# INFLUENCE OF SUB-GRID SCALE MODELS FOR LARGE EDDY SIMULATIONS ON THE ACOUSTIC NOISE PRODUCTION IN JETS

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*Abstract* A high subsonic jet is simulated by solving the compressible Navier-Stokes equations using Large Eddy Simulation. The sub-grid scales (SGS) are handled by using three different approaches, e.g. the Smagorinsky-Lilly model, a dynamic SGS model and an implicit approach. Lighthill's acoustic analogy indicates that the Reynolds-stress term is a significant term to predict accurately acoustic noise. The obtained turbulent production and dissipation terms are analyzed and compared for all three SGS methods. The obtained statistics are linked with the turbulent acoustic noise production.

## INTRODUCTION

Aeronautic noise generated by jet engines represents an issue in the urban regions of airports. As a consequence, development of acoustic noise reduction technologies and aeronautic noise prediction tools accelerated in the last years.

For a systematic strategy to decrease the radiated acoustic noise into the ambience, it is important to understand the noise generation mechanisms. Experimental measurements and numerical prediction of acoustic noise have been carried out successfully. Despite of this fact, the noise production mechanism it is not completely understood. The flow data includes the acoustic noise production terms. However, the analyzation and visualization of the process is not trivial.

Numerically, the determination of the origins of a particular acoustic noise source has been performed using correlation analysis [1]. Also experimentally, the localization of turbulent acoustic noise sources has been done based on cross-correlation analysis of pressure and velocity data [5].

The term *acoustic analogy* refers to a wave propagation formulation valid in stagnant ambience with acoustic source terms originating from the complex compressible flow governing equations. Hence, result of a fluid-dynamic simulation in a limited area embedded in a uniform stagnant fluid can be used for calculating the acoustic sources. Then the non-homogeneous wave equation can be solved to calculate the acoustic propagation into the far-field.

To obtain the acoustic field Direct Numerical Simulations of the unsteady Navier-Stokes equations can be performed. All fluctuations, spatially and temporally, up to the smallest hydrodynamic scales, i.e. the Kolmogorov scales, are resolved within these calculations. This results in a high numerical effort, which can be carried out only on segments of realistic applications. In these simplified cases, acoustic analogies could be used successfully to visualize acoustic noise sources in the hydrodynamic flow-field [4, 7].

In many industrial applications, the relevant scales separate. The smallest hydrodynamic scales, e.g. in a boundary-layer, are quite small compared to the length-scales of the acoustic waves radiated into the far-field. This discrepancy in length-scales makes it difficult to resolve all scales. The numerical effort would be too high to resolve all scales of fluid-dynamic simulations of industrial applications. Hence, Large Eddy Simulation is the preferred approach. However, the small turbulent scales, as e.g. initial boundary-layer [2], have relevance for acoustic noise predictions, and the sub-grid model can have an influence on the development of the small turbulent scales and therefore have an impact on acoustic noise estimations.

## METHOLOGY

The three-dimensional compressible Navier-Stokes equations are simulated numerically by a finite volume code, using the Large Eddy Simulation approach. Hence, the substantial fluid-motion and the turbulent fluctuations within the inertial subrange are resolved using a fine enough numerical grid. The scales smaller than the computational cell size are filtered by the numerical grid. Within three cases, the sub-grid scales are modeled by the Smagorinsky-Lilly model, a dynamic SGS model, and handled implicit.

A low-storage four-stage Runge-Kutta scheme using standard coefficients is applied for the time integration. A second order central difference scheme is used for the spatial discretization of the convective terms. A blend of second and fourth order differences is employed to ensure the required artificial dissipation.

## OBJECTIVE OF THIS STUDY

A high subsonic jet originating from a coaxial nozzle is simulated by solving the three-dimensional Navier-Stokes equations [6]. The application is treated in three cases by three different SGS approaches. The density-field showing the occurring structures in the exhausting jet of the coaxial nozzle can be seen in figure 1. The shape of the small scale vorticity generated at the nozzle trailing edges of the nozzle system is highly dependent on the mesh-grid resolution and the turbulent viscosity.

The main aim of this study is to link turbulent production and dissipation terms with the turbulent acoustic noise generation process. Therefore, statistics of the turbulent properties will be presented and the significance of the terms in the turbulent transport equation for an acoustic event will analyzed.

Further, the suitability for acoustic noise prediction of three approaches for handling the sub-grid scale terms are compared to each other. Cross-correlation analysis of data (pressure and velocity) in monitoring points within the shear-layer, jet-plume, and the acoustic near-field region will be presented and contrasted for all SGS approaches.

The attempt is made to visualize the pseudo noise sources in the hydrodynamic region by calculation of the acoustic terms in usually employed acoustic analogies.

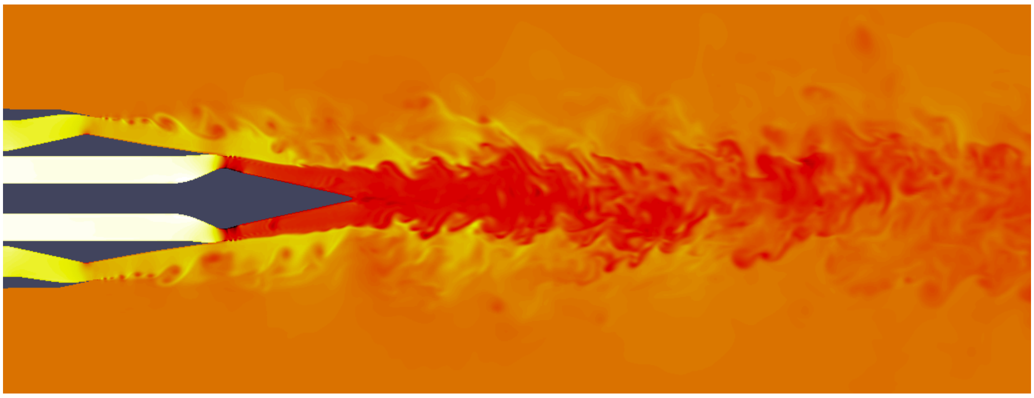

**Figure 1.** The density-field of the high subsonic jet exhausting a coaxial nozzle is shown. Small-scale phenomena in the shear-layers can be seen, hows evolution depends highly on the mesh-resolution and turbulent viscosity. The importance of resolving these for acoustic purposes, can be stated by correlation analysis of the emitted pressure and the far-field pressure observation[3].

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