UNCERTAINTY OF NOISE PREDICTION IN CASE OF FLOW OVER A FORWARD-FACING STEP

Alexander Kolb[1], Michael Grünewald[1] & Michael Manhart[2]
[1]*Airbus Group Innovations, Airbus Defence and Space GmbH, Munich, Germany*
[2]*Chair of Hydromechanics, Technical University of Munich, Germany*

Abstract The demand of development and application of computational aeroacoustic (CAA) prediction tools for turbulence related noise is increasing to overcome the future requirements of low noise design. Fast and accurate prediction methods are necessary to be integrated into early design processes. Several numerical and experimental studies show that the complex flow physics even of simple geometries is still not fully understood. A great interest is the identification and quantification of noise sources. Hence, immense effort has to be spent for a detailed investigation of the capability of experimental and numerical methods with respect to industrial applications. In this context the uncertainty analysis of aeroacoustic computation is a key issue for the evaluation of low-noise design.

Summary

Aeroacoustic wind tunnel experiments have been performed within the Bavarian funded research project ‘StreamNoise’ for various configurations of a forward facing step [1]. Broad band noise is generated by the step with a height H=12mm and U_0=30m/s in a frequency range between 1kHz and 8kHz for $Re_H = 24000$. In the present work various acoustic wave propagators are compared based on unsteady Large-Eddy Simulations (LES) to investigate the acoustic source term and the acoustic radiation directivity.

A large eddy simulation is performed with the finite volume code MGLET [2]. The incompressible Navier-Stokes equations are solved on a non-equidistant staggered grid using second-order central approximations. The Poisson equation is solved by a Stones Implicit Procedure (SIP) accelerated by a multigrid cycle. Time-dependent inflow profiles are constructed by a superposition of a time-mean profile taken from experiments and scaled downstream fluctuations. A Lagrangian dynamic subgrid-scale model is used for all fluid simulations.

Acoustic sources are determined from the resolved flow fields and interpolated to a coarser acoustic grid. The acoustic computation is performed with a high-order finite difference solver in time domain. A DRP [3] scheme is used for the spatial reconstruction in combination with an explicit fourth-order Runge-Kutta scheme. The linearized Euler equations [4][5] are applied as wave propagation operator and are compared with results of an integral Ffowcs-Williams Hawkings approach which is based on Lighthill’s acoustic analogy. The noise source mechanisms are investigated in detail in [6].

In this paper, various sensitivity studies are conducted for a single large eddy simulation of $\Delta z = 5H$ in span-wise direction to estimate influences on the noise prediction. The influence of sampling frequency, source term approximation, spatial source extension, grid refinement and subgrid-scales on the acoustic fields will be presented. The investigations show the uncertainty of the source input and its influences on the acoustic results in the far field.

Figure 1 shows vortical structures generated at the step and being convected with the flow. The surface pressure fluctuations are used as source term for the Ffowcs-Williams & Hawkings approach and propagated with the 3D Green’s function into the far field. Several investigations are performed to identify the influence of the source input on the acoustic radiation. Figure 2 and Figure 3 show a comparison of the Ffowcs-Williams Hawkings approach in 3D based on different sampling frequencies of the aerodynamic input and a variation of the span-wise resolution of the large-eddy simulation. In a second step acoustic source terms are computed based on unsteady pressure fluctuations and propagated with the Linearized Euler equations. In Figure 4 an instantaneous acoustic pressure field is shown. Similar sensitivity investigations are performed. A final comparison of the two approaches with microphone measurements in the far field above the step is shown in Figure 5. Conclusions on the sensitivity of aeroacoustic simulations are derived and presented in the paper.

Acknowledgements

The support of the Bavarian Research Foundation (BFS) is highly acknowledged.

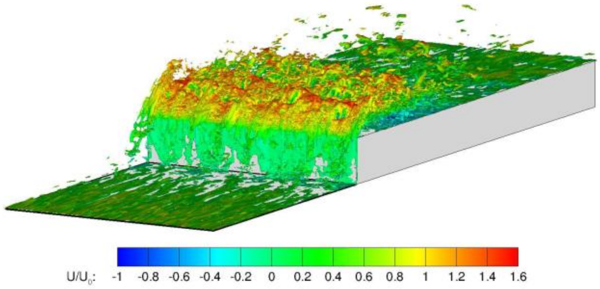

Figure 1. Instantaneous vortical structures computed by a large eddy simulation.

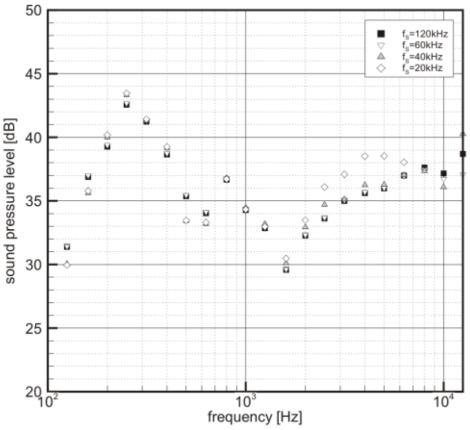

Figure 2. Ffowcs-Williams & Hawkings sound propagation propagation 3D – Representation of a third-octave plot of the acoustic signal at R = 1m and φ = 90° for selected sampling frequencies.

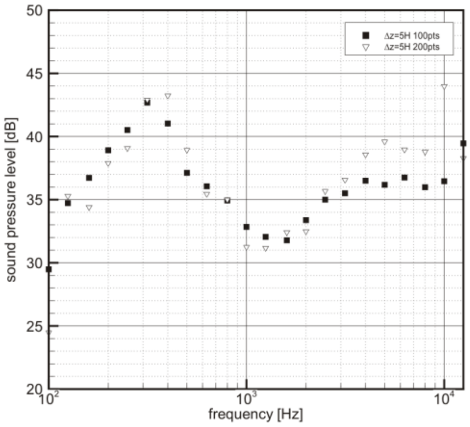

Figure 3. Ffowcs-Williams & Hawkings sound propagation propagation 3D – Representation of a third-octave plot of the acoustic signal at R = 1m and φ = 90° for NPZ = 100 and NPZ = 200.

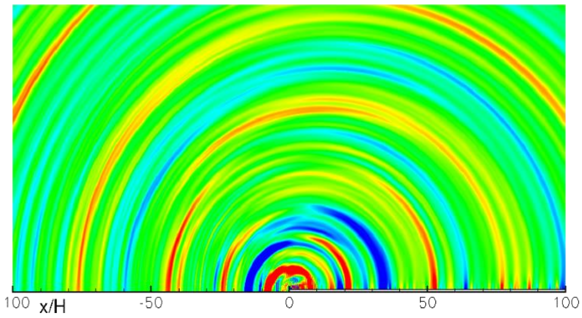

Figure 4. Acoustic pressure field at a forward-facing step obtained by solving the LEE.

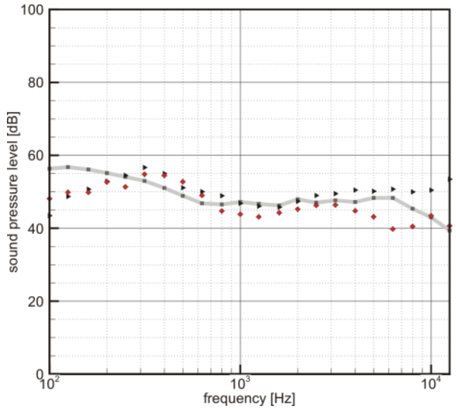

Figure 5. Acoustic far field spectra (FWH – black triangles, LEE - red diamonds) in comparison to measurements.

References

[1] S. Becker et al. 'Experimental and Numerical Investigation of Flow induced Noise from a Forward Facing Step" AIAA 2005-3006

[2] N. Peller, A. Le Duc, F. Tremblay, M. Manhart. 'High-order stable interpolations for immersed boundary methods' Int. J. Numer. Meth. Fluids, 52:1175–1193, 2006.

[3] C. Bailly et al. 'Computation of flow noise using source terms in Linearized Euler's Equations', AIAA 2000-31153

[4] R. Ewert. 'A Hybrid Computational Aeroacoustics Method to Simulate Airframe Noise', PhD thesis 2002

[5] C. Tam, J. Webb. 'Dispersion-relation-preserving finite difference schemes for computational acoustics' J. Comput. Phys., 107:pp262–281, 1993.

[6] A. Kolb. 'Noise prediction using hybrid aeroacoustic methods for generic test case', PhD thesis 2015