Hessisches Kompetenzzentrum
für Hochleistungsrechnen

Development of a Coupled CFD-CAA Tool for the Acoustic Simulation of Modern Combustion Chambers



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Introduction

Next generation aircraft engines will rely on premixed combustion systems, which are more prone to thermoacoustic instabilities and thus require improved methods for the prediction of combustion noise. This project aims to develop a numerical methodology which exploits the different scales prevalent in these combustion systems by computing the flow field and acoustics separately and coupling both simulations in real time. This approach is at least ten times more computationally efficient than current state of the art compressible simulations, while still accounting for all relevant physical phenomena and delivering predictions of similar fidelity.

Methods

Future air traffic regulations are going to further limit the pollutant emissions of aero engines, which can only be achieved by lean premixed combustors. However, these next generation combustion systems are more prone to acoustic instabilities than the conventionalrich-quench-lean setups [1]. In order to predict these instabilities during the design phase of a combustor and better understand existing designs, improved combustion noise simulation tools are required.

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Different approaches with varying degrees of abstraction have been proposed, which differ vastly with regard to their computational cost and predictive capabilities. The most accurate predictions, even for complex combustors, are currently obtained from fully compressible Large Eddy Simulations (LES) [2,3]. However, these simulations require immense computational power due to their small timestep size, which is bound by the time scales of the acoustics. In the current project, this issue is overcome by the use of a low Mach number Computational Fluid Dynamics (CFD) solver, which only needs to resolve the flow field time scales and can consequently operate at considerably larger timesteps. Since the low Mach number solver can not account for the acoustic wave propagation, this part is offloaded to a dedicated Computational Aero Acoustics (CAA) solver.The scope of the CAA is limited to the acoustic wave propagation, meaning that largetime scale phenomena such as the flow field, turbulence and combustion can be neglected. This facilitates the use of much simpler governing equations, more appropriate numerical schemes, coarser numerical meshes and non-conforming computational domains. These simplifications amount to the CAA being able to operate at the compressible LES timestep size with considerably greater efficiency, causing the developed methodology to require substantially less computational time than a compressible LES.

Results

While for the CFD part, a finite volume based LES solver is used, a time-domain, spectral h/p element solver is used for the CAA. This enables the application to account for complex, three-dimensional geometries and non-quiescent media. The different numerical approaches and temporal and spatial scales of the CFD and the CAA required designing an elaborate coupling scheme, that provides optimal accuracy, prevents numerical instabilities and introduces minimal computational overhead. This setup, consisting of the low Mach number CFD tool, the time domain CAA solver and the coupling layer,which enables running high fidelity time domain combustion noise simulations of complex geometries at reasonable computational cost for the first time.

Reference

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