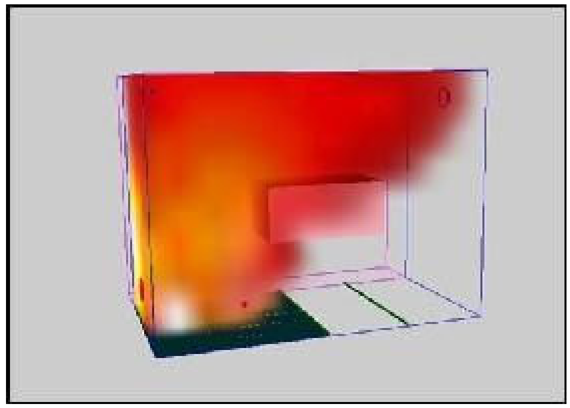
Fire Integrity in Advanced Ship Structures

SURVICE Engineering Company
4695 Millennium Drive
Belcamp, MD, 21017-1505

Dr. Dave Keyser
Phone: (410) 297-2378
Fax: (410) 297-2379
Email: dave.keyser@survice.com
Website: www.survice.com



Command: ONR - SBIR
Topic: N07-098

PROBLEM STATEMENT

Composite materials are increasingly being used as structural components in new Navy platforms such as the DDG-1000 Zumwalt destroyer. Engineers need cost effective desktop modeling tools to predict the residual structural integrity of non-traditional composite materials during and after a damaging fire. The tool may also be used for post-event investigations and in the evaluation of preventive countermeasures.

As new materials are developed and integrated into front-line combat systems, it is essential to properly evaluate the potential impact of integrating these materials. Although new materials have significant benefits in terms of reduced weight, lower signature, etc., the ability to maintain structural integrity during and after a fire is a critical issue. This is especially important for ships, where fires must be controlled, extinguished, and repaired at sea. Specifically, structural integrity of the basic hull is essential.

Current tools to model composite materials and fire damage reside on high-speed main-frame computers because of the amount of computing power required to process current algorithms. This restricts access of many engineers to an important engineering design tool aid. A more cost-effective solution to extend this modeling capability to more engineers is to develop a high-performance CFD code that can run on a desktop PC, and produce accurate results in a fraction of the time of traditional/legacy CFD codes.

An accurate yet fast-running engineering computer model is needed to simulate all the key processes of combustion. SURVICE's high-performance computer model, Apollo™, is being developed to support this need, and to predict the growth and spread of a fire in a shipboard environment and the effects of the fire on the ship's structure. The goal is to create an accurate fire-growth model that simultaneously tracks and evaluates heat transfer to composite ship structures and evaluates structural integrity during and after the fire.

WHO CAN BENEFIT?

The ability to combine CFD and FEA analyses, and optimize and package this capability into a fast-running engineering desktop utility has tremendous potential to increase the analytic fidelity engineers use for performing a wide variety of analyses. In the specific case of ONR, this capability, combined with custom composite heat transfer and material degradation models, will allow structural designers the ability to compare homogeneous metal structures with next-generation composite materials.

Design engineers in the naval, automotive, construction, fire protection, and aerospace industries need a tool that can be used rapidly to assess the impact of design changes on the spread of fire and the residual structural integrity. First responders would also benefit from knowing the potential for fire spreading, and when and where to fight a fire to maximize success and ensure safety. The tool may also be used for post-event investigations and in the evaluation of preventive countermeasures.

Interest in Apollo™ development has been expressed by NAVAIR, the U.S. Army Research Laboratory, the Joint Aircraft Survivability Program, SPAWAR, and the Naval Research Laboratory among others. Other organizations that would benefit include NAVSEA, PEO Ships, the Naval Surface Warfare Center, the Department of Homeland Security, General Dynamics, Bath Iron Works, Northrop Grumman, and PEO Submarines.

BASELINE TECHNOLOGY

Many computer models for simulating the spread of fire are not designed to model confined compartments (such as those on-board ships), and they are complex to operate, generally requiring long periods to set-up and process.

There are generally two methods available for calculating the effects of fires in enclosures. They differ primarily in their treatment of the gas phase. Zone-based modeling relies on describing a relatively small number of characteristics about the situation. Typical characteristics might include the thermal plume rising above the fire source, a distinct layer of hot products of combustion, or a stream of gases spilling through an open window or into an adjacent compartment. Such zone models are based mostly on assumptions guided by observation and empirical results. These zone-based models provide gross estimates and are not suited for detailed analyses required to support design studies.

The second method, known as field modeling, relies on three-dimensional, time-dependent equations describing the laws of conservation subject to the particular initial and boundary conditions of interest. These field models are based on the application of computational fluid dynamics (CFD) and generally provide more accurate simulations. However, they are also more difficult to use and consume more computational resources.

Apollo™ provides CFD modeling at speeds commensurate with zone-based modeling. It can thus provide the accuracy of detailed simulations in time frames (and computational hardware) usually associated with zone-based modeling.

TECHNOLOGY DESCRIPTION

Apollo™ is built upon the Fire Prediction Model (FPM) which was developed by SURVICE over the past decade to focus on ballistically-induced fires in aircraft dry-bay areas such as those surrounding fuel tanks. SURVICE is re-engineering the basic FPM fire-sustainment code into a next-generation CFD engine that not only improves upon the methodology in FPM, but also takes advantage of multi-core, multi-processor desktop systems. The Apollo™ core is being designed to replace the fire-sustainment module within FPM. A screen shot of an early prototype of Apollo is shown in Figure 1, demonstrating the ability to interactively model pressure waves.

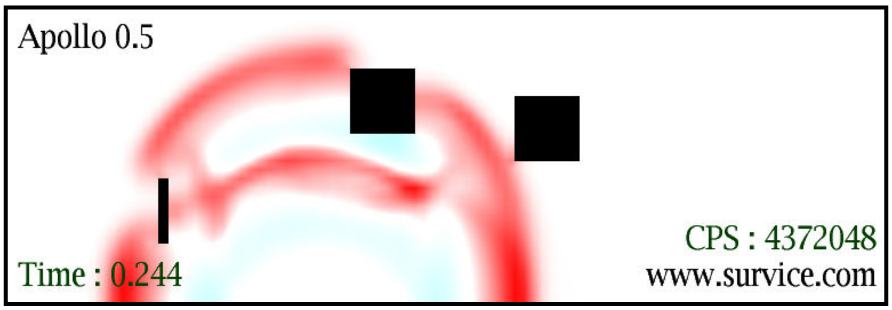


Figure 1. Apollo™ Test Case Screen Shot

While Apollo™ can run on any desktop PC, it runs best on multi-processor multi-core configurations as it is fully optimized to take advantage of the computational horsepower associated with these newer systems. A features, advantages, and benefits (FAB) table for Apollo™ is provided in Table 1.

Table 1. Feature, Advantages, and Benefits of Apollo

Features	Advantages	Benefits
Accurate. Simulates all key processes of combustion.	Increased analytical fidelity	Assesses the impact of design changes on spread of fire and residual structural integrity.
Uses high-performance CFD methodology	Leverages multiple core, multi-processor desktop systems	World-class CFD performance achieved on desktop computer hardware
Designed to model confined compartments (such as those on-board ships).	Provides insight as to when and where to fight a fire to maximize success and ensure safety.	Can be used as a tool for first responder training, allowing scenario modeling. Can also be used for post-event investigations and evaluation of preventive countermeasures.
Tracks and evaluates heat transfer. Evaluates structural integrity.	Can be used to compare homogeneous metal structures with next-generation composite materials.	Predicts fire growth and spread in a shipboard environment. Predicts effect of fire on ship structure.

CURRENT STATE OF DEVELOPMENT

With the implementation of multi-core processing, Apollo™ can simulate basic test cases interactively. Plans for supporting the next-generation Intel Larrabee processing units is expected to achieve real-time performance for most applications.

Apollo™ is approximately 4X faster than was demonstrated in the Spring of 2009 for quad core systems, and 8X faster for dual quad core systems. We are optimizing time steps through our investigation of means for data smoothing to allow larger time steps, and expect 10-30X increase in performance for low-velocity analyses. The pending implementation of Single Instruction Multiple Data (SIMD) intrinsics will provide an additional 3-4X increase in performance over current technology by taking advantage of larger CPU registers specifically designed to handle parallel processing. The next-generation desktop system, Larrabee, promises an additional order of magnitude performance increase with 32 cores and ultra-wide SIMD registers.

We have executed several verification/validation test cases modeling orifice flow, which revealed some software discrepancies and boundary condition issues. The code was revised to bring model results to within a few percent of theoretical. Upcoming tasks include the completion of the command-driven user interface, time step optimizations, and of the combustion and heat transfer methodologies, to include energy deposition and products of combustion.

Apollo™ is currently at a technology readiness level (TRL) of 4. It is expected to be at TRL 6 at the end of the Phase II effort.

REFERENCES

Dr. Shridhar Yarlagadda
University of Delaware, Center for Composite Materials
(302) 831-4941
yarlagad@udel.edu

Dr. Yarlagadda provides composites expertise to SURVICE Engineering through several ongoing cooperative research efforts. SURVICE is also a member of the UD-CCM Industry-University Consortium, a premier technology transfer network focused on transitioning research accomplishments to industry.

ABOUT THE COMPANY

SURVICE Engineering's primary core business areas have been in the area of aircraft, ground, and ship survivability assessment, test, and design. We have been providing Department of Defense and industry customers with high-quality analytical products and services for more than 25 years. Our Aberdeen Area Operation (Figure 2) is one of eight U.S. office locations positioned to provide our customers with dedicated engineering services.

Figure 2. SURVICE's Aberdeen Area Operation in Belcamp, MD

SURVICE is intimately familiar with the development of custom applications in support of these business areas. In our desire to continuously improve our processes and procedures, we are adapting our FPM code to the specific application of composite structure fire modeling and structural analysis. Our innovative approach to CFD processing expedites the analysis while maintaining both accuracy and fidelity of the results. High-speed raytracing and CFD analyses in support of survivability engineering have become significant development areas for the company, and SURVICE has since been infusing this technology into custom solutions for our DoD customers.