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Two-Way Coupling between Flow and High-Order Non-linear Acoustic Unstructured Solvers: Application to Space Launcher Lift-off Acoustics

François Vuillot¹, Adrien Langenais, Julien Troyes
DMPE, ONERA, University of Paris-Saclay, F-91123 Palaiseau, France

Christophe Peyret,
DAAA, ONERA, University of Paris-Saclay, F-92322 Châtillon, France

Introduction

During the lift-off phase of a space launcher, rocket motors generate a harsh acoustic environment that is a concern for the payload and surrounding structures. The hot supersonic jets contribute to the emitted noise from both their own noise production mechanisms and their interactions with launch pad components, such as the launch table and the flame trenches. With the rapid development of CPU power, aeroacoustic simulations have become available in the recent years, in particular for jet noise. Due to the high acoustic levels (> 150 dB) and the complex secondary flows that are created during launch, empirical methods or linear acoustic approaches, such as the FW-H (Ffowcs-Williams & Hawkings) method, fail to accurately predict the generated acoustic field and the acoustic stresses received by the launcher and its payload. This limitation motivated the development of advanced numerical methods that combine a high fidelity LES flow solution of the jet, to resolve the acoustic sources, and a non-linear high-order acoustic solver, to compute the acoustic wave propagation and interactions with complex flows and surrounding structures. The presentation discusses the main choices performed to establish the unsteady, two-way coupling, methodology and to validate it on academic test cases. The methodology is then evaluated on a subscale experiment, conducted by CNES at the MARTEL facility [1] operated by Institut P' in Poitiers, to study the main flow and the far field noise of a hot, over-expanded, supersonic jet. The benefits of the present methodology are discussed.

Main principles

The proposed methodology aims at fully coupling a NS/LES solver to a full Euler acoustic solver in a robust and precise way, in a demanding HPC context. ONERA in-house codes CEDRE [2] and SPACE [3, 4] are respectively used and are fully coupled through the CWIPI library [5]. Both codes operate on unstructured grids which permit to easily describe the complex geometries typical of actual launch pads. The coupling is operated along a common boundary of the two solvers. In order to avoid temporal and spatial aliasing, the solvers are set to operate at identical time steps and the coupling is conducted at every time step. Further, the boundary shares the same grid points on both sides, meaning that the grids are fully

¹ francois.vuillot@onera.fr

coincident along the coupling interface. The coupling is purely surfacic and no overlapping is needed, which greatly simplifies the coupling procedure in view of HPC computations. The order mapping permitted by the acoustic solver is used to match the solver order at the interface where the spatial resolution is dictated by the second order LES simulation. Away from the interface, the grid in the acoustic domain is coarsened, as the order of the acoustic solver is increased up to the fourth order, to reduce the CPU cost while preserving the overall second order accuracy of the simulation. These choices ensure a robust and consistent coupling, free of any aliasing problems, while keeping the accuracy and CPU costs under control. Another important point, permitted by the CWIPI library, is that no specific boundary condition is needed in any solver as the coupling interface can emulate existing boundary conditions of both solvers. The coupling procedure operates in a two-way mode, allowing that the information be freely exchanged from one solver to the other according to the physics of the solution.

Validation and Application

The coupling procedure has been thoroughly checked and validated thanks to a series of academic test cases, as described in [6]. This work covered the cases of spherical waves, planar waves in a wave guide, reaching high acoustic levels leading to non-linear wave propagation. In order to check the two-way coupling, the case of a standing wave in a cavity divided by the interface was considered as well as the case of a convected isentropic vortex crossing two successive interfaces. Finally, the case of a launch pad model proved the robustness of the methodology on a complex geometry. All test cases demonstrated the good properties of the proposed approach. These results opened the way for applications to actual test cases. The methodology was then applied to the case of the free jet operated in the MARTEL facility. This configuration had been previously computed with a simpler approach where the far field noise was computed through a FW-H linear approach. Based on the same LES computation, the two-way coupled NS-Euler provided improved results on the far field acoustic [7]. Further, the attention was focused on the LES part of the computation and an improved jet flow solution was achieved on a refined mesh, thanks to a better turbulence description. As mentioned by several authors, the turbulent state of the exiting nozzle boundary layer is a key parameter for jet noise simulation (e.g. [8]). A small geometric step was added to the nozzle wall to force the turbulence transition. The combination of turbulence tripping that produced highly perturbed conditions at the nozzle exit and the present non-linear acoustic wave propagation provided far-field levels within 1 dB of experimental measurements. These results (see Fig. 1 and 2) obtained on a 300 Mcell grid and on 1736 cores of the ONERA super computer will be detailed in the symposium presentation.



Fig. 1: instantaneous vorticity field

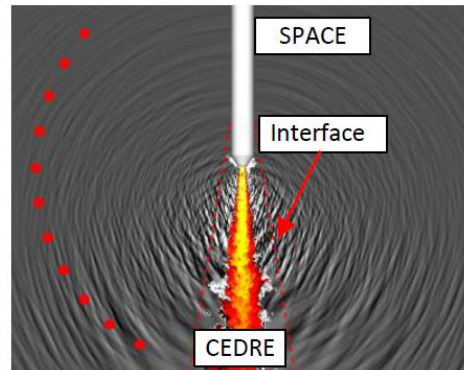


Fig. 2: overall view of instantaneous density field

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