11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Modelling and Simulation of Airframe Flow and Noise Generation

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Key Words: *Numerical modelling, Turbulent flow, Airframe noise, Low-noise configuration.*

Noise reduction for greener aircraft has been, and will remain, a significant challenge confronting aeronautic industry. Airframe noise (AFN) is recognized as being one of the major sources contributing to the overall noise radiated by modern aircraft. AFN is usually dominated by a broadband character stemming from three main sources: (a) turbulent flow at and close to the flap side edges and slat cove, as well as over the trailing edges of high-lift devices; (b) the scattering of the energy of the turbulent eddies in the boundary layer of the wing and around the fuselage; and (c) bluff-body vortex shedding of landing gears and, to a second extent, unstable shear layers over cavities/surface sinks, as well as unsteady flows over spoilers and other protuberances, with sound generation due to turbulent flow and pressure fluctuations.

Aero-acoustics problems are characterized inherently by multiple scales. This is particularly true in terms of turbulent flow-generated acoustic sources with widely spanning length scales in different parts of the computational domain. Furthermore, aero-acoustics problems are time-dependent and involve typically a frequency range spreading over a wide bandwidth. By nature, tackling aero-acoustic propagation emitted from turbulent flow-generated sources requires essentially to incorporate turbulent flow fluctuations and their correlations in analysis using Computational Aero-Acoustics (CAA) methods. Direct numerical simulation approach is computationally very demanding and unsuitable for practical use. To handling high-Reynolds number flows as being commonly encountered in aeronautic applications, moreover, large eddy simulation (LES) may also become unrealistic to resolve turbulent flow motions associated to noise generation around airframe configurations.

For the formulation of flow-generated noise sources associated to turbulent fluctuations, the stochastic method remains an efficient approach for industrial use. A stochastic method generates synthetic turbulence based on RANS solutions. To obtain resolved turbulent flow properties for noise-source modelling, instead of using DNS or LES, hybrid RANS-LES modelling has been increasingly used for its feasibility and affordability in aeronautical applications. Hybrid RANS-LES modelling approaches employ (unsteady) RANS in the wall boundary layer and LES in off-wall regions. This contribution presents some recent applications in modelling and simulation of airframe flows and related noise-source analysis using turbulence-resolving simulations based on hybrid RANS-LES modelling, as well as using the stochastic method based on RANS computations. Aerodynamic and aero-acoustic analysis will be presented for flows over several different high-lift and landing-gear

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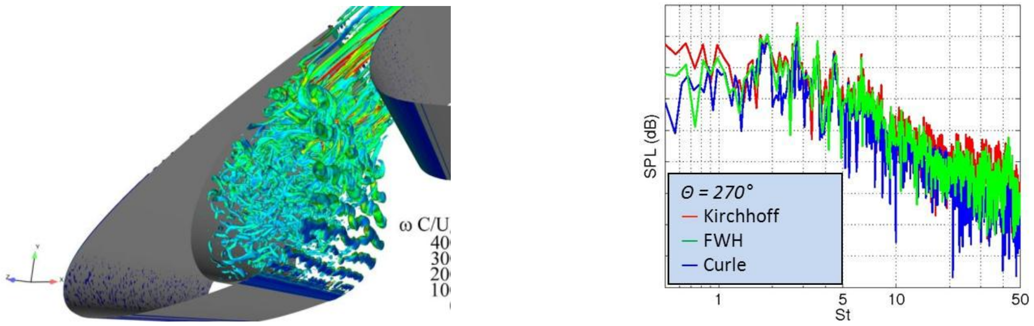
configurations. In the presentation, resolved (or RANS-modelled) turbulent flow features in association to noise generation will be discussed. Where relevant, analysis on low-noise airframe configurations will also be highlighted. It is shown that potent noise generation is usually conformed to flow regions with intensive production of turbulent kinetic energy separation and vortex motions.

In Figure 1 an example is given for analysis of a high-lift flow, where the flow structures resolved in the slat cove is highlighted using a hybrid RANS-LES method. Also illustrated in Figure 1 (b) is the SPL predicted at the location below the high-lift configuration based on three different acoustic analogies.



(a) (b)

Figure 1: Example of acoustic analysis for a high-lift configuration. (a) Resolved turbulent structure in the slat cove. (b) Sound pressure level (SPL) for observer below the configuration with a distance of 300m.

As an example, in Figure 2, the resolved flow around a rudimentary landing gear is illustrated. The overall sound pressure level (OASPL) due to surface pressure fluctuations is also highlighted, which clearly indicates the potent noise generation regions with high OASPL due to, among others, vortex motions and shear-layer impingement on the rear LG wheels.

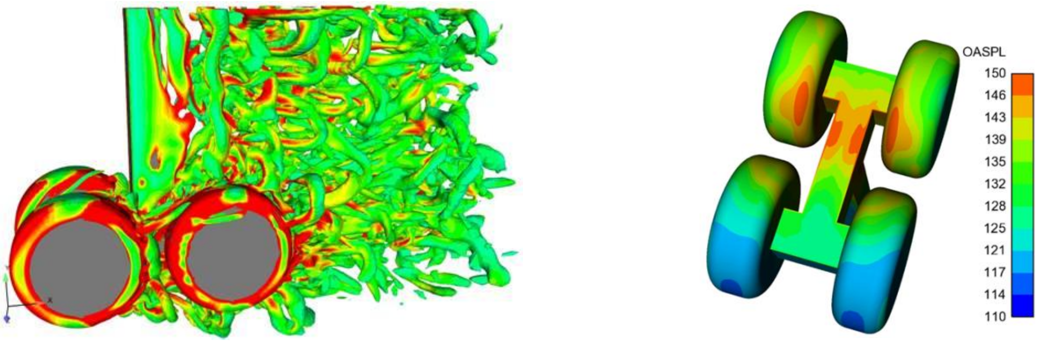


Figure 2: Example of resolved flow structure (left) and overall sound pressure level (OASPL) on the bottom surface of a rudimentary landing-gear configuration.

In the presentation, along with an exploration of resolved flow physics, acoustic analysis for other complicated main LG and flap side-edge high-lift configurations will be reported.