Parallel Applications of a Computational Aeroacoustics Software Suite

Paul Batten* and Sukumar Chakravarthy
Metacomp Technologies, Inc.
28632 Roadside Drive, Suite 255
Agoura Hills, California 91301, USA
Email: batten@metacomptech.com

Key Words: Parallel Algorithms, Domain Decomposition, Volume Integration, Surface Integration, Wave Propagation.

ABSTRACT

Simulation of aeroacoustics phenomena in realistic engineering environments represents a challenge to even the best available modern supercomputers. The inherently time-dependent nature of acoustics, coupled with the possible interactions with, and non-linear feedback from, complex geometries, creates challenges beyond those encountered in most conventional fluid mechanics simulations. The majority of aeroacoustics problems of engineering interest face such severely disparate scaling issues that one can only begin to tackle the problem by separating the physical processes. The physics is typically segregated into the near-field generation process, and the far-field propagation, or scattering, of the resulting acoustic waves. Both steps can challenge the limits of conventional computing requirements and thus the use of parallel computing has become an essential tool to allowing engineers obtain useful predictions within a realistic time frame. This paper discusses the experiences, accumulated over several years, of implementing and utilizing a range of acoustics tools that collectively comprise the CAA++ suite, developed at Metacomp Technologies, Inc.

The most widely-used concept in computer simulation of field equations is that of domain decomposition (Fig. 1), which attempts to load balance by sharing the work evenly between the available computing nodes, whilst minimizing the communication to calculation ratio. Tree- or graph-based algorithms produce suitable decompositions by minimizing interconnects (the region boundary or surface area), relative to the number of internal nodes or cells which form the smallest work unit. Explicit wave propagation algorithms are well suited to this parallelization strategy and are widely used for computational aeroacoustics (CAA), since acoustic wave speeds are often relatively constant far from the noise source and the computational mesh is usually (and intentionally) made isotropic and homogeneous in that region, because of accuracy requirements. Other than global input/output, such algorithms require the communication of only a minimal set of data comprising a small number of halo layers of cells surrounding the region or data assigned to each processor. Such algorithms are often termed loosely synchronous, since each processor requires only a communication from its immediate neighbors before advancing its own data to the next time level.

In practice, however, implicit methods[1,2] play the more dominant role in most computational engineering simulations, including CAA simulations, due to the relaxed requirement on the choice of time step. Complex geometries are increasingly treated using automatic or semi-automatic mesh generation software, in which any form of mesh clustering (even very localized)

can render explicit methods ineffective, due to the tiny time steps that would be required for stability. Implicit schemes based on dual time-stepping algorithms, on the other hand, allow an appropriate time step to be chosen based on accuracy considerations; the user typically does not then have to worry about stability. An effective implementation of a parallel implicit scheme is somewhat more challenging, since the communication requirement between regions, or CPUs, grows (as physically one should expect, with increasing time step or Courant number). Issues facing implicit multi-grid schemes are discussed in the full paper.

The parallelization of specialized acoustics algorithms usually require separate strategies, since most algorithms used for far-field propagation do not use numerical simulation for acoustic wave propagation, but treat this step instead with a semi-analytic approach, based on the assumption of a spherical decay as the acoustic waves spread from their source. The CAA++ suite involves two such methods. The mcaa_wavepropl tool provides a means of extracting noise directly from RANS statistics, based on a volume integration of the noise sources. Although domain decomposition can also be used for volume integration, the global communication requirements are different. The other important class of semi-analytic acoustic solver uses surface-source integration, an example of which is the mcaa_wavepropf (Ffowcs-Williams/Hawking[3]) solver in CAA++. These algorithms are based on retarded-time integrals of data captured, a priori, on user-specified surfaces. Although surface decomposition can be used to partition the problem, the retarded time requirements dictate that different regions are not only processing data at different physical locations, but also that this data is being processed at physically different times. Further consideration of these issues is provided in the full paper.

Fig. 1: Domain/CPU partitioning for time-domain CAA simulation of a trap-wing

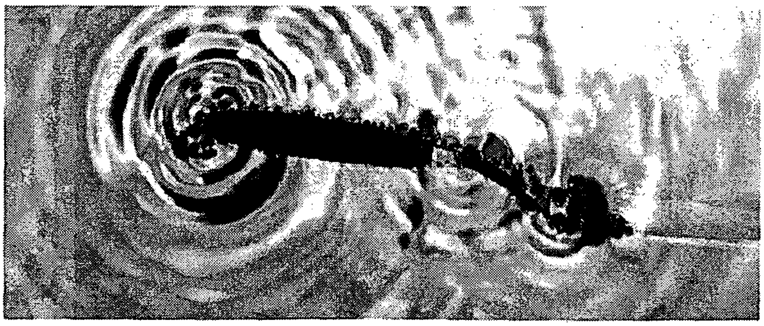

Fig. 2: Acoustic pressure from time-domain CAA simulation of a trap-wing

The full paper will also provide more details on the multiprocessor performance of the CAA++ simulation methodologies. We present below, in Figure 3, an example.

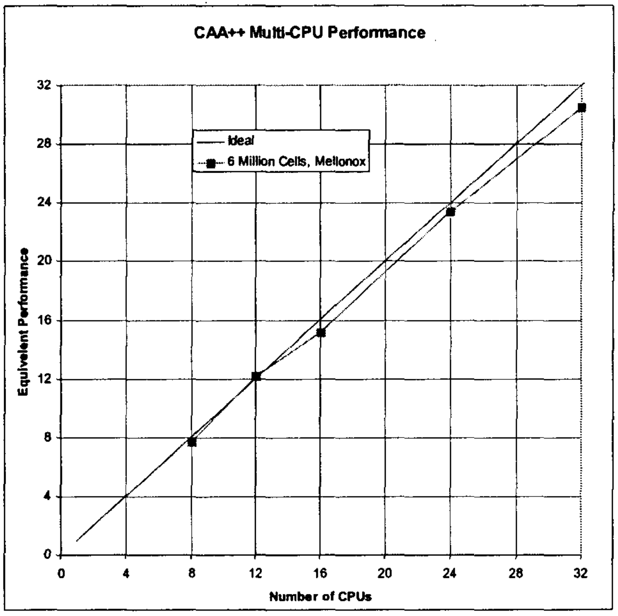

Fig. 3: Multi processor performance of CAA++ component

REFERENCES

1. Peroomian and S. Chakravarthy "A 'Grid-Transparent' Methodology for CFD," AIAA Paper No. 97-0724, Reno 1997.

2. P. Batten, E. Ribaldone, M. Casella, S. Chakravarthy, "Towards a Generalized Non-Linear Acoustic Solver", AIAA-2004-3001, 10th AIAA/CEAS Aeroacoustics Conference, Manchester, 2004.

3. Ffowcs-Williams, J. E and Hawkings, D.L., Sound Generated by Turbulence and Surfaces in Arbitrary Motion, Phil. Transactions of the Royal Society of London, Series A, 264, 1969.