Abstract

NUMERICAL ALGORITHMS FOR THREE DIMENSIONAL COMPUTATIONAL FLUID DYNAMIC PROBLEMS

The target of this work is to contribute to the enhancement of numerical methods for the simulation of complex thermal systems. Frequently, the factor that limits the accuracy of the simulations is the computing power: accurate simulations of complex devices require fine three-dimensional discretizations and the solution of large linear equation systems.

Their efficient solution is one of the central aspects of this work. Low-cost parallel computers, for instance, PC clusters, are used to do so. The main bottle-neck of these computers is the network, that is too slow compared with their floating-point performance.

Before considering linear solution algorithms, an overview of the mathematical models used and discretization techniques in staggered cartesian and cylindrical meshes is provided. The governing Navier-Stokes equations are solved using an implicit finite control volume method. Pressure-velocity coupling is solved with segregated approaches such as SIMPLEC.

Different algorithms for the solution of the linear equation systems are reviewed: from incomplete factorizations such as MSIP, Krylov solvers such as BiCGSTAB and GMRESR to acceleration techniques such as the Algebraic Multi Grid and the Multi Resolution Analysis with wavelets. Special attention is paid to preconditioned Krylov solvers for their application to parallel CFD problems.

The fundamentals of parallel computing in distributed memory computers as well as implementation details of these algorithms in combination with the domain decomposition method are given. Two different distributed memory computers, a Cray T3E and a PC cluster are used for several performance measures, including network throughput, performance of algebraic subroutines that affect to the overall efficiency of algorithms, and the solver performance. These measures are addressed to show the capabilities and drawbacks of parallel solvers for several processors and their partitioning configurations for a problem model.

Finally, in order to illustrate the potential of the different techniques presented, a three-dimensional CFD problem is solved using a PC cluster. The numerical results obtained are validated by comparison with other authors. The speedup up to 12 processors is measured. An analysis of the computing time shows that, as expected, most of the computational effort is due to the pressure-correction equation, here solved with BiCGSTAB. The computing time of this algorithm, for different problem sizes, is compared with Schur-Complement and Multigrid.

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Contents

List of Algorithms

Acronyms

ACM	Additive Correction Multigrid
AMG	Algebraic Multi Grid
BiCGSTAB	Bi Conjugate Gradient STABilized
CFD	Computational Fluid Dynamics
CFL	Courant Friedrich Levy condition
CG	Conjugate Gradient
CGA	Coarse Grid Approximation
CTTC	Centre Tecnologic de Transferencia de Calor
DFT	Discrete Fourier Transform
DPC	Biblioteca per al Desenvolupament de Programes aplicats a la resolucio de problemes Combinats de transferencia de calor i massa
DDACM	Domain Decomposed ACM
FVM	Finite Volum Method
GMRESR	Generalized Minimal RESidual Restarted
GS	Gauss-Seidel
HPC	High Performance Computing
HMT	Heat and Mass Transfer
ILU	Incomplete Lower Upper
JFF	Joan Francesc Fernandez PC cluster
LU	Lower Upper decomposition
MIMD	Multiple Instruction Multiple Data
MG	Multi Grid
MPI	Message Passing Interface
MPMD	Multiple Program Multiple Data
MRA	Multi Resolution Analisys
MSIP	Modified Strogly Implicit Procedure
PC	Personal Computer
SC	Schur Complement method
SIMD	Single Instruction multiple Data
SIMPLE	Semi-Implicit Method for Pressure-Linked Equations
SIP	Strongly Implicit Procedure
SIS	Strongly Implicit Solver
SPAI	SParse Approximate Inverse
SPMD	Single Program Multiple Data