Fuselage Excitation During Cruise Flight Conditions: Aircraft Structural Vibration Measurement vs. SEA Estimation

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In the context of aircraft cabin interior noise, the fuselage structural excitation by turbulent boundary layer (TBL) flows is an important noise source for aircraft manufacturers to deal with. Aircraft at cruise conditions are flying at high Mach numbers, typically between Ma = 0.78 ... 0.85, dependent on the type and mission of the aircraft. At these flight conditions, the TBL around the fuselage is turbulent and features regions with high turbulence intensity. The vortices within the TBL cause pressure fluctuations on the fuselage and therefore, its structure receives energy and starts to vibrate. This vibration is inter alia dependent on the flow velocity and thus, the strength of the TBL. Due to advanced low-noise engine technologies the TBL remains the dominating source of cabin noise at current state-of-the-art aircraft. Therefore, Airbus has launched dedicated research efforts to characterize the TBL as a source of cabin acoustics and to predict the induced structural excitation of any fuselage section. Especially in an early design stage sufficiently precise noise level estimates are important to evaluate/optimise design variants (e.g. different aircraft shapes) from an acoustical viewpoint. Today's semi-empirical models to predict the TBL-induced pressure fluctuations have been mainly developed on the basis of wind-tunnel tests on flat plates. Correspondingly, these commonly applied predictions are not applicable in areas subjected to disturbed flows (i.e. at the junction between the wing and fuselage, the cockpit or tail regions). A universal prediction approach requires more detailed model descriptions of the TBL strength and spatiotemporal development as characterized by the surface pressure auto-spectrum and wavenumber-frequency spectrum, respectively.

In this paper an approach is presented to bridge the gap between simple flat plate estimates and higher-fidelity predictions based on computational fluid dynamics (CFD) and computational aeroacoustics (CAA). As the result of an in-depth literature review on available auto-spectrum models the semi-empirical GOODY model [1, 2] was selected and extended to cover arbitrary regions of the fuselage. In the new approach aerodynamic parameters are directly taken from CFD calculations. Besides, the turbulence kinetic energy (TKE) was identified as major driving quantity and was therefore, included in the new model. This new model was derived and verified using measured auto-spectra from flight tests, performed on the Advanced Technology Research Aircraft (ATRA) of the German Aerospace Centre (DLR), an Airbus A320. It is therefore valid in a large parameter space, covering the operational range of a short- to medium-haul aircraft. The aircraft and areas of high sensor density is shown in Figure 1.

In parallel, a fully numerical procedure is proposed to predict the auto-spectrum as well as the wavenumber-frequency spectrum by making use of the Fast Random Particle-Mesh Method (FRPM) of the DLR. In selected areas the FRPM approach provides both auto-spectra and wavenumber-frequency spectra with high prediction quality. Currently, the method is limited to frequencies $f \leq 2500$ Hz.

Beside these source modelling activities, rhombic and elliptical wavenumber-frequency models from litera-

Figure 1: Advanced Technology Research Aircraft (ATRA) and areas of high sensor density

ture are reviewed and the effect on a flat plate vibrational response is described. This study is conducted by using GRAHAMS method [3, 4] implemented in Matlab and by a commercial implementation in an Statistical Energy Analysis (SEA) software package. Both approaches show equal results for the flat plate test.
Finally, the developed auto-spectrum model, the different reviewed wavenumber spectrum models, the FRPM-based predictions and a wavenumber spectrum model fitted to ATRA flight test data are used as variable inputs for an SEA at the real aircraft. For the SEA computations the commercial software VA One is employed with Airbus A320 SEA models used for research and development at Airbus. Structural vibration data, estimated with these models are finally compared with measured structural vibrations from flight tests in different areas of the aircraft. Estimated structural vibrations give an overall good collapse with the measured accelerations. However, detailed parametrical comparisons indicate the individual weaknesses of different wavenumber-frequency models in distinct frequency ranges. Especially in the low frequency range semi-empirical models tend to deviate from measurements.

References

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