Fast Non-Empiric Rotor Noise Prediction Model for Installed Propulsors

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Introduction

The recent demand for sustainable aviation designs challenges aircraft manufacturers to reconsider existing technologies in light of the required cuts in environmental pollution. One of the key factors in addressing these green targets is represented by the integration of unconventional propulsion concepts on the airframe, exploiting electrically driven designs, due to their potential noise emission reduction. Since the new aircraft designs could include existing or novel propulsion system components to address the challenge of reliably predicting noise emissions, a simplified, fast and physical principles-based rotor noise model was developed, together with suitable adapted perturbation equations to represent current and possibly newly arising noise sources mechanisms. In this contribution, the results obtained in the context of the European Union's Horizon 2020 research and innovation program project ENODISE (ENabling Optimized DISruptivE airframe-propulsion integration concepts) will be presented, including additional results obtained in the project Cluster of Excellence SE^{2}A - Sustainable and Energy-Efficient Aviation at Technische Universität Braunschweig, part of the Germany's Excellence Strategy initiative of the Deutsche Forschungsgemeinschaft (DFG).

Rotor Model

The rotor noise model is based on rotating line sources that represent loading noise and thickness noise in terms of equivalent body sources. It relies on aerodynamic predictions based on Reynolds Averaged Navier Stokes (RANS) computations that provide the background flow solution for the proposed Computational Aeroacoustics (CAA) method, which considers Gaussian regularised line-source distributions of strengths defined from either Actuator Disc (AD) surface loads solutions obtained with a RANS solver, or tabulated aerodynamic data used in combination with a model based on Blade Element Theory (BET). The model is applied in the time domain. The systems of perturbation equations considered are the Linearized Euler Equations (LEE), the Non-Linear Disturbance Equations (NLDE), and a newly proposed system of perturbation equations that consists of the Acoustic Perturbation Equations (APE), in combination with the newly introduced Vortical Convection Equations (VCE), named APE+VCE. The APE+VCE system of equations is obtained from the LEE, which are split into two coupled perturbation equation systems for the acoustic and non-acoustic eigenmodes, respectively, allowing to investigate their interaction. The new noise prediction model was implemented in both the DLR's PIANO and DISCO++ codes. The simulations in PIANO are carried out on hierarchical Cartesian meshes that resolve geometries by means of an Immersed Boundary Condition (IBC) for the solid-wall surfaces. The 4th order Dispersion-Relation-Preserving (DRP) scheme is used with explicit fourth-order Runge-Kutta (RK) time integration to solve linear and non-linear governing equations describing the dynamics of – not necessarily small – perturbations over a steady background flow field provided by precursor RANS simulation. In particular, the results included in the presentation will consider the LEE and NLDE system of equations. DISCO++ is an unstructured quadrature-free experimental Discontinuous Galerkin (DG) CAA solver, where the APE+VCE system of perturbation equations was implemented. The equations' system is solved on a tetrahedral grid, where, for each tetrahedron, the solution is represented with a third-order polynomial. Time integration is performed with an explicit fourth-order RK method. More details can be found in [1].

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Results

In ENODISE, the rotor model implementation in PIANO was considered, investigating a tractor propeller-pylon configuration. A four-bladed propeller was simulated, with a diameter D = 0.237 m, rotational frequency n = 211.9 Hz, and free-stream velocity U_∞ = 40 m/s, corresponding to a Mach number Ma = 0.12. Details of the computational setup can be found in [2]. Two computational setups were realized, of which only the setup in which the parallel flow around the entire configuration without propeller is used as input for the NLDE system of equations is highlighted in this abstract. This setup was used in combination with the rotor model option involving the loads definition of the line sources from BET. In Fig.1 the acoustic pressure field is shown together with the blade-tip vortices development. The expected qualitative acoustic patterns can be seen, highlighting in particular the interaction with the downstream pylon. Figure 2 shows the narrow-band spectrum of the pressure fluctuations for a particular microphone located in the X-Z plane at a radial distance of 4*D/2 and at 276° (measured from the positive X direction, in a counter-rotating direction). A good agreement with higher-fidelity data obtained from provided PowerFLOW® simulations results can be seen, up to the 4th harmonic.

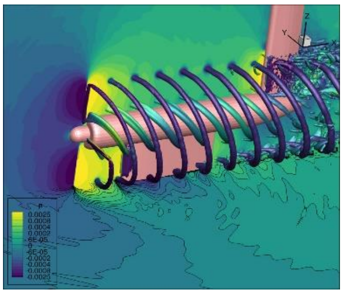

Fig. 1 Instantaneous contours of the acoustic pressure field and Q-criterion of perturbed velocities.

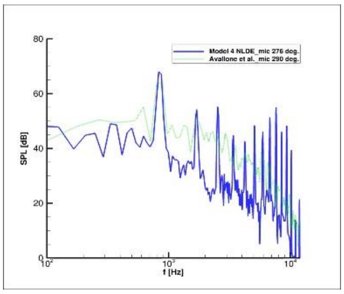

Fig. 2 Narrow band spectrum of pressure fluctuations at a distance of 4*D/2 and 276° (X-Z plane)

In SE^{2}A, the rotor model implementation in DISCO++ was considered, validated qualitatively with a variant of the conceptualized SE^{2}A short-range aircraft, which includes 2 propellers of diameter D = 4.10 m. The simulations performed considered two typical climb and cruise configurations, investigating counter and co-rotating propellers by comparing the results for both isolated and installed setups. The CAA simulations are based on CFD simulations using the AD modelling option to replace the propeller blades. The propeller sources for the APE+VCE are prescribed as distributed line sources of strength appropriately interpolated from the AD disc surface solution. Figure 3 and 4 show the results obtained for the climb configuration with counter-rotating propellers. The rotational frequency was n = 18.33 Hz, the free-stream velocity U_∞ = 72 m/s, corresponding to a Mach number Ma = 0.21. In Fig.3 the acoustic pressure field is shown together with the superimposed modelled blades-tip vortices development, highlighting the acoustic response due to the installed propellers configuration. Figure 4 shows the directivity plot of the Sound Pressure Level (SPL) of signals recorded in the X-Z plane at a radial distance of 4*D/2, comparing installed and isolated propellers configurations. An overall increase of SPL in all directions for the installed configuration can be seen. A more extensive description of all the results obtained in ENODISE and SE^{2}A will be included in the presentation.

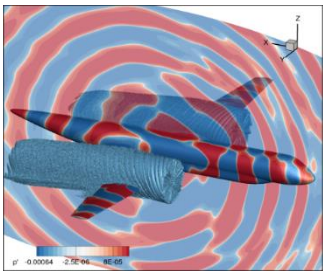

Fig. 3 Acoustic pressure field for the climb, counter-rotating propellers configuration

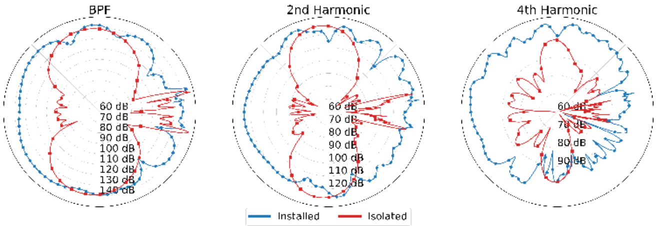

Fig. 4 Directivity plot of the SPL for the BPF, 2nd and 4th harmonic on a circle at 4R, for the climb, counter-rotating propellers configuration.

References

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