CAA Calculations of Aero- and Hydrodynamically Induced Noise

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Introduction

The authors aim to use CAA like methods for the prediction of rotating machinery noise induced by its aero- as well as hydro-dynamical flow. CAA - Computational Aero-Acoustics are high order finite difference methods, especially designed for the fieldwise computation of aerodynamically generated wave propagation. The method is well established in aircraft noise investigation, such as noise generated by aircraft wings. However, in the context of rotating machinery, especially when it comes to internal flows, several additional problems arise, concerning the source-interpolation in the non-linear source region, grid dependance and accuracy etc. With rotationg machinery also flow driven structural vibrations become an issue. Within this contribution, approaches of using CAA for both aero- and hydro-dynamically generated noise and an integrated approach for acoustics with fluid structure interaction will be presented and will be discussed in the context of fluid machinery.

Overview and Aims

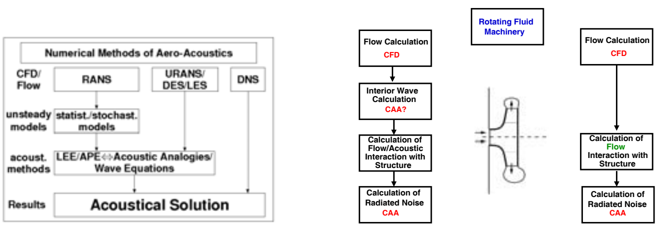

Figure 1: CAA schemes

Fig. 1 (left) shows an overview on typical hybrid acoustical methods compared to Direct Numerical Simulation (right column, DNS). DNS contains all scales of flow motion - including acoustical waves - but is still not feasible with present high performance computers for flow cases of realistic geometries and high Reynolds numbers. The hybrid methods like CAA have been developed to fill in, being able to calculate flow cases of engineering importance. The aim is the automization of the recognition of source information in a flow system, the interpretation of the sources' strengths and a proper conclusion on the generated sound waves, pressure levels and intensities. In the following, only those methods consisting of a field calculation method for acoustical waves are called CAA.

Requirements for Fluid Machinery

Fig. 1 (right) shows a sequence of schemes that would provide fluid machinery with an overall acoustic prediction. The left column of this figure shows what would be desired: A flow calculation, determining the acoustical sources, a calculation of the generated waves within the machine, one for the flow/wave induced structure vibrations and a final one of the excited waves propagating to the outside. Since the majority of fluid machinery, e.g. in climatization or plumbing, is surrounded by steady walls (casings, pipelines), their effect on the sound wave propagation cannot be neglected. For inclusion of such effects, CAA fieldwise calculations seem a consequent approach for the inner and outer wave propagation, whereas fluid-structure interaction methods account for the noise transport through the casings. As in CFD, a CAA calculation resolves the waves' movements, numerical boundaries must be defined, e.g. fully reflective walls. Can this goal be achieved easily? Several critical points must be discussed and investigated.

Closed Systems

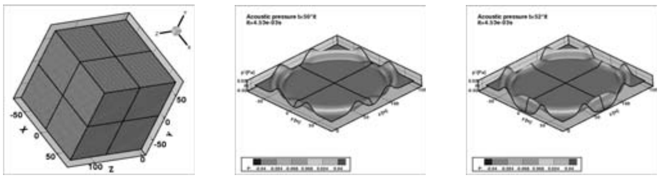

Figure 2: Cube grid geometry (left) and wave initiated by a pulse in the cube center and travelling to the cube walls (middle and right, cut through cube center along x-z-plane)

Most CAA methods use a linear set of equations (e.g. lin. Euler) for the sound wave calculation. These methods were developed mainly for calculation of wave generation and propagation from jet streams and aircraft wing noise. Here, a CFD calculation is necessary to predict the acoustical source information. The grids for acoustics and CFD are not necessarily identical, and in most cases are not, but overlap. The required source information is interpolated in the overlap region from the CFD grid to the CAA grid. The CAA calculation appears as a postprocessing procedure, e.g. after a certain amount of CFD time steps. To demonstrate the ability of linearized equations for CAA calculations, it is not necessary to interpolate from CFD calculations. It can be defined a type of source and observed the generated wave movement. An example is given in fig. 2 [2] and will be demonstrated within the presentation in more detail.

CAA was originally developed for open air flow problems. The application of these methods to rotating machinery seems straight forward. However, two problems arise: with internal flows, both grids are identical in their bounds (though not necessarily in their cell distribution), so that the source interpolation at the bounds (CFD boundary conditions differ from acoustical ones) is not straight forward. Second, both grids span eventually a source region which is highly non-linear, so non-linearized equations for acoustics have to be chosen. This is the reason why in fig. 1 (right), left column, the first CAA entry ends with a question mark. So for those cases, where the flow dominates the structural excitation, this step might be neglected and the right column of fig. 1 (right) might be followed instead.

Hydraulic Systems

A third problem arises, when the flow medium is a liquid. Due to their often lower Mach numbers, liquids require either incompressible CFD - which does not predict shocks, or require special treatment with compressible CFD, since those equations tend to get stiff for low Mach numbers and the results degenerate. The latter would be desirable for capturing shock effects also with liquids. Using a preconditioning is a solution, however, it works only with implicit time advance schemes [5]. This is not a principle draw back, since explicit time advance schemes require smaller time steps to be stable than implicit time schemes, which are unconditionally stable. With such small time steps a low Mach numbered flow calculation would require far more calculation time for the solution to develop in the whole computation domain. The example in fig. 2 will be shown with wave carrier medium water, too.

Grid Sensitivity

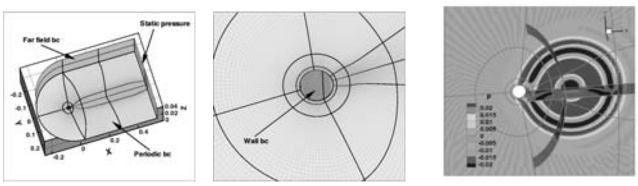

Figure 3: Cylinder geometry (left and middle) and wave initiated by a pulse behind the cylinder (right), being reflected by the cylinder wall

CAA methods imply high order schemes to avoid too much wave dispersion by the numerical scheme. Though using generalized curvelinear coordinates, for strongly curved mesh regions unphysical effects are observed. As long as the acoustical mesh is close to equidistant, the DRP [4] scheme, which became a popular standard, works perfectly. However, typical CFD meshes follow closely the geometry, which is perfectly acceptable for flow calculations. For CAA this must be thought over. Immersed boundary conditions where they are defined implicitely, allowing Cartesian grids, might be a future solution. An example of a strongly curvelinear mesh will be presented as sketched in fig 3.

Fluid Structure Interaction

For the calculation of flow excited structural movements, an interface was created within the authors' CFD/CAA code with the aim to attach a suitable structure code.

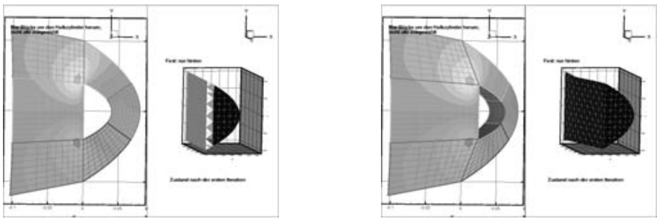

Figure 4: Deformation of structure due to flow around half cylinder; left: initial position, right: moment shot of deformation

A well documented code was found in Z88, created by F. Rieg, University of Bayreuth, Germany [3]. The interface provides interpolation of flow pressures on the structure surface, which consists of tetraedrons on the unstructured structure mesh, and the backward interpolation of the structural deformation to update the flow grid. Fig. 4 shows the initial position and a moment shot of the flow induced structural deformation of a flow around a half cylinder. This will be discussed in more detail within the presentation.

Conclusion

For noise predictions of closed rotor systems as appearing in most of the fluid machinery applications, a sequence of methods like sketched in fig. 1 (right) should be followed. Integrated in a single code, as the authors propose, this could be an effective method to calculate the overall noise of fluid machinery systems. Major steps are already implemented in the authors' code. The step requiring most development is the use of CAA like methods in the non-linear source region of the interior of the rotor.

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