New Code Analyzes Fluid Flow for Better Designed Aerospace Vehicles and Components

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This article describes the Wind Computational Fluid Dynamics code developed by the National Project for Applications-Oriented Research in Computational Fluid Dynamics (NPARC) alliance, a formal partnership between the U.S. Air Force Arnold Engineering Development Center and the NASA Glenn Research Center. The project was nominated to CROSSTALK *in its 2001 search for the top five software projects in the U.S. government. It received high scores by the Software Technology Support Center review team. The NPARC mission was to develop, validate, and support an integrated, general purpose computational flow simulator for the U.S. aerospace community that can be used to analyze fluid flow to better design and develop aerospace vehicles and components.*

The Wind Computational Fluid Dynamics code was developed to analyze fluid flow to better design and develop aerospace vehicles and components. This was the primary software product developed by the National Project for Applications-Oriented Research in Computational Fluid Dynamics (NPARC) alliance, a formal partnership between the U.S. Air Force (USAF) Arnold Engineering Development Center (AEDC) and the NASA Glenn Research Center (GRC).

The NPARC mission was to develop, validate, and support an integrated, general purpose computational flow simulator for the U.S. aerospace community. The NPARC project's success is exemplified by its large number of registered users from government, industry, and academic organizations during the past three years. In addition to AEDC and GRC, other government, commercial, and academic organizations participated in the planning and execution of the project. One of the primary contributors was The Boeing Company.

The Wind code solves the Navier-Stokes equations using a variety of iterative algorithms. The flowfield can be two-dimensional, three-dimensional, or axisymmetric and may represent steady or unsteady flow conditions. Turbulence is simulated using a variety of turbulence models, and the convection, dissipation, and reaction of chemical species can be modeled. A variety of numerical algorithms are available to integrate the flow equations depending on user accuracy requirements. The solution domain may be divided into multiple zones, each of which is transformed into cubicle regions in the computational space.

The code has been applied to a variety of systems, including air-breathing engine inlets and nozzles, liquid and solid propellant rocket propulsion systems, full aircraft systems, missile control systems, test cell and wind tunnel aerodynamics, and hypersonic vehicles. Computational fluid dynamics has become a major contributor to the design and test process for Department of Defense (DoD) weapons systems by allowing the flow around and through systems to be evaluated before costly designs become reality. The result is significant reduction in the overall cost and cycle time of the acquisition process.

Wind Code Specifics

The NPARC alliance consists of diverse organizations across a large geographical area. These organizations perform first-rate operations coordinating configuration management, development efforts, code distribution, and user support. To facilitate this coordination, the NPARC project developed an Internet Version Management System (IVMS) to provide centralized support for multisite, multiplatform software distribution and development.

With IVMS, files are provided to users and developers for each major release. This browser-based system allows developers to log into the system, check out a software module, modify it, and insert it back into the system. IVMS prevents other developers from simultaneously updating the same module. IVMS also allows users to have immediate access to the latest code versions from a protected file transfer protocol (FTP) site.

The Wind code is written in FORTRAN90 and C and includes excellent code reuse examples from the individual efforts of the USAF AEDC, NASA GRC, and The Boeing Company. Excluding libraries maintained by other organizations, the Wind program consists of 160,000 lines of FORTRAN90 code and 18,000 lines of C code. There are also 29 auxiliary programs used for processing. Altogether, these utility programs contain about 240,000 lines of FORTRAN90 code and 75,000 lines of C code.

Documentation is provided on the Wind code and its associated utilities in HTML, PDF, and PostScript formats. The documentation is extremely detailed and constantly updated to reflect changing capabilities and to clarify descriptions of existing capabilities. Developer documentation is also provided on the Web, but is accessible only to registered developers. This documentation consists of information on code structure, memory management, and details on specific modules. During the last year, this Web site has handled, on average, approximately 30,000 user inquiries per month. The documentation and other Web-based information can be accessed at <www.arnold.af.mil/nparc>.

NPARC software is developed primarily in a Unix environment, and it runs on a multitude of platforms, including systems using SGI IRIX, Sun Solaris (Sparc CPUs), Linux (Intel-compatible CPUs), and Hewlett-Packard HP-UX (PA-RISC CPUs). The code has been ported to and used on most major systems at DoD's Major Shared Resource Centers.

Wind Code Application and Operation

The Wind code can run in parallel on a network of workstations or a large multiprocessor machine using either message passing interface (MPI) or parallel virtual machine (PVM) protocols. To run in parallel, the user creates a multi-processor control file containing a list of hosts on which to run. The Wind run-scripts set up an entire virtual machine environment. The scripts check the remote machine to see whether it is overloaded before adding it to the virtual machine. This prevents the job from waiting for the overloaded machine to complete its tasks.

The parallel methodology used is a

master-worker paradigm, where the master controls the work allocation and communications between the workers. The master assigns a grid block to each worker as it completes work on the previous grid block. This approach results in excellent load balancing, provided there are sufficiently more grid blocks than worker processes. Worker-to-worker communication is allowed to improve the overhead for exchanging zonal interface information.

To ensure product quality, a developer's programming approach must be discussed with other developers and approved before implementation. Before modifying any modules through the IVMS, developers must have their work checked by at least one other developer at another organization. A description of the modification and the name of the individual who checked the work must be entered into the IVMS.

To aid in quality assurance, a validation Web site is maintained containing numerous test cases with experimental data for comparison. The Web site contains all of the files and input data required to reconstruct a test case. All output files are also available. When modifications are made to the code, the test cases on this site are used to validate that the modification operates as expected.

A set of standards documents was developed as one of the project's first tasks. A document describing programming guidelines provides a set of required programming practices. A document describing documentation guidelines provides a description of all NPARC documentation and the information required to document new features. Finally, a document describing testing standards provides guidance on procedure, documentation, and achievement of validation and functional testing.

Each year, key customers and the alliance partners hold a NPARC workshop to identify customer and user needs. The NPARC support team is also available year round via a dedicated e-mail address and phone number. User-identified bugs are handled on a priority basis and the modified code is made available to the user community as soon as the bug is fixed.

Project Performance

The NPARC project is an ongoing development effort geared to rapidly respond to customer needs, which require frequent schedule modifications as the environment shifts. Recently, AEDC completed a three-year High Performance Computing (HPC) Modernization Office effort under the Common HPC Scalable Software Initiative (CHSSI). CHSSI milestones, including improved parallelization and usability, were established and were exceeded in most cases. In 1999, the project received an Honorable Mention in the NASA Software of the Year Award competition.

The NPARC project places a huge emphasis on supporting the aerospace community, which is confirmed by the projects' large following. The code has been requested by more than 273 organizations in the past three years. User organizations include 42 DoD organizations, 21 government organizations, 149 commercial companies, and 61 universities. The customers are primarily associated with aerospace design and testing, although there are users associated with other industries. By supporting a large number of users, the United States' principal aerospace organizations (USAF and NASA) benefit greatly from the code's exposure to unforeseen situations as it is applied to configurations and flow conditions that are not normally encountered within a single organization.

This project demonstrates a new way of doing software development in general and governmental software development in particular through the coordinated development efforts between NASA, DoD, and industry organizations using Internet-based tools. The NPARC product is a true government off-the-shelf success story. The unique development environment allows each organization to leverage the high cost of program development with other organizations.

Usually, a development effort of this nature requires investments from $1 to $2 million annually to adequately maintain and support the software tools. By leveraging resources, no single organization must invest more than $500,000 while reaping the benefit of the entire investment. The ultimate beneficiary of these products is the U.S. taxpayer, through prudent cost sharing among government agencies and leveraging resources with commercial and academic partners.

This leveraging also provides the aerospace community with a first-class free product and a greater ability to share data and produce technological advances for the United States. The involvement of commercial organizations in the utilization, planning, and execution of the software development helps to ensure that the United States maintains worldwide economic and military superiority.

More information on all aspects of the NPARC project may be found at <www.arnold.af.mil/nparc>.

Conclusion

The Wind code is a computational fluid dynamics software package used within the government and industry to analyze fluid flow to better design and develop aerospace vehicles and components. This software is jointly developed by the NPARC Alliance, a consortium of partners in the DoD, NASA, and industry, through Internet version management tools and disciplined coordination. While joint development of software is a significant challenge, the NPARC Alliance has demonstrated that a multi-site software development effort can result in a high-quality product and development cost savings.

Additional Readings

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