TOWARDS OVERSET LES FOR AEROACOUSTIC SOURCE PREDICTION

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Abstract In this contribution an application of a computational aeroacoustics code (CAA) as a hybrid Zonal DNS tool is presented. The here used hybrid approach is based on a novel implementation of the Non-Linear Perturbation Equations (NLPE) extended with viscous terms, denoted as overset since a perturbation analysis is performed on top of a background flow. It is found that Direct Noise Computation results of a cylinder in uniform flow show the dipolar sound radiation characteristic as well as the expected decay of sound pressure level with distance. The extension to LES is illustrated with isotropic decaying turbulence, where the expected -5/3 slope of the reference DNS data is recovered with the LES employing the classical Smagorinsky model.

INTRODUCTION

The PIANO-code (Perturbation Investigation of Aerodynamic NOise) is a Computational Aeroacoustics (CAA) code which encompasses many traditional CAA-features such as block-structured, high-order, low dispersive and dissipative characteristics [3]. PIANO solves perturbation equations over a time-averaged background flow and therefore constitutes a hybrid approach. Such hybrid approaches are common in simulating aeroacoustic problems (see, e.g., [4, 2]). The task of computing the sound generation is separated from the sound propagation, where this latter propagation is computed with perturbation equations. The perturbation equations include the Linearised Euler Equations (LEE), Acoustic Perturbation Equations, and also non-linear Euler Equations. In the majority of cases, the base flow is obtained with a Reynolds Averaged Navier-Stokes (RANS) simulation (i.e., constitutes a steady background flow).
Viscous and nonlinear effects are generally neglected as they play a minor role when sound propagation is studied over small distances. However, approaches based on such disturbance equations ignore the direct influence of viscosity on the sound generation and the subsequent sound propagation. To correctly account for viscous effects is considered essential for direct noise simulation of sound generation and propagation problems. The nonlinear Euler equations have been supplemented by fluctuating viscous terms and therefore represent the full (non-linear) Navier-Stokes equations expressed in perturbation form over a given background flow (see, e.g., [4, 1]). Hence, the CAA-code PIANO can be applied as a Direct Numerical Simulation (DNS) tool to directly simulate laminar or turbulent sound generation or even Direct Noise Computation (i.e., DNC, see [2] for an overview). As opposed to the so-called embedded approach (see, e.g., [5]), the here proposed method is denoted as Overset to emphasise that the DNS is performed on top of a background flow.

GOVERNING EQUATIONS AND NUMERICAL METHOD

The basis of the present work are the viscous Non-Linear Perturbation Equations (NLPE), which are derived from the compressible Navier-Stokes equations in nonconservative form. For a detailed derivation the reader is referred to Ref. [4]. The primitive variables are decomposed into a base flow part and a fluctuating part, e.g., by substituting the $\boldsymbol{p}^0$ and $\boldsymbol{p}'$. Terms containing solely background flow contributions are grouped on the right-hand side. Typically, these residuals source terms represent the residual turbulent viscous stress and heat flux whose definition is related to the base flow. In general, the only assumption made is that the background flow is also a solution of the Navier-Stokes equations.
The CAA-Code PIANO [3] is a structured code, based on curvilinear, multi-block grids. In addition to the above mentioned viscous NLPE, it also supports the computation of sound propagation by the Linearized Euler Equations (LEE), Acoustic Perturbation Equations (APE) and non-linear Euler equations in primitive disturbance form as governing equations. Spatial gradients are approximated by the Dispersion Relation Preserving (DRP) scheme[7], whereas temporal integration is facilitated by a 4th-order low-dispersion Runge-Kutta (LDDRK) algorithm [6].
In Fig. 1 (left) isocontours of pressure are displayed for the cylinder flow. The pressure fluctuations strongly radiate in the flow-normal direction (dipole radiation character) and the convective amplification can be appreciated in the upstream direction as well as strong hydrodynamic fluctuations in the cylinder wake. Note that this is a Direct Noise Computation (DNC) result. In Fig. 1 (right) the decay of peak pressure fluctuations is presented. Comparison with the theoretical expected decay of $r^{-0.5}$ reveals an excellent agreement for the considered Mach numbers.

DECAYING TURBULENCE

Isotropic decaying turbulence is a canonical test case for higher-order CFD methods. Furthermore, it serves the purpose of a generic test case for the subgrid-scale investigation. The flow is initialised with high-resolved DNS data from Wray [8] after which decay sets in. In Fig. 2 (left) isocontours of the Q-criterion are displayed for $t^* = \frac{1}{3}t$. In the right plot

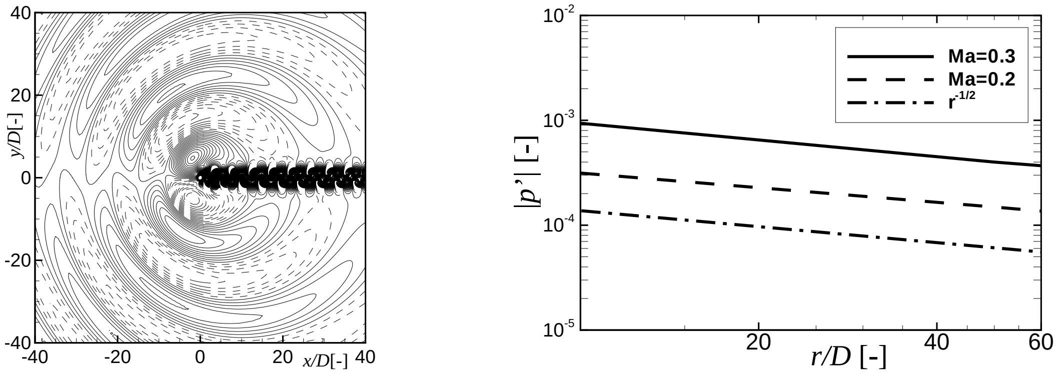

Figure 1. (left) Isolines of pressure fluctuations p' around the cylinder (solid line indicates positive values, dashed ones negative), and (right) decay of pressure peaks with distance r compared to the theoretical decay of $r^{1/2}$ for two Mach numbers.

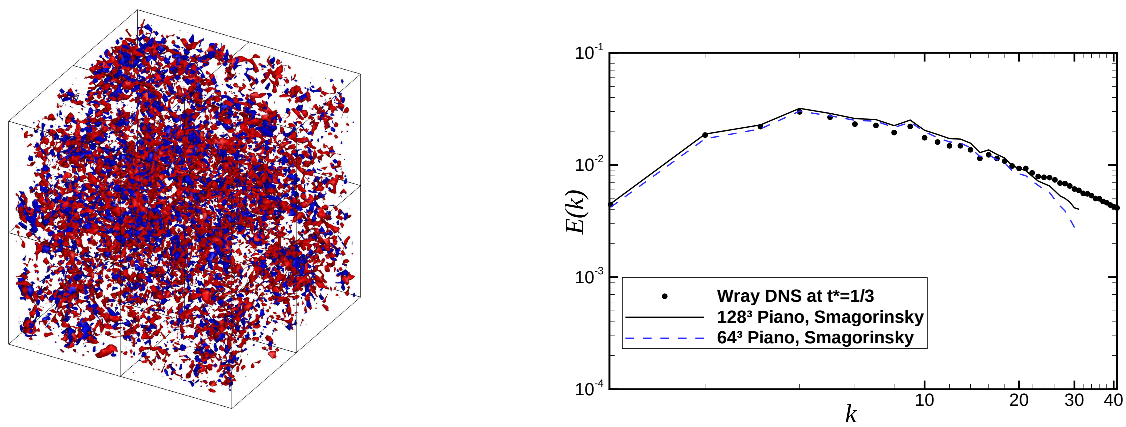

Figure 2. (left) Isosurfaces of the Q-criterion for isotropic decaying turbulence at $t^* = \frac{1}{3}t$, and (right) 3D energy spectrum of the velocity components.

of Figure 2 the wavenumber spectra is displayed of the simulation together with the reference spectrum obtained with resolution 512^3 by Wray at $t^* = \frac{1}{3}t$. The close agreement between the data confirms the expected low-dissipation and dispersion character of the numerical method. Furthermore, it illustrates the correct implementation of the subgrid-scale model (dashed line 64^3) thereby completing all necessary components of a hybrid Zonal LES tool for aeroacoustic source predictions.

References

[1] R.A.D. Akkermans, R. Ewert, M.S.A. Moghadam, J. Dierke, and N. Buchmann. Overset dns with application to sound source prediction. In *Proceedings of 5th Symposium on Hybrid RANS/LES Methods, 19-21 March 2014*.

[2] C. Bailly, C. Bogey, and O. Marsden. Progress in direct noise. *International Journal of Aeroacoustics*, **9**:123–143, 2010.

[3] J.W. Delfs, M. Bauer, R. Ewert, H.A. Grogger, M. Lummer, and T.G.W. Lauke. *Numerical Simulations of Aerodynamic Noise with DLRs aeroacoustic code PIANO, Version 5.2*. User Manual, 2008.

[4] R. Ewert, M. Bauer, and M. Lummer. A review of state-of-the-art aeroacoustic prediction approaches. In *Aircraft Noise, VKI Lecture Series, 2012-02*.

[5] J. Fröhlich and D. von Terzi. Hybrid les/rans methods for the simulation of turbulent flows. *Progress in Aerospace Sciences*, **44**:349–377, 2008.

[6] F.Q. Hu, M.Y. Hussaini, and J. Manthey. Low-dissipation and low-dispersion runge-kutta schemes for computational acoustics. *Journal of Computational Physics*, **124**:177–191, 1996.

[7] C.K. Tam and J.C. Webb. Dispersion-relation-preserving finite difference schemes for computational aeroacoustics. *Journal of Computational Physics*, **107**:262–281, 1993.

[8] A. Wray. Unpublished dns data. Test Cases for the Validation of Large-Eddy Simulations of Turbulent Flows, ftp://torroja.dmt.upm.es.