referred to as puller configuration) and pusher configurations. Various aerodynamic calculations have been made comparing also to Actuator-Disc model results. The preliminary noise evaluation of the propeller cases is performed using the VKI code BATMAN^{p} that is implementing noise prediction methods based on the Amiet's theory [3], [4] framework. In the present case different noise mechanisms are considered, depending on the propeller configuration (tractor or pusher).

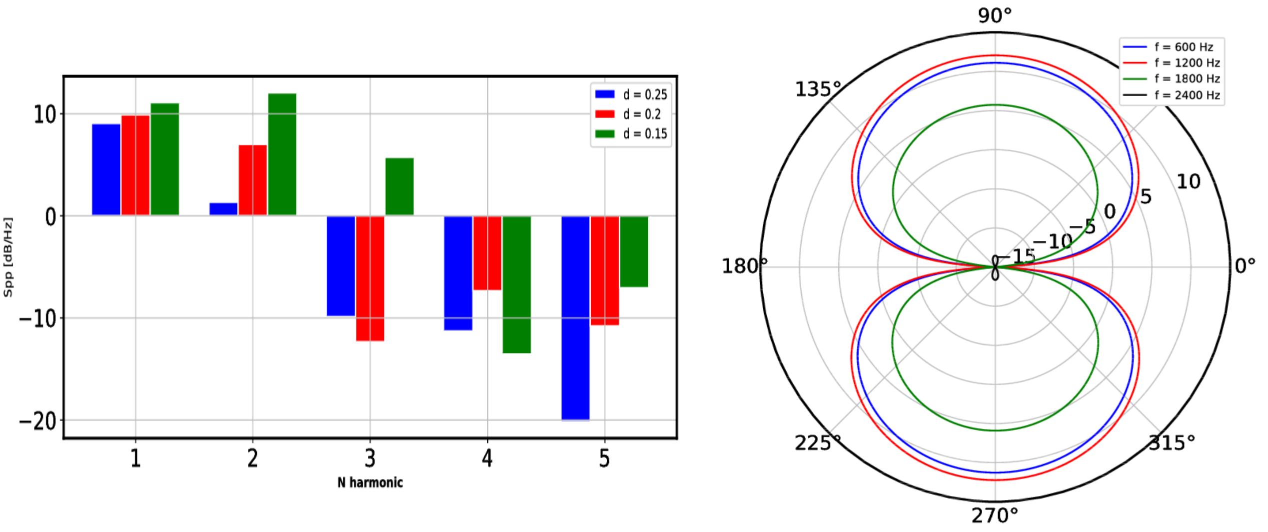


Figure 12: Left: Wake interaction noise sound at the first five rotor harmonics for three propeller-wing separation distances (0.15, 0.2 and 0.25 m) at 1m, perpendicular to the main wing and (right) sound directivity at 1m distance around the main wing, upstream *(© VKI 2019).*

After settling the position with respect to the leading edge, some actuator/disc calculations with all three propellers were made varying the lateral distance (0.03, 0.06 and 0.09 m) between blade tips. At 0.09 m distance there was nearly no interaction between the propellers, whereas, at 0.03 m distance the interaction effects were strong. It was decided that at reference position for three propeller set-up, the propellers will be 0.06 m apart. An example of CFD simulation using an AD approximation for the three tractor propellers is depicted in Figure 13.

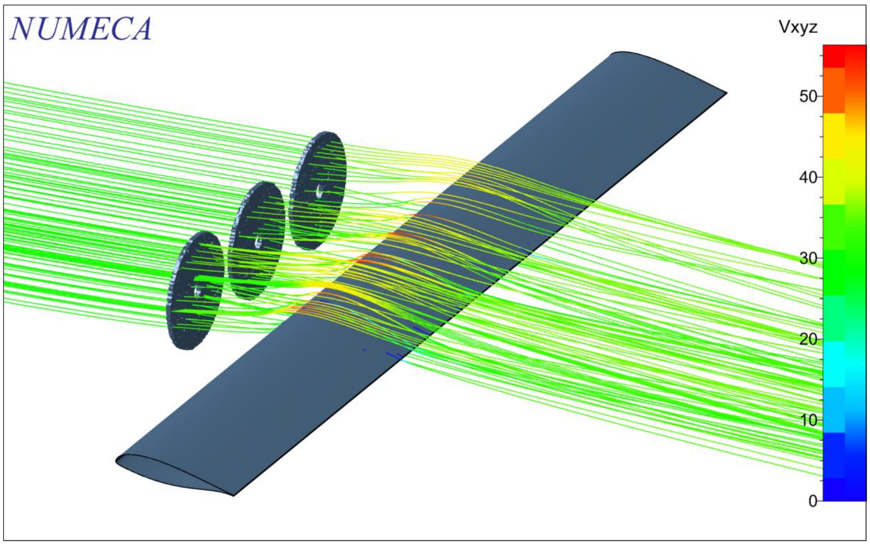


Figure 13: An example of a CFD simulation of a tractor configuration using three ADs as an approximation of three propellers. Velocity vectors passing ADs are depicted *(© PVS 2019).*

The final design of the wind-tunnel model allows for the investigation of pusher/puller/ and clean-wing configuration as depicted in Figure 14.

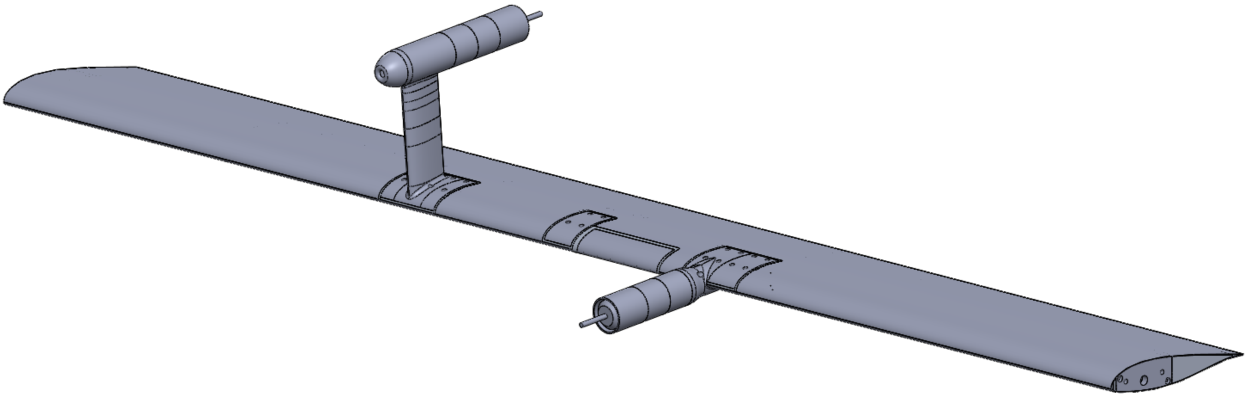


Figure 14: Isometric view of the final structure with all 3 configurations from left – pusher, clean, tractor *(© PVS 2019).*

The parameters of the wind tunnel model are given in the following table:

Wing chord [m]	0.3
Freestream velocity [m/s]	30
Propeller diameter [m]	0.28
Propeller number of blades []	3
Propeller tip Mach number []	0.51
Wing Re []	$0.6x10^6$
Wing Mach []	0.09
Propeller RPM [/min]	12000

The required freestream flow in the wind tunnel will be 30 m/s and the propellers will spin at 12,000 RPM in order to achieve noise similarity with the full-scale DEP system as defined earlier in the project.
The model will have a scale factor of approximately 1:3, and it will consist of a wing with maximum thickness of 17% (with respect to the chord length) and three propellers of diameter equal to 0.28 m positioned in front (tractor configuration) or above (pusher configuration) the wing. Mechanical design features a modular type of assembly, which simplifies the design, reduces the manufacturing effort and gives more degrees of freedom during the wind tunnel tests. The modular approach will allow to measure noise sources in different configurations and in this way give the consortium insights into propeller-propeller and propeller-wing noise interferences. The design took into account the attachments for INCAS wind tunnel, positioning of the dynamic pressure sensors, static pressure tubes and all wiring.

M19-M24 Further activities during the recent period:

- A plasma actuator as active noise attenuating structure has been set up and a control algorithm was implemented and tested in impedance tube setup (EPFL).
- 3D-printing of different liner structures has been successfully finished. Investigations are mainly concerned with the manufacturing-related surface roughness and its implications for flow drag. Further, the capabilities for the creation of complex structures aiming at broadband and low-frequency acoustic performance are in focus of this work (NLR, SOTON).
- Analytical models for the radiation and shielding of acoustic sources originating from the aircraft engine or other aircraft components have been thoroughly analysed and improved (TSAGI, SOTON).

Management Issues:

Following the project review by the supervising agency INEA in June 2019, the consortium received the final vote confirming “..the Agency considers the project implementation satisfactory..." stating also that no changes in the implementation are required.

References

[1] Manoha, E., and Pott-Pollenske, M., LEISA2: An Experimental Database for the Validation of Numerical Predictions of Slat Unsteady Flow and Noise. 21st AIAA/CEAS Aeroacoustics Conference, AIAA Paper 2015-3137, (2015).

[2] Brooks, T., Pope, D. and Marcolini, M. “Airfoil self-noise and prediction,” NASA Reference Publication, 1989

[3] Amiet, R., Noise due to Turbulent Flow past a Trailing Edge, J. Sound Vib., Vol. 47, 1976, pp 387-393

[4] Amiet, R., Acoustic Radiation from an Airfoil in a Turbulent Stream, J. Sound Vib., Vol. 41, 1975, pp 407-420

3. Dissemination activities (M19-M24 only)

Project progress and results are frequently published in order to inform the scientific community and partners from aerospace industry about the project progress.

The project has been introduced to **aerospace and aircraft noise community** at following occasions:

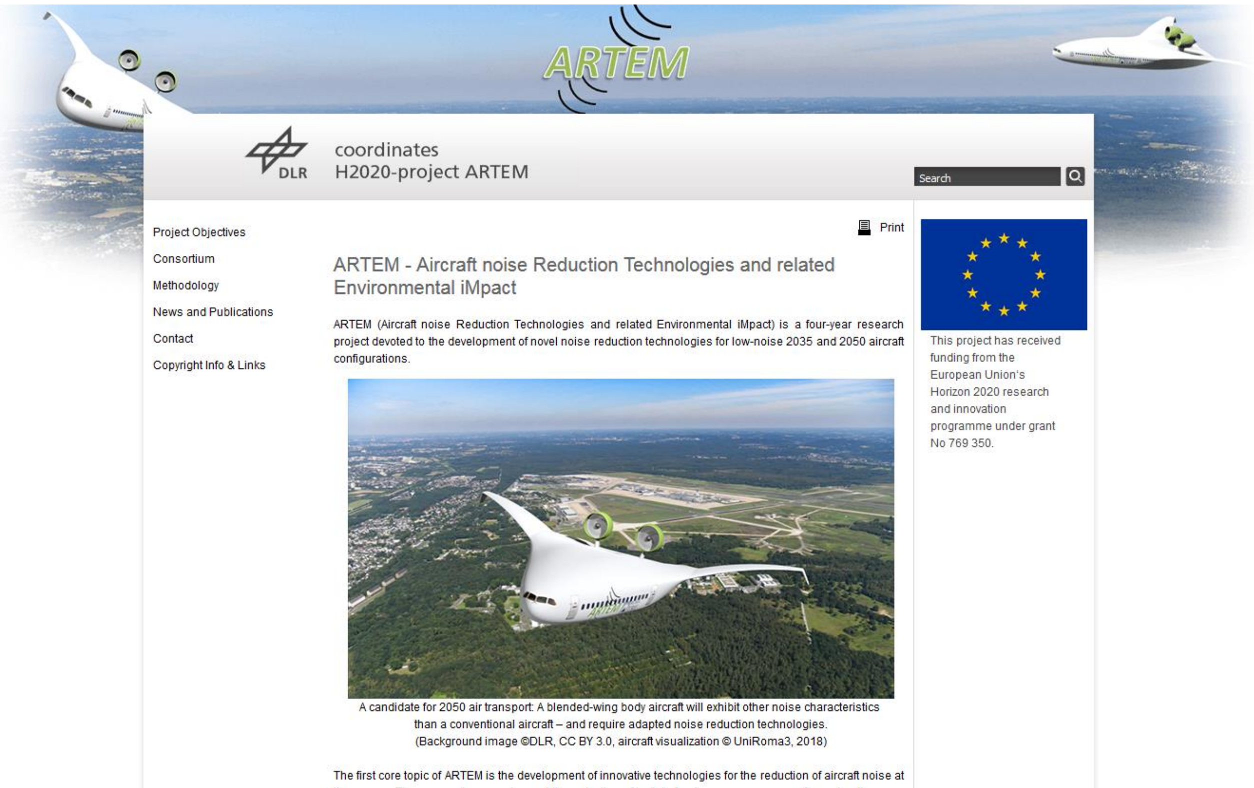
- "Noise Reduction Technologies for Future Aircraft Concepts – first results of the H2020 project ARTEM", Karsten Knobloch, 9th EASN International Conference on Innovation in Aviation & Space, 3.-6.9.2019. Athens/Greece
- Full Network-Meeting of "European Aviation Noise Research Network" supported by ANIMA global coordination task, Rome/ITaly, 25.09.2019

Scientific publications:

- "Future low-noise aircraft technologies and procedures – Perception-based evaluation using auralised flyovers", Pieren, R., Bertsch, L., Lauper, D. und Schäffer, B. (2019) 23rd International Congress on Acoustics, ICA 2019, 9.-13. Sept. 2019, Aachen. S.1654-1658. ISBN 978-3-939296-15-7 ISSN 2226-7808
- "Aeroacoustic Numerical Characterization of Propellers Interaction", Bernardini, G. et al. ICSV26 Congress, 7.-11. July 2019, Montreal, Canada

Online resources

The **ARTEM website** is accessible at**:** www.dlr.de/ARTEM



A project flyer and the publishable summaries are available for download at the ARTEM website.

- ARTEM at the EC information site (CORDIS):
  https://cordis.europa.eu/project/rcn/212367/en

- Project fiche of ARTEM at the INEA site:
  https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/aviation/artem

LINKS:

- Coordination Action for European Noise Research within H2020 project ANIMA:
  https://anima-project.eu/what-does-anima-do/global-co-ordination/

- Future Sky initiative of EREA:
  http://www.futuresky.eu/projects/quiet-air-transport

4. The ARTEM Consortium

Advanced Engineering Design Solutions SARL (AEDS)

Airbus Operations SAS (Airbus)

Centro Italiano Ricerche Aerospaziali (Italian Aerospace Research Center CIRA)

Le Centre National de la Recherche Scientifique (CNRS)

COMOTI, Romanian Research & Development Institute for Gas Turbines

Dassault Aviation SA (DASSAV)

Deutsches Zentrum für Luft- und Raumfahrt (DLR), German Aerospace Center

Ecole Central de Lyon (ECL)

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Swiss Federal Laboratories for Material Science and Technology (EMPA)

National Institute for Aerospace Research Elie Carafoli (INCAS)

Stichting Nationaal Lucht- en Ruimtevaartlaboratorium (NLR), Netherlands Aerospace Centre

Office National D'Etudes et de Recherches Aerospatiales (ONERA), French Aerospace Lab

PIPISTREL VERTICAL SOLUTIONS d.o.o. (PVS)

Rolls-Royce Deutschland Ltd & Co KG (RRD)

Safran Aircraft Engines (SAE)

University of Southampton (home of the Airbus Noise Technology Centre and the Rolls-Royce University Technology Centre in Noise) (SOTON)

Central Aerohydrodynamic Institute (TsAGI)

Technische Universität Braunschweig (TUBS)

Delft University of Technology (TUDelft)

University of Bristol (U Bristol)

Université de Cergy-Pontoise (UCP)

Universita' Degli Studi Roma Tre (URoma3)

The von Karman Institute for Fluid Dynamics (VKI)

5. Contact for further information

The project is coordinated by the German Aerospace Center (DLR), Dept. Engine Acoustics.

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