NATIONAL TECHNICAL UNIVERSITY OF ATHENS
School of Mechanical Engineering
Fluids Section
Laboratory of Thermal Turbomachines

PhD Thesis

AERODYNAMIC ANALYSIS AND DESIGN METHODS AT HIGH AND LOW SPEED FLOWS, ON MULTIPROCESSOR PLATFORMS

Varvara G. Asouti

Athens 2009

Supervisor: **Kyriakos C. Giannakoglou,** As. Professor NTUA

Abstract

This PhD thesis focuses on the development and assessment of methods for the analysis and design – optimization of aerodynamic shapes, at high and low speed flows, using low Mach number preconditioning. It comprises the development of deterministic optimization methods, by laying emphasis on the computation of the objective function gradient using the adjoint technique with the aforementioned preconditioning as well as stochastic, population–based methods by proposing new asynchronous Evolutionary Algorithms (EA) for multiprocessor systems.

Aiming at possessing a single CFD analysis software for all flow speeds, the preconditioning technique is applied to an existing software for the solution of the compressible flow equations. It ensures faster convergence for very low Mach numbers, allows the solution even in cases in which the non – preconditioned equations fail and provides smooth solution at singular areas (in the vicinity of the leading and trailing edges).

This software is used to numerically predict steady and unsteady flows in turbomachines (including predictions of tip clearance flows), ducts, isolated airfoils, flow around aircraft as well as flows in the presence of smoke in 3D enclosures. The computational gain due to the preconditioning is superimposed to that of multiprocessing.

Concerning the gradient – based optimization methods, the adjoint technique (discrete and continuous) using preconditioning and parallelization is developed. The proposed technique allows the aerodynamic design at very low speed flows and is validated in design – optimization problems of 2D turbomachinery cascades and isolated airfoils. The use of preconditioning during the optimization cycles results to faster solutions of both the mean flow and adjoint equations.

The discrete adjoint technique is developed using the already discretized preconditioned flow equations. For the continuous adjoint formulation there are two possibilities, namely either to precondition the adjoint equations or to form the adjoint to the preconditioned flow equations. In this thesis, these two options are proved to be equivalent (by choosing an appropriate preconditioning matrix). During the formulation of the continuous adjoint equations, “necessary” assumptions, concerning the handling of preconditioning matrix and the discretization, are made. These assumptions introduce a small error to the sensitivity derivatives which, however, does not affect the convergence of the optimization algorithm.

Concerning the stochastic optimization method, a fully asynchronous structured EA – AEA is developed and assessed. The lack of generations removes synchronization problems and allows the maximum utilization of all available processors. The population lies on the nodes of a 2D supporting structured mesh and is divided into overlapping demes, that determine the communication between demes and the implementation of evolutionary operators. The way demes interact determines the asynchronous operation of the algorithm. As soon as an evaluation is over and a processor is “temporarily” idle, the new candidate solution to undergo evaluation is “immediately”' selected by means of intra – and inter – deme procedures, giving rise to the maximum possible parallel speed – up. AEA is coupled, in a new way, with metamodels (radial basis functions networks) for the inexact pre – evaluation of candidate solutions. In the absence of generations, the next candidate solution is selected among a small number of pre – evaluated, using local metamodels, new individuals. The cost of using metamodels is negligible compared to the evaluation cost for the solution of Navier – Stokes equations and assures that all processors are always busy.

Design – optimization problems of 2D compressor cascades and isolated airfoils, the single and multi – objective design of a supersonic business jet and mathematical benchmarks are presented to assess the proposed algorithm. The parallelization both evaluations and evaluation software reduces the wall clock time of an optimization and enables the use of the proposed method for industrial applications.

Keywords: Thermal Turbomachines, Computational Fluid Dynamics, Low Mach Number Preconditioning, Aerodynamic Design – Optimization, Adjoint Methods, Synchronous and Asynchronous Evolutionary Algorithms.