TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

INSTITUTE FOR MECHANICS AND MECHATRONICS

Examination of the thesis of Paul Croaker

with the title

A Particle Accelerated Hybrid CFD_BEM Method For Low Mach Number Flow Induced Noise

Since the beginning of computational aeroacoustics (CAA), several numerical methodologies have been proposed, each trying to overcome the challenges that the specific problems under investigation pose for an effective and accurate computation of the radiated sound. The main difficulties that have to be considered for the simulation of flow noise problems include energy and length scale disparity, preservation of the multi-pole character of the acoustic sources and dispersion and dissipation occurring in numerical schemes. Currently available aeroacoustic methodologies overcome only some of these broad range of physical and numerical issues which not only restricts their applicability but also makes them problem dependent in many cases. Owing to the practical advantages provided by the separate treatment of fluid and acoustic computations, the hybrid methodologies still remain the most commonly used approaches for aeroacoustic computations. Among the group of hybrid approaches, integral methods remain widely used in CAA for solving large open acoustic domain problems such as airframe noise, landing gear noise, fan (turbines) noise and submarine noise. In this context the thesis of Paul Croaker is focused and concentrates on two main research topics: (1) correct and precise formulations of the source terms; (2) data reduction algorithms for the source terms obtained by CFD computations.

The thesis itself is without any doubt a step forward in computational aeroacoustics. It is very well written and of high mathematical level. All developed algorithms are precisely analysed by demonstrative examples including error and convergence analysis. The first chapter "Introduction and Literature Review" contains the best state of the arte, I have up to now read. On the one hand it contains the main modelling approaches for aeroacoutics in a physical absolute correct description and on the other hand it discusses the main contributions in a quite understandable way. Furthermore, it demonstrates the high level of understanding of Paul Croaker towards aeroacoustics. I appreciate to use the idea of computing the incident acoustic pressure and pressure gradient by solving Lighthill's integral and then apply this to a Boundary Element (BE) formulation to compute the scattered field. In this way, we obtain a clear separation between the main acoustic source terms and the radiated acoustic field. Furthermore, this approach uses the physical correct volume source terms as obtained by

Lighthill's derivation. Classical approaches as, e.g., the Kirchhoff - Ffowcs Williams and Hawkings (FWH) method is based on surface integrals using equivalent sources and do not provide inside into the actual acoustic sources generated by the flow within the volume. The same is true for the classical FWH integral, where in most calculations the computational expensive volume term is neglected. However, a main challenge in such an approach as used by Paul Croaker is the precise representation of the source terms (which include derivatives of the CFD data) and a data compression technique to achieve an efficient computation of the radiated sound. These two challenges are the main focus of the thesis and I strongly appreciate the solution approaches provided within the thesis. The application of the k-exact reconstruction technique to evaluate the Lighthill tensor as well as its derivatives based on cell centred CFD data results for k larger than two to extremely accurate result. This is also true for the computed pressure and pressure gradient of the incident field, where the occurring singular and hyper-singular integrals have been solved in a quite elegant approach. The second challenge concerning the data compression technique is based on a multi-pole particle condensation method. Thereby, the particle approach is combined by a Taylor series expansion of the harmonic Green's function relative to the particle's centre. Here, a reduction by a factor of approximately 120 resulted in just a deviation of 0.5 dB within the sound pressure level compared to non-condensed computations.

Overall the thesis is well written, the presented approaches towards computational aeroacoustics are of a high scientific level and the achieved results can be considered as a step forward in aeroacoustics. Furthermore, I have just found minor errors and omissions (see attached pdf-file).

In summary, after examination of the thesis I recommend that the thesis merits the award of the degree (category A).

M. Kalten

Vienna, 15th May 2014 Prof. Dr. Manfred Kaltenbacher