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Noise Emissions from Installed Propeller-Wing Configurations using Mid-Fidelity Unsteady Panel Method coupled to FW-H equation-based solver

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Propeller Installation Noise

The following work is carried out in the scope of L²INK project at DLR and presents an approach to determine noise emissions from small aircraft due to propeller installation effects, using a mid-fidelity numerical scheme. The small aircraft selected for this particular study is the DLR DO-228 research aircraft with a 5 bladed, wing mounted tractor propeller of 2.5m diameter. The mid-fidelity based unsteady panel method code is coupled with the acoustics prediction code based on the FW-H equations solver for the computation of aerodynamic loads and acoustic pressure signals in the far-field of the source (DLR APSIM code). The DLR unsteady panel code simulates the aerodynamic loads under the assumption of incompressible, inviscid, irrotational, and unsteady flow. The aerodynamic loading data, i.e., lift-drag coefficient, and the surface pressure, obtained from the propeller blade and wing are further used as an input to the FW-H equation-based solver code. Loading noise and the thickness noise generated from the lifting surfaces in the near-field are determined from the surface pressures provided via UPM aerodynamics simulations, and the spatial coordinates of the propeller blade and of the wing. The pressure signal in the near-field of the noise source is further propagated in a uniform flow to calculate the acoustic pressure in the far-field. An array of microphones is defined at distinctive polar and azimuthal angles, forming a hemispherical shape to capture the noise directivity in the far-field from the source. Further, the DLR noise assessment tool PANAM [5] takes this hemisphere with acoustic pressures as input and propagates it to selected observer positions on the ground. The noise levels predicted by the coupling of UPM (DLR panel code) and APSIM (DLR time domain code for FW-H), on the ground using propagation in uniform flow is validated with the measured data from a flyover campaign. The validation shows that the noise levels predicted by the coupling of UPM and APSIM, at a distance of 158.9 m corresponding to an observer on the ground matches the noise levels obtained from the measurement campaign up to frequencies of 4 kHz. Furthermore, the noise levels from APSIM are compared to the noise levels computed at the observer position on ground using PANAM.

Mid-Fidelity Aerodynamic Simulations using the DLR Panel code

The DLR panel code i.e., the Unsteady full-span free-wake panel method (UPM), is used for the mid-fidelity aerodynamic simulations of the isolated propeller and the propeller installed with the wing. It models the hydrodynamic interaction of the vortices shed from propeller tip, with the wing placed in downstream of the propeller at a distance of (0.9, -2.584, 0.354) m in x, y, z direction, considering the propeller centre to be origin of the simulation framework. UPM is a velocity based indirect potential flow solver, which makes it a meshless calculation method. The geometry/noise-source is approximated using surface panels that represent the source/sink and doublet singularities that are defined on the surface of the propeller blade, and the wing [1]. The Prandtl-Glauert equation for subsonic flow, which is a mixed PDE, is solved to determine the velocity potential on these surface panels, and based on this velocity, pressure, forces and moments are also calculated in the panel centre. The root and the tip sections of the propeller blade and wing are kept open to avoid instabilities in the numerical process due to two singularities defined too close to each other. In the course of the research work, a grid sensitivity study is carried out by varying the panel density on propeller blade and on the wing. The number of panels required to approximate the propeller blade and the wing geometry has a significant effect on the aerodynamic loading and on the acoustic pressure signal radiated to the far-field. The shed vortex from the tip of the propeller interacts with the wing placed downstream of the propeller. Therefore, the panel density is increased in those sections of the wing where the shed vortex from the propeller interacts with the wing. It helps to model the wing-vortex interaction in a more appropriate manner by accurately calculating the fluctuations in the time history of the lift coefficient for the refined sections. The same criterion is also applicable for the propeller blades, as the vortices roll up to the tip and are then shed. Therefore, the tip of the blade is refined, i.e., the panel density at the tip section is increased compared to the root section, to model the vortex core more accurately. Figure 1

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shows the aerodynamic interaction of the propeller wake with the wing. Furthermore, a study was done to considers the effect of size of vortex core diameter and the vortex core model selected, on the aerodynamic loading of the wing and the noise radiated in the far-field. A smaller core diameter results in numerical instabilities in the simulation over the course of time as the wake propagates. A much larger core diameter of the vortices results in vortex-wake and vortex-vortex interactions over the wing leading to increased vortex strength and eventually to increased sound pressure levels. Therefore, an optimum value of the core diameter is used with an appropriate vortex core model to avoid numerical instabilities in the simulations.

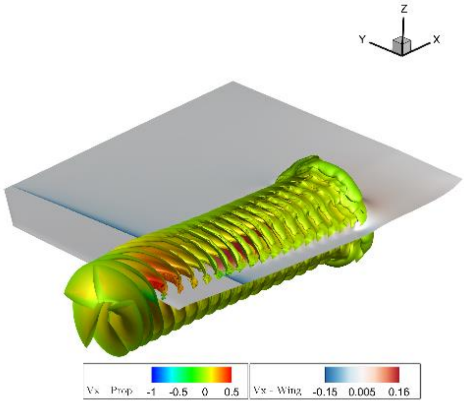

Fig. 1 DO-228 propeller installed with half wing

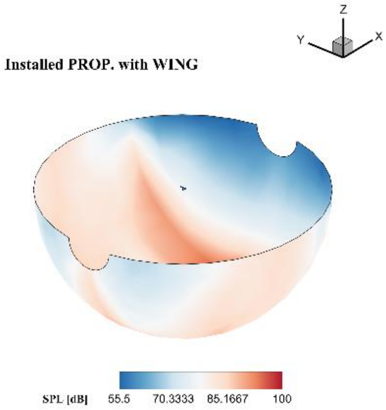

Fig. 2 Noise directivity of installed propeller-wing configuration on the hemisphere

Aeroacoustics Simulation based on Farrasat 1A solution of FW-H equation

The aerodynamic loading data obtained from the UPM simulation of the propeller installed with the half wing is used as an input to the APSIM code. The DLR APSIM code is based on the FW-H equation and Kirchhoff's formula for permeable and non-permeable surfaces [2]. The following research work uses the formulation 1A derived by F. Farrasat from NASA [3] to solve the FW-H equation for non-permeable surfaces. The reason for using a non-permeable surface approach being; UPM code is a velocity-potential based solver with singularities defined on the surface of the blade in form of panels. Thus, it can only produce loading data, i.e., pressure on the surface of propeller blades and on the wing, and doesn't produce a pressure signal on a permeable surface bounding it. APSIM uses this surface pressure data to calculate the acoustic pressure in the near-field and propagates it to the far-field linearly onto a hemisphere. This is shown in figure 2, where the directivity of acoustics pressure signal is shown on the hemisphere with a radius of 158.9 m. This distance corresponds to the height at which the aircraft was flying during the flyover campaign. The effects of compressibility and the turbulent flow interacting with the trailing edge are currently not being considered in the DLR's panel code. Therefore, only the tonal part of noise is calculated using the coupling of mid-fi UPM simulation with APSIM code.

Results from the measurement indicate a considerable broadband contribution being present atop of the propeller tones [4]. Simulations with UPM/APSIM reveal a very close agreement with the measured broadband spectrum for frequencies up to 4kHz when propeller wake-wing interaction is accounted for in the simulation. This implies that propeller installation noise sources as discussed are of paramount importance for the overall sound characteristics. Furthermore, apparent broadband contributions actually would be attributed to the periodic but rich of higher-harmonics wake-wing interaction effects.

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