An Adjoint Solver For An Industrial Cfd Code Via Automatic

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Low-cost Unsteady Discrete Adjoint Techniques for Aerocentric Optimization: This book presents selected papers presented in the Symposium on Applied Aerodynamics and Design of Aerospace Vehicles (SAROD 2018), which was jointly organized by Aeronautical Development Agency (the nodal agency for the design and development of combat aircraft in India), Gas-Turbine Research Establishment (responsible for design and development of gas turbine engines for military applications), and CSIR-National Aerospace Laboratories (involved in major aerospace programs in the country such as SARAS program, LCA, Space Launch Vehicles, Missiles and UAVs). It brings together experiences of aerodynamicists in India as well as abroad in Aerospace Vehicle Design, Gas Turbine Engines, Missiles and related areas. It is a useful volume for researchers, professionals and students interested in diversified areas of aerospace engineering.

Design Optimization of Periodic Flows Using a Time-spectral Discrete Adjoint Method: A Coupled-adjoint Method for High-fidelity Aero-structural Optimization: Presents papers from the November 1995 congress demonstrating the utilization of CFD in a design environment. Topics include pre- and post-optimization sensitivity analyses; discrete and variational sensitivity methods; stochastic and genetic algorithms; shape optimization; inverse methods; trade-off

AIAA Aerospace Sciences Meeting and Exhibit: 42nd

CFD for Design and Optimization Abstract: "This paper describes the implementation of optimization techniques based on control theory for wing and wing-body design of supersonic configurations. The work represents an extension of our earlier research in which control theory is used to devise a design procedure that significantly reduces the computational effort by employing an adjoint equation. In previous studies it was shown that control theory could be used to devise transonic design methods for airfoils and wings in which the shape and the surrounding body-fitted mesh are both generated analytically, and the control is the mapping function [5, 6, 8]. The method has also been implemented for both transonic potential flows and transonic flows governed by the Euler equations using an alternative formulation which employs numerically generated grids, so that it can treat more general configurations [16, 9, 17]. Here results are presented for three-dimensional design cases subject to supersonic flows governed by the Euler equation." 37th AIAA Aerospace Sciences Meeting and Exhibit

Extension of the ADjoint Approach to a Laminar Navier-Stokes Solver Design and Development of Aerospace Vehicles and Propulsion Systems A Discrete Navier-Stokes Adjoint Method for Aerodynamic Optimisation of BlendedWing-Body Configurations: AIAA Journal 40th AIAA Aerospace Sciences Meeting & Exhibit Supersonic Wing and Wing-body Shape Optimization Using an Adjoint Formulation: 4th European Conference on Turbomachinery In this thesis, mesh adaptation using continuous adjoint is tested on two-dimensional Euler equations. Both the flow solver and the adjoint solver are implemented with the high order spectral difference (SD) method. Both h and p adaptation are studied. The test cases include a half-cylinder in subsonic flow and a NACA 0012 airfoil in subsonic and transonic flows. It is found that h-refinement is more suitable for flow discontinuities while p-refinement offers a better performance in smooth flows. Both adaptation methods lead to a faster functional convergence than the uniform h or p refined meshes. In addition, the adapted meshes show similar patterns as those arrived at using the discrete adjoint method. Comparisons between different adjoint target output functionals are also made. Automatic Mesh Adaptation Using the Continuous Adjoint Approach and the Spectral Difference Method: Robust and Stable Discrete Adjoint Solver Development for Shape Optimisation of Incompressible Flows with Industrial Applications Abstract: "This work describes the implementation of optimization techniques based on control theory for complex aircraft configurations. Here control theory is employed to derive the adjoint differential equations, the solution of which allows for a drastic reduction in computational costs over previous design methods [13, 12, 43, 38]. In our earlier studies [19, 20, 22, 23, 39, 25, 40, 41, 42] it was shown that this method could be used to devise effective optimization procedures for airfoils, wings and wing-bodies subject to either analytic or arbitrary meshes. Design formulations for both potential flows and flows governed by the Euler equations have been demonstrated, showing that such methods can be devised for various governing equations [39, 25]. In our most recent works [40, 42] the method was extended to...
treat wing-body configurations with a large number of mesh points, verifying that significant computational savings can be gained for practical design problems. In this paper the method is extended for the Euler equations to treat complete aircraft configurations via a new multiblock implementation. New elements include a multiblock-multigrid flow solver, a multiblock-multigrid adjoint solver, and a multiblock mesh perturbation scheme. Two design examples are presented in which the new method is used for the wing redesign of a transonic business jet.}

A Mixed Hybrid Finite Volumes Solver for Robust Primal and Adjoint CFD. With the rapid growth of aircraft traffic and the new modes of transport such as Urban Air Mobility systems crowding the air space, aircraft noise is no longer a mere design constraint but an important factor to design and optimize for. Reducing aircraft noise however requires efficient coupling of simulation tools with design methods to be able to meet the stringent future aircraft noise requirements that allow for sustainable growth. Gradient-based design optimization based on adjoint method for sensitivity analysis offers a feasible design approach. Adjoint methods based on steady state physics have been widely in practice in industrial applications mainly for aerodynamic optimization so far. However, extending this approach to aeroacoustic optimization is not straightforward and not a common practice in industrial settings due the requirement of unsteady adjoint solutions that is prohibitively expensive. This dissertation presents temporal and spatial coarsening techniques for the computation of low-cost unsteady adjoint solutions to obtain sensitivities for aeroacoustic shape optimization. The effects of the coarsening driving the optimization for these test cases. Finally, an extension to the temporal coarsening technique is proposed with non-uniform time stepping of adjoint solver based on the local flow truncation error estimation of the Euler solver. The proposed extension is demonstrated to further improve the accuracy of the low-cost gradients providing motivations for the future directions of the work done in this thesis.

Adjoint-based Constrained Aerodynamic Shape Optimization for Multistage Turbomachines

Complete Configuration Aero-Structural Optimization Using a Coupled Sensitivity Analysis Method "Due to advances in computing, engineers in the aerospace industry over the past decade have incorporated more advanced numerical algorithms into their computational fluid dynamics (CFD) codes. These advancements have not only allowed routine numerical investigation on the aerodynamics and performance of complete aircraft configurations but the redesign of aircraft geometries through adjoint-based optimization (ASO). A fundamental step required for ASO is the computation of gradients of objective functions with respect to design variables; where, adjoint-based methods form the predominant choice. An essential stage in adjoint-based aerodynamic shape optimization is to obtain the Lagrange multiplier by solving a sparse linear adjoint system of equations based on the Jacobian matrices from the converged flow states. Such an approach has been applied widely in the aerospace community for the design of aircraft and other optimization problems for aerospace applications. However, the need to resolve the flow over complex geometries of ten requires highly stretched grids and gives rise to anisotropic flow fields which increase the stiffness of the discrete Jacobian needed for the solution of the adjoint system. When a generalized minimal residual (GMRES) algorithm preconditioned by an incomplete LU factorization is used, this stiff linear system requires the use of a large number of Krylov subspace vectors and a high level of fill-in; both require an increase in the amount of memory. Deflated restarting, which distributes spectral eigen-pairs, has proven to be an effective method to enhance the convergence rates when solving an ill-conditioned linear system of equations. In this thesis, a novel adjoint solver based on the Krylov-subspace method is proposed where Krylov subspace basis vectors are dynamically evaluated. The solver is applied within two Krylov subspace solvers; GMRES and the generalized conjugate residual method with an inner orthogonalization (GCRO). The efficiency of the solvers is demonstrated on a series of two-dimensional and three-dimensional benchmark test cases."

Adjoint-based Aerodynamic Shape Optimization of Multi Stage Turbomachines

Adjoint- and Grid Adaptation for Functional Outputs from CFD Simulations. The Second-Order Adjoint Sensitivity Analysis Methodology generalizes the First-Order Theory presented in the author's previous books published by CRC Press. This breakthrough has many applications in sensitivity and uncertainty analysis, optimization, data assimilation, model calibration, and reducing uncertainties in model predictions. The book has many illustrative examples that will help readers understand the complexity of the subject and enable them to apply this methodology to problems in their own fields. Highlights: * Covers a wide range of needs, from graduate students to advanced researchers * Provides a text position to be the primary reference for high-order sensitivity and uncertainty analysis * Applies to all fields involving numerical modeling, optimization, quantification of sensitivities in direct and inverse problems in the presence of uncertainties. About the Author: Dan Gabriel Cacuci is a South Carolina SmartState Endowed Chair Professor and the Director of the Center for Nuclear Science and Energy, Department of Mechanical Engineering at the University of South Carolina. He has a Ph.D. in Applied Physics, Mechanical and Nuclear Engineering from Columbia University. He is also the recipient of many awards including four honorary doctorates, the Ernest Orlando Lawrence Memorial award from the U.S. Dept. of Energy and the Arthur Holly Compton, Eugene P. Wigner and the Glenn Seaborg Awards from the American Nuclear Society.

Adjoint Sensitivity Analysis Methodology generalizes the First-Order Theory presented in the author's previous books published by CRC Press. This breakthrough has many applications in sensitivity and uncertainty analysis, optimization, data assimilation, model calibration, and reducing uncertainties in model predictions. The book has many illustrative examples that will help readers understand the complexity of the subject and enable them to apply this methodology to problems in their own fields. Highlights: * Covers a wide range of needs, from graduate students to advanced researchers * Provides a text position to be the primary reference for high-order sensitivity and uncertainty analysis * Applies to all fields involving numerical modeling, optimization, quantification of sensitivities in direct and inverse problems in the presence of uncertainties. About the Author: Dan Gabriel Cacuci is a South Carolina SmartState Endowed Chair Professor and the Director of the Center for Nuclear Science and Energy, Department of Mechanical Engineering at the University of South Carolina. He has a Ph.D. in Applied Physics, Mechanical and Nuclear Engineering from Columbia University. He is also the recipient of many awards including four honorary doctorates, the Ernest Orlando Lawrence Memorial award from the U.S. Dept. of Energy and the Arthur Holly Compton, Eugene P. Wigner and the Glenn Seaborg Awards from the American Nuclear Society.

The Variational Method for Aerodynamic Optimization Using the Navier-Stokes Equations / Adjoint-based Error Estimation and Grid Adaptation for Functional Outputs from CFD Simulations. This paper focuses on the demonstration of a new integrated aero-structural design method for aerospace vehicles. The approach combines an aero-structural analysis solver, a coupled aero-structural adjoint solver, a geometry-based analysis and design integration strategy, and an efficient gradient-based optimization algorithm. The aero-structural solver ensures highly accurate solutions by using high-fidelity models for both disciplines as well as a high-fidelity coupling procedure. The Euler equations are solved for the aerodynamics and a detailed finite element model is used for the primary structure. The coupled aero-structural adjoint solution is used to calculate the needed sensitivities of aerodynamic and structural cost functions with respect to both aerodynamic shape and.

Shape Optimization of Turbomachinery Blades Using an Adjacent Harmonic Balance Method

Airfoil Design Using a Coupled Euler and Integral Boundary Layer Method with Adjoint Based Sensitivities An aerodynamic shape optimisation capability based on a discrete adjoint solver for Navier–Stokes flows is developed and applied to a Blended Wing-Body future transport aircraft. The optimisation is gradient-based and employs either directly a Sequential Quadratic Programming optimiser or a variable-fidelity optimisation method that combines low- and high-fidelity models. The shape deformations are parameterised using a Bézier-Bernstein formulation and the structured grid is automatically deformed to represent the design changes. The flow solver at the heart of this optimisation chain is a Reynolds averaged Navier–Stokes code for multiblock structured grids. It uses Other approximate Riemann solver for accurate shock and boundary layer capturing, an implicit temporal discretisation and the algebraic turbulence model of Baldwin-Lomax. The discrete Navier-Stokes adjoint solver based on this CFD code shares the same implicit formulation but has to calculate accurately the flow Jacobian. This implies a linearisation of the Baldwin-Lomax model. The accuracy of the resulting adjoint solver is verified through comparison with finite difference. The aerodynamic shape optimisation chain is applied to an aeroflight drag minimisation problem. This serves as a test case to try and reduce computing time by simplifying the fidelity of the model. The simplifications investigated include changing the convergence level of the adjoint solver, reducing the grid size and modifying the physical model of the adjoint solver independently or in the entire optimisation process. A feasible optimiser and the use of a penalty function are also tested. The variable-fidelity method proves to be the most efficient formulation so it is employed for the three-dimensional optimisations in addition to parallelisation of the flow and adjoint solvers with OpenMP. A three-dimensional Navier–Stokes optimisation of the ONERA M6 wing is presented. After describing the concept of Blended Wing-Body and.

New Results in Numerical and Experimental Fluid Mechanics X Standard methods for unsteady optimization carry heavy computational costs and large storage requirements, mostly due to the lengthy time integration involved in the unsteady flow simulations. Such difficulties limit its practical application to cases where
The time integration is performed over only a smaller segment of the entire period. The result is a loss of accuracy in the representation of the physical model. For certain unsteady flows with periodicity, a dramatic reduction in both computational cost and required storage is realized through implementing the Time Spectral Method. Furthermore, by introducing an adjoint-based method as an alternative way of obtaining gradient information, computational cost is further reduced. This combination of Time-Spectral and adjoint-based optimization therefore allows for unsteady problems to be optimized with a reasonable turnaround while maintaining accuracy. In this dissertation, the Discrete Adjoint Method is implemented and applied to unsteady flows with periodicity, in the context of the Time Spectral Method. The acquired adjoint gradient information is fed into an optimizer and truly unsteady optimization work is carried out for the first time on a realistic test case. The development and implementation of necessary boundary conditions prove crucial for the successful implementation of the Discrete Adjoint Method. A simple test case, the Navier-Stokes formulation in steady inviscid, unsteady viscous, and steady viscous flows. In each case, the resulting gradient information obtained from both the adjoint and finite difference method is compared. Upon completion of the airflow test case, the adjoint-based method is applied to a helicopter blades, UH60, for both steady and unsteady inviscid flows. The gradient information obtained by the adjoint-based method shows good agreement with the conventional, Finite Difference Gradient information. The design methodology was developed for a single process, however, multi-process capability is also implemented. In order to accommodate realistic meshes, multi-block capability is added as well. With all of the above mentioned improvements implemented, the objective function is time-averaged over time, selected in steady and unsteady cases. The development of the turbomachinery specific features of the adjoint solver, i.e. on the derivation of flow-consistent adjoint inlet and outlet boundary conditions prove crucial for the successful implementation of the Discrete Adjoint Method to unsteady flows with periodicity. The graden information more easily than the traditional finite difference method which is hindered by its computational cost and large storage requirements. This research establishes a new optimization methodology which utilizes Discrete Adjoint gradient information derived from flow solutions, obtained using the Time Spectral method.

Aerodynamic Shape Optimization Using Control Theory. The adjoint method is an efficient approach to computing sensitivities, and has been successfully applied in many fields. However, this approach has not seen widespread acceptance for unsteady problems primarily due to very large storage requirements of present algorithms. The fundamental challenge in unsteady adjoint approaches is the need to integrate the equations in reverse time, which requires all previous flow solutions to be available during the backwards integration. The straightforward treatment of storing all previous flow solutions is prohibitive for simulations with a large number of grid points and time steps. To alleviate this challenge, we propose to compress the flow solutions and store only the reduced bases and expansion coefficients. The flow solutions are recovered when needed in solving the unsteady adjoint equations. In this work, an unsteady discrete advection scheme has been developed and an adjoint solver based on the latter is validated against finite-difference based sensitivities. A novel adaptive-multi-window compression algorithm has been proposed, where the reduced bases are generated by solving a Proper Orthogonal Decomposition (POD) problem of a matrix consisting flow solutions within a time window. We propose an innovative algorithm that employs an error indicator to determine whether the current bases are sufficient to represent the solution at new time steps; thus saving both computational and storage cost. We apply the unsteady adjoint-based framework to evaluate sensitivity of functionals for turboshaft flows in hydraulic turbine draft tubes. We conduct this research within a numerical framework based on the compressible Reynolds-Averaged Navier-Stokes equations coupled with the stiffened gas equation of state to model incompressible flow, and a low-speed preconditioner to accelerate convergence. A secondary novel contribution is an extended eddy-preserving limiter scheme to capture strong turbulent vortices within draft tubes. The numerical framework is first verified on three-dimensional vortex advection cases and then applied to flow simulations in a full turbine draft tube. Finally, sensitivities computed with the use of full and compressed flow solutions are compared to demonstrate the feasibility of the approach.**

Introduction to Optimization Methods and Tools for Multidisciplinary Design in Aeronautics and Turbomachinery

The Second-Order Adjoint Sensitivity Analysis Methodology This book presents contributions to the 19th biannual symposium of the German Aeronautics and Astronautics (STAB) and the German Society for Aeronautics and Astronautics (DGLR). The individual chapters reflect ongoing research conducted by the STAB members in the field of numerical and experimental fluid mechanics and aerodynamics, mainly for (but not limited to) aerospace applications, and cover both nationally and EC-funded projects. Special emphasis is given to collaborative research projects conducted by German scientists and engineers from universities, research-establishments and industries. By addressing a number of cutting-edge applications, together with the relevant physical and mathematics fundamentals, the book provides readers with a comprehensive overview of the current research work in the field. Though the book’s primary emphasis is on the aerospace context, it also addresses further important applications, e.g. in ground transportation and energy.

36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit 2000-3200 - 2000-3249 Abstract: "This work describes the application of a control theory-based aerodynamic shape optimization method to the problem of supersonic aircraft design. The design process is greatly accelerated through the use of both control theory and a parallel implementation on distributed memory computers. Control theory is employed to derive the adjoint differential equations whose solution allows for the evaluation of design gradient information at a fraction of the computational cost required by previous design methodologies [13, 12, 44, 38]. The resulting problem is then implemented on parallel distributed memory architectures using a domain decomposition approach, an optimized communication schedule, and the MPI (Message Passing Interface) Standard for portability and efficiency. The final result achieves very rapid aerodynamic design based on the new adjoint-based adjoint sensitivity analysis method (19, 20, 21, 23, 39, 22, 41, 42, 43, 49) was shown to be effective for the optimization of airfoils, wings, wing-bodies, and complex aircraft configurations using both the potential equation and the Euler equations [39, 25]. In our most recent paper, the Euler method was extended to treat complete aircraft configurations via a new multiblock implementation. Furthermore, during the same conference, we also presented preliminary results demonstrating that this basic methodology could be ported to distributed memory parallel computing architectures [24]. In this paper, our concern will be to demonstrate that the combined power of these new technologies can be used routinely in an industrial design environment by applying it to the case study of the design of typical supersonic transport configurations. A particular difficulty of this test case is posed by the propulsion/airframe interaction."

Fast Radial Basis Functions for Engineering Applications

Higher-order Discrete Adjoint ODE Solver in C++ for Dynamic Optimization "This work proposes a framework for fully-automatic, gradient-based constrained aerodynamic shape optimization in a multistage turbomachinery environment. A turbomachinery solver which solves the Reynolds-averaged Navier-Stokes (RANS) equations to a steady-state in both rotating and stationary domains is developed. Characteristic-based inlet and outlet boundary conditions are imposed, while adjacent rotor- or stator rows are coupled by mixing-plane interfaces. To allow for an efficient but accurate gradient calculation, the turbomachinery RANS solver is attached at a discrete level. The systematic approach for the development of the discrete adjoint solver is discussed. Special emphasis is put on the development of the turbomachinery specific features of the adjoint solver, i.e. on the derivation of flow-consistent adjoint inlet and outlet boundary conditions and, to allow for a concurrent rotor-stator optimization and stage coupling, on the development of an exact adjoint counterpart to the non-reflective, conservative mixing-plane formulation used in the flow solver. The adjoint solver is validated by comparing its sensitivities with finite-difference gradients obtained from the full nonlinear RANS solver, including a parallel algorithm and an optimized communication schedule utilizing a block-structured, multi-block grid configuration, is applied to calculate the gradient from the adjoint solution. A sequential quadratic programming algorithm is utilized to determine an improved blade shape based on the gradient information. The functionality of the proposed optimization method is demonstrated by the redesign of two different transonic compressor configurations. The design objective is to maximize the isentropic efficiency while constraining the mass flow rate and the total pressure ratio. The influence of the constraints on the design problem is investigated by comparing the results with those of an unconstrained optimization."

43rd AIAA Aerospace Sciences Meeting & Exhibit This study seeks to reduce the degree of uncertainty that often arises in computational fluid dynamics simulations about the computed accuracy of functional outputs. An error estimation methodology based on discrete adjoint sensitivity analysis is developed to provide a quantitative measure of the error in computed outputs. The developed procedure relates the local residual errors to the global error in output function via adjoint variables as weight functions. The three major steps in the error estimation methodology are: (1) development of adjoint sensitivity analysis
Estimation of Precursors for Extreme Events Using the Adjoint Based Optimization Approach We formulate a generalized optimization problem for a non-linear dynamical system governed by a set of differential equations. The plant under focus is the 2-D Kolmogorov flow, as this flow has inherent turbulence which would give rise to chaos and intermittent bursts in a selected observable. As a first step, an observable with potential extreme events in its time series is selected. In our case, we choose the kinetic energy of the flow field as the observable under study. The next step is to derive the adjoint equations for the kinetic energy that is the quantity of interest with the velocity field as the optimizing variable. This obtained velocity field forms the precursor for extreme events in the kinetic energy. The prediction capabilities for this precursor are then explored in more detail. The goal is to select the precursor such that it predicts the extreme events in a given time horizon which can generate warning signals effectively. We also present a coupled flow solver in Nek5000 and adjoint solver in MATLAB, the latter can be applied to any dynamical system to study the extreme events and obtain the relevant precursor. In a consecutive section, the results for extreme events in the kinetic energy and the lift coefficient for the flow over a 2-D airfoil are presented. As part of future work, the implementation and application of the solver for the flow past the airfoil and over a 3-D Ahmed body are proposed.

Modelling and Discretization in Continuum Mechanics The high-dimensional harmonic balance (HDHB) method has recently become popular in the field of periodic unsteady flow prediction due to its accuracy and high efficiency. In the present dissertation research, two and three-dimensional parallelized computational fluid dynamic (CFD) codes based on the HDHB method are developed and validated for unsteady turbulent flows. It is found that the stability condition for an explicit solver is highly dependent on the reduced grid frequency, a non-dimensional parameter that depends on the grid size, characteristic wave speed, and the highest frequency retained in the harmonic balance solver. Furthermore, for certain moderately and highly nonlinear problems, the pseudo-spectral operator used in the HDHB method is found to introduce aliasing errors, which may lead to nonlinear instabilities or non-physical solutions. As a remedy, a temporal spectral viscosity operator is proposed for de-aliasing purpose so as to stabilize HDHB solver. The proposed method is validated for a simple nonlinear Duffing oscillator case and laminar vortex shedding over an oscillating circular cylinder at Re=500. Another focus of this research is the design optimization of the turbomachinery blades for unsteady flows. The “steady state” nature of the HDHB technique is well suited for an adjoint sensitivity analysis mainly due to the fact that the storage requirements are greatly reduced. To date, the investigators have used the adjoint technique mainly for steady shape optimization. To the author’s best knowledge, the technique has not been applied for unsteady design optimization of turbomachinery blades. In this dissertation, a discrete adjoint HDHB method is employed for unsteady turbomachinery shape optimization. With the help of the automatic differentiation (AD) tool, TAPENADE, the development time for an optimization solver can be reduced substantially. Both inverse design and optimization problems are considered to validate the optimization solver.

Introduction to Optimization and Multidisciplinary Design This study seeks to reduce the degree of uncertainty that often arises in computational fluid dynamics simulations about the computed accuracy of functional outputs. An error estimation methodology based on discrete adjoint sensitivity analysis is developed to provide a quantitative measure of the error in computed outputs. The developed procedure relates the local residual errors to the global error in output function via adjoint variables as weight functions. The three major steps in the error estimation methodology are: (1) development of adjoint sensitivity analysis capabilities; (2) development of an efficient error estimation procedure; (3) implementation of an output-based grid adaptive scheme. Each of these steps is investigated. For the first step, parallel discrete adjoint capabilities are developed for the variable Mach version of the 2D HCL flow solver. To compare and validate the implementation of adjoint solver, this study also develops direct sensitivity capabilities. A modification is proposed to the commonly used unstructured flux-limiters, specifically, those of Barth-Jespersen and Venakatkrishnan, to make them piecewise continuous and suitable for sensitivity analysis. A distributed-memory message-passing model is employed for the parallelization of sensitivity analysis solver and the consistency of linearization is demonstrated in sequential and parallel environments. In the second step, to compute the error estimates, the flow and adjoint solutions are prolonged from a coarse-mesh to a fine-mesh using the meshless Moving Least Squares (MLS) approximation. These error estimates are used as a correction to obtain highly-accurate functional outputs and as adaptive indicators in an iterative grid refinement algorithm to enhance the accuracy of the chosen output to a prescribed tolerance. For the third step, an output-based adaptive strategy that takes into account the error in both the primal (flow) and dual (adjoint) solutions is implemented. A second-order accurate finite volume method is employed for the flow solver and the meshless method is found to introduce aliasing errors, which may lead to non-physical solutions. As a remedy, a temporal spectral viscosity operator is proposed for de-aliasing purpose so as to stabilize HDHB solver. The proposed method is validated for a simple nonlinear Duffing oscillator case and laminar vortex shedding over an oscillating circular cylinder at Re=500. Another focus of this research is the design optimization of the turbomachinery blades for unsteady flows. The “steady state” nature of the HDHB technique is well suited for an adjoint sensitivity analysis mainly due to the fact that the storage requirements are greatly reduced. To date, the investigators have used the adjoint technique mainly for steady shape optimization. To the author’s best knowledge, the technique has not been applied for unsteady design optimization of turbomachinery blades. In this dissertation, a discrete adjoint HDHB method is employed for unsteady turbomachinery shape optimization. With the help of the automatic differentiation (AD) tool, TAPENADE, the development time for an optimization solver can be reduced substantially. Both inverse design and optimization problems are considered to validate the optimization solver.

An Efficient Numerical Framework for Sensitivity Analysis for Unsteady Flows Aerodynamic Shape Optimization of Supersonic Aircraft Configurations Via an Adjoint Formulation on Parallel Computers Abstract: “Aerodynamic shape design has long persisted as a difficult scientific challenge due [sic] its highly nonlinear flow physics and daunting geometric complexity. However, with the emergence of Computational Fluid Dynamics (CFD) it has become possible to make accurate predictions of flows which are not dominated by viscous effects. It is thus worthwhile to explore the extension of CFD methods for flow analysis to the treatment of aerodynamic shape design. Two new aerodynamic shape design methods are developed which combine CFD technology, optimal control theory, and numerical optimization techniques. Flow analysis methods for the potential flow equation and the Euler equations form the basis of the two respective design methods. In each case, optimal control theory is used to derive the adjoint differential equations, the solution of which provides the necessary gradient information to a numerical optimization method much more efficiently than [sic] by conventional finite differencing. Each technique uses a quasi-Newton numerical optimization algorithm to drive an aerodynamic objective function toward an optimum. An analytic grid pertid to modify body fmitus is used to accommodate shape changes during the design process. Both Hicks-Henne perturbation functions and B-spline control points are explored as suitable design variables. The new methods prove to be computationally efficient and robust, and can be used for practical airfoil design including geometric and aerodynamic constraints. Objective functions are chosen to allow both inverse design to target a pressure distribution and wave drag minimization. Several design cases are presented for each method illustrating its practicality and efficiency. These include non-lifting and lifting airfoils operating at both subsonic and transonic conditions.”

Studying Turbulence Using Numerical Simulation Databases This book presents the first “How To” guide to the use of radial basis functions (RBF). It provides a clear vision of their potential, an overview of ready-for-use computational tools and precise guidelines to implement new engineering applications of RBF. Radial basis functions (RBF) are a mathematical tool mature enough for useful engineering applications. Their mathematical foundation is well established and the tool has proven to be effective in many fields, as the mathematical framework can be adopted in several ways. A candidate application can be faced considering the features of RBF: multidimensional space (including 2D and 3D), numerous radial functions available, global and compact support, interpolation/regression. This great flexibility makes RBF attractive – and their great potential has only been partially discovered. This is because of the difficulty in taking a first step toward RBF as they are not commonly part of engineers’ cultural background, but also due to the numerical complexity of RBF problems that scale up very quickly with the number of RBF centers. Fast RBF algorithms are available to alleviate this and high-performance computing (HPC) can provide further aid. Nevertheless, a consolidated tradition in using RBF in engineering applications is still missing and the beginner can be confused by the literature, which in many cases is presented with language and symbols familiar to mathematicians but which can be cryptic for engineers. The book is...
divided in two main sections. The first covers the foundations of RBF, the tools available for their quick implementation and guidelines for facing new challenges; the second part is a collection of practical RBF applications in engineering, covering several topics, including response surface interpolation in n-dimensional spaces, mapping of magnetic loads, mapping of pressure loads, up-scaling of flow fields, stress/strain analysis by experimental displacement fields, implicit surfaces, mesh to cad deformation, mesh morphing for crack propagation in 3D, ice and snow accretion using computational fluid dynamics (CFD) data, shape optimization for external aerodynamics, and use of adjoint data for surface sculpting. For each application, the complete path is clearly and consistently exposed using the systematic approach defined in the first section.

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