Phase I Project Summary

Firm: CFD Research Corporation
Contract Number: NNX11CG69P
Project Title: Implicit Higher Order Temporal Differencing for Aeroacoustic and CFD Applications

Identification and Significance of Innovation: Two innovations of the Phase I research are: a) development of a standalone temporal integrator that can interface with various numerical analysis solvers; and b) the ability to easily simulate arbitrarily high implicit temporal orders of accuracy. During Phase I, the Spectral Deferred Correction (SDC) algorithm was developed into a general standalone component for use with various numerical solvers. The SDC algorithm provides arbitrarily high order implicit time integration by solving a series of low order correction equations. Spectral integration is used for the higher order integral to provide robustness and efficiency, resulting in a robust and stable high order time integration scheme. Software interfaces were created using the Trilinos library, providing easy integration with existing numerical analysis codes. The Trilinos library also includes matrix and vector operations as well as linear equation solvers and preconditioners, both of which were used in our software for efficiency and ease of coding. The Phase I feasibility study showed: a) the SDC time integration algorithm is stable, efficient, and accurate; b) other temporal integration schemes (e.g. Runge-Kutta) can easily be incorporated into the software framework; and c) the software interface provides an easy and robust method for incorporating different spatial solvers.

Technical Objectives and Work Plan: The Technical Objectives of the Phase I work were: a) extract the SDC algorithm from an existing CFD solver and create a standalone component; b) verify the order of accuracy claims of the SDC algorithm; c) Incorporate a high order Runge-Kutta algorithm into the temporal integrator for comparison purposes, and d) integrate the standalone component with various spatial solvers to demonstrate proof-of-concept. The work plan consisted of the following steps: a) definition of interface protocols for communication between the temporal solver and various spatial solvers (both data and frequency of exchange), b) development of the standalone temporal integrator based on the defined interface protocols, c) integration of the temporal solver with various spatial solvers demonstrating its use and verifying the formal order of accuracy, and d) run a series of test and demonstration cases, including comparison of the SDC algorithm with a higher order implicit Runge-Kutta algorithm.

Technical Accomplishments: During Phase I we successfully developed a high order standalone temporal integrator, and interfaced the software with 4 different spatial solvers: a simple 1-D heat conduction solver, a 2D heat conduction solver, a 3D CFD solver that uses a segregated pressure-based solution algorithm, and a 3D CFD Euler solver that uses a coupled density-based algorithm with adaptive mesh capability. The 2D solver used a Method of Manufactured Solutions (MMS) approach in which the analytical solution was known and the temporal error was isolated. Using the MMS approach we proved the formal order of accuracy of the SDC method. Using the segregated CFD solver, stable temporal solutions from 2^{nd} order to 22^{nd} order were demonstrated. We also incorporated a 4^{th} order Runge-Kutta (RK) algorithm into the temporal solver and compared the SDC and RK algorithms on the 2D conduction and 3D pressure-based CFD solvers. In both cases the SDC approach was more efficient for the same order of accuracy.

NASA Application(s): Many NASA scientists and engineers are involved in the development and use of numerical analysis codes for applications in physics, engineering, biotechnology, etc. The developed tool can incorporate higher order differencing into these computational codes, allowing high order temporal solutions without developing a new solver or requiring massive infrastructure changes to existing solvers. The software tool will be applicable whenever high numerical accuracy is desired. Potential CFD applications include acoustics and noise generation/propagation, combustion (including instability), and turbulence (e.g. LES). Other applications include transient analyses involving a very large number of time steps where numerical errors can grow over time.

Non-NASA Commercial Application(s): Scientists and engineers in a wide range of physical disciplines, such as mechanics, medicine, physical cosmology, nano-technology, etc., employ transient computational analysis to solve governing equations that are too difficult to solve analytically. Many of these computational disciplines require efficient and accurate transient analyses. The temporal differencing solver developed in this project will serve as an important aid for these researchers to obtain high temporal accuracy with a reasonable amount of computational effort.

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