High Performance Computing

Pilot Study.

AlphaSTAR and Composites DOC: Leveraging HPC for the Design of Durable and Reliable Military Ground Vehicles

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Information Sciences Institute
USC School of Engineering

Study of a University of Southern California
Information Sciences Institute pilot program

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Pilot Partners

U.S. Army TARDEC
http://tardec.army.mil/

Ohio Supercomputer Center
http://www.osc.edu/

University of Southern California (USC)–Information Sciences Institute (ISI)
http://isi.edu

AlphaSTAR and Composites DOC

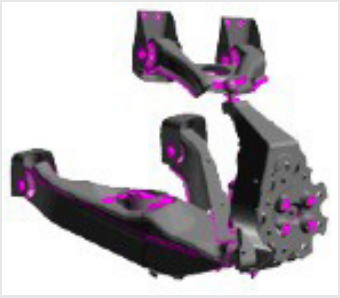
AlphaSTAR Corp is a leading provider of advanced engineering analysis services and of specialized software (GENOA) for accurately predicting the strength, durability, life, and reliability of complex structural systems made from metals and advanced composite materials (polymers, fiber metal laminates, ceramics, chopped fibers, and nano).

http://www.ascgenoa.com/

Composites DOC, a spinoff company from the National Composite Center, specializes in not only the design of composite structures but also the optimization of the design by utilizing advanced composite software such as GenesisTM

http://www.compositesdoc.com

HMMWV Double A-Arm Suspension Unit



Challenges

- Reduce weight and increase durability and reliability of key military vehicle components and systems while keeping cost down
- Progress beyond analysis of vehicle component subsystem in isolation, which can lead to additional design cycles and expensive physical prototype testing
- Move toward whole-vehicle modeling and analysis to provide increased design yields and reduced operational and manufacturing costs
- Reduce the number of parts (via consolidation)
- Reduce vehicle breakdowns, decrease fuel consumption and extend vehicle lifespan

Approach

- Leverage HPC to provide robust design capability of complex automotive structures by applying coupled durability-reliability-optimization solution to insert light weight materials in components of military vehicles
- Optimize product performance by eliminating subsystem modeling in isolation to improve reliability and Durability and Damage Tolerance (D&DT)
- Move beyond finite element analysis (FEA) by employing GENOA for comprehensive D&DT through FEA-based progressive failure analysis and modeling of complex advanced materials
- Utilize the increased computing power of the Ohio Supercomputer Center
- Use HPC to increase effectiveness of advanced polymeric composites in military vehicles

HPC Immediate Impact

- Reduced weight of double A-Arm suspension unit by 31 percent with increased performance and longer life
- Increased static load carrying capability by 1.6 times and fatigue life by 1.75 times
- Reduced runtime for reliability simulation by an order of magnitude
- Reduced run time for analysis of static and fatigue durability by a factor of three
- Opportunity to reduce development cost by 40 percent
- Saved nearly $1,000,000 by using virtual prototyping over physical testing alone
- Provided an estimated 10x time speedup by simulating full vehicles

HPC Ultimate Benefits

- Facilitate building block verification for rapid certification by performing a priori assessment of performance and reliability of the part or system of parts (Product certification ensures that the structure meets safety and reliability requirements)
- Capability to rapidly assess advanced technologies for insertion in existing vehicle systems
- Enable the use of advanced lightweight materials to their maximum potential through more accurate characterization
- Virtual simulation that employs shape optimization to produce lightweight parts with performance that surpass those made from traditional metals currently in production
- Virtual prototyping capability allows for the diversification of products and markets

Learn more at Compete.org/hpc/darpapilots/

AlphaSTAR Corporation and Composites DOC: Leveraging HPC for the Design of Durable and Reliable Military Ground Vehicles

Everything fails eventually—it is an inevitable fact of life. When important systems or components (especially those in demanding military settings) are pushed beyond their initial design expectations and either break or degrade none-too-gracefully, the failure analysis experts are called in. These specialists—like the forensic team at AlphaSTAR Corporation and Composites DOC—deploy advanced engineering analysis technology to assess what went wrong in order to prevent future occurrences.

AlphaSTAR is a highly specialized engineering firm whose services are retained by large, global manufacturers. International customers account for 40 percent of the company's business and include Alenia Aeronautica in Italy and EADS in Germany. Based in Long Beach, Calif., AlphaSTAR is a unique provider of advanced engineering analysis services and specialized capabilities for predicting the strength, durability, life and reliability of complex structure systems made from advanced materials. Their material capabilities include metals, polymeric composites, fiber metal laminates, nano and chopped fiber composites, and ceramics. AlphaSTAR assesses advanced structures behavior under a broad range of environmental conditions and subject to various loading conditions, including static, fatigue and dynamic impact loads. Effects of extreme temperatures, moisture and factors that cause erosion and corrosion are also accounted for in the analysis process.

The company's flagship software product, GENOA, couples finite element analysis (FEA) and micro-mechanics (all the way down to the nanoscale level) to track damage and crack growth progressively in polymeric composites, ceramics and metals. The software has a proven track record in the aerospace, automotive and infrastructure industries. Indeed, it is AlphaSTAR's automotive experience that has helped the company win a variety of contracts to work with the U.S. Department of Defense (DoD).

Composites DOC, located in Northeast Ohio, specializes in finite element-based design, optimization and prototyping of automotive composite components. It provides close technical support to prominent automotive manufacturers.

Today, weight reduction in vehicles like the one shown in Figure 1 is a key focus for the DoD, a problem that TARDEC, working with entities like AlphaSTAR, is able to help the DoD solve with their unique capabilities.

"Today, weight reduction in vehicles is a key focus for the Army," notes TARDEC's Dr. David Lamb, senior technical expert for modeling and simulation. "Many improvements over the years—for example extra armor or functionality—have tended to make vehicles heavier and heavier. That weight is now becoming a problem, as heavier vehicles result in more frequent breakdowns, increased fuel consumption and a shorter vehicle lifespan overall. But it's a problem that TARDEC has been working with AlphaSTAR to address."

"We are primarily concerned with determination of a structure's usable life and its residual strength," Galib Abumeri, AlphaSTAR's senior program manager, says. "The DoD and their suppliers comes to us with a new concept for a system design, and we evaluate and develop the advanced concepts and materials that enable them to make lightweight parts that are lighter, cheaper, more durable and more reliable. We use our software and engineering capabilities to carry out virtual simulations that not only model individual parts, but also prototypes in which the parts are integrated into full systems. We couple durability with reliability and opti-

Figure 1: TTypical vehicle systems that could benefit from the kinds of analyses Alpha STAR completes.

mization to deliver un-matched predictive accuracy of individual components or set of structural systems. Without access to high performance computing (HPC) these challenges would be very difficult to undertake.

"Three structural states are of interest to us—the structure's condition as it was designed; the structure's condition as it was built, including manufacturing defects and anomalies, and component revision prior to acceptance; and the structure's current in-service conditions. We are able to account for damage initiation and growth to failure. For military vehicles, it is important to assess the effect of fatigue cyclic and impact and post-impact loadings on the overall performance of the structure. Environmental effects and aging can impact the desired performance of the structure. These effects must be included in the analysis and design of these complex structures. They can easily reduce the load carrying ability of the structure and reduce its life and reliability. Additionally, it is important to evaluate any effects on the part's performance due to repairs/modifications." He notes that determining the structural life and residual strength is accomplished with a finite element-based progressive failure analysis (PFA). Such a PFA is computationally intensive, requiring detailed analysis and numerous iterations to deliver accurate results. "To achieve all of this requires significant computing power," Abumeri says. Until now, the company's engineers used high-end workstations and PCs running both Windows and Linux operating systems.

Abumeri says: "Running on our high-end desktop workstations, GENOA, our primary software product, augments commercial FEA such as Nastran, to perform accurate progressive failure analysis of the structures we're interested in."

But even with powerful desktop workstations, these types of advanced analysis can take days of computing time.

Designing Tomorrow's Lighter, More Durable and More Reliable Military Systems with HPC

The AlphaSTAR team recently had the chance to leverage the computing power and expertise of the Ohio Supercomputer Center (OSC) for their work with the DoD on a highly utilized and versatile vehicle system. The company was chosen as one of four private-sector firms to participate in an HPC pilot program sponsored by the Defense Advanced Research Projects Agency (DARPA), a research arm of the DoD. The project was designed to investigate HPC adoption within the DoD's private sector supply chain and demonstrate the real business and competitive value of HPC-based analysis, modeling and simulation for DARPA, the DoD, and other small- to medium-sized companies.

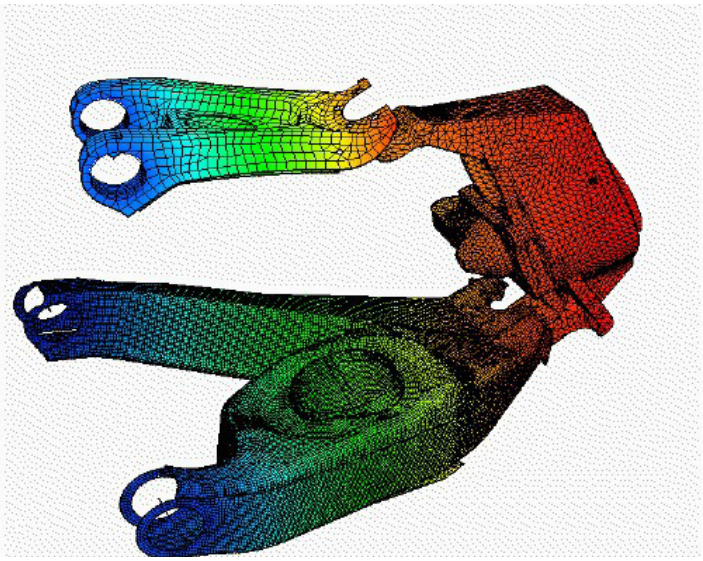
In AlphaSTAR's and Composites DOC pilot program, the goal was to work in partnership with supercomputing experts at OSC—taking advantage of their advanced HPC hardware and expertise—and employ the company's GENOA Progressive Failure Analysis software

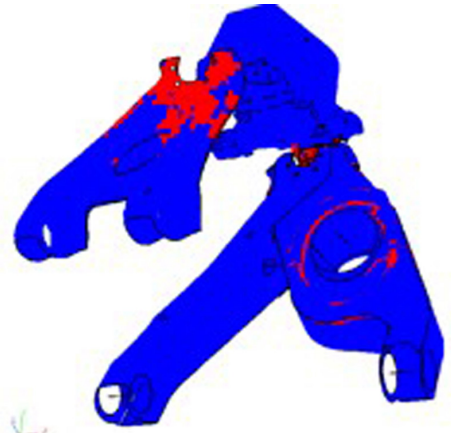
package to work with Genesis optimization code to redesign some critical components that have been failing on a particular vehicle systems for increased strength and weight reduction. The weight reduction and durability enhancement were achieved with the application of advanced hybrid lightweight polymeric composites wrapped over a sheet of metal. The technical efforts undertaken by AlphaSTAR and Composites DOC ensured that the redesigns met stiffness, strength, weight, natural frequency, fatigue and durability requirements, yet was feasible from a cost standpoint.

As a benchmark, AlphaSTAR first analyzed the traditional all-steel and composite hybrid lower control arm and` complete suspension unit for strength, durability, life and reliability. Then Composites DOC optimized the design of these parts using advanced light weight hybrid systems (metallic and composite materials) to maximize weight savings while maintaining the same stiffness. This optimized design was then analyzed by AlphaSTAR for fatigue and durability (see Figure 2). The analysis showed that a minimum of 30 percent weight savings is attainable for large systems with an increase in durability by more than 50 percent (that is, the structure will fail at much higher loads as compared to existing parts).

Next, the team redesigned the shape of the lower control arm and suspension unit while replacing the traditional steel used for the part entirely with composite material–an area where the expertise of Composite DOC's Brian Knouff was crucial. "You have to be careful how stiff you make these parts," he points out. "If you make a part too stiff using composites, the stress can increase elsewhere in the frame it's attached to. Now that part of the frame wasn't designed to handle that stress–and that could cause failure somewhere else."

Knouff said that the team's analysis work eventually demonstrated that the best option for optimizing the lower control arm and the entire suspension unit was to use the original shape while constructing the part from a hybrid of steel and composite materials. The team also modeled the optimum way to build up the different layers of composite material. It was done by taking mass out where not needed and putting it in regions that are highly loaded.





Top, Figure 2a: Finite Element Model of Double A-Arm Suspension Unit of a HMMWV.

Bottom, Figure 2b: Failure of the Suspension Unit at End of Life Under Cyclic Fatigue Loading (red color indicates structural damage).

Knouff added that the result has been a substantial reduction in the control arm's weight and the whole suspension unit weight, along with a major boost in durability, all within the DoD's cost constraints. In the end, the team was able to produce a design that reduced the weight of the control arm by more than two thirds and increased its load carrying capacity more than two times.

Faster Results Now and a Taste of the Future

The team's successful work with OSC on the control arm and double A-Arm suspension unit represents how crucial modeling and simulation with HPC can be in optimizing individual components and subsystems. Abumeri says: "For the analysis of a component like this, we do a large number of PFA runs to assess durability and the damage tolerance of the various structures. Basically, with HPC we can solve problems that in the past would have taken from about 12 hours to three or four days. Now we can turn them around in just under four hours. These runs pertain to durability under static or fatigue loading. As far as reliability assessment is concerned, HPC can be a big booster. The engineering community use probabilistic methods to assess structural reliability and probability of failure under design and service conditions. Traditionally, designers rely on safety factors which would result in overdesign with increased weight and cost, instead of designing for the right reliability."

The computational effort that is required for probabilistic methods has deterred engineers from making good use of the technology. For example, an accurate evaluation of reliability with a Monte Carlo method requires the generation of thousands of samples and analysis runs. For complex parts and structures, it is impossible to attempt to run PFA for a reliability assessment without HPC; simply the time and cost involved of running these kinds of jobs are impractical. "For example," Abumeri notes, "not too long ago I had a project that involved a reliability simulation consisting of more than 10,000 samples and analysis runs with PFA. On our conventional systems, running this job took a few weeks. With HPC, I can get the job done in just a few days (under a week) while maintaining fidelity requirements for the analysis. This is a tremendous time and cost savings, as it enables the design of parts and structures that are light, durable and more reliable."

However, the real value of HPC in this domain will be borne out as the more than 10x simulation speedup provided by HPC will allow AlphaSTAR's engineers to work with full vehicle models instead of being limited to individual components. Overall, whole-vehicle modeling provides increased design yields and reduced operational costs. As Abumeri says: "Advanced HPC capabilities will allow engineers to design a vehicle that can sustain the harshest terrain possible without loss in performance or life. We can improve the design and ensure the vehicle can survive in the most challenging service environment. Specifically, not only will the design be successful, but also we will significantly reduce development costs and life cycle costs as the redesigned vehicle will require less frequent maintenance and repair."

Abumeri continues: "Without this kind of analysis and optimization capabilities, your only recourse is to overdesign the part to handle the anticipated stress. But this is a messy solution—you spend too much money on material, you lose efficiency, and you increase wear and tear and the cost of maintenance. By moving toward full system analysis using HPC, you can avoid these kinds of costly, time-consuming inefficiencies."

And there is another, major benefit, he adds: "You can catch design flaws early in the project so you don't have to waste time and money on testing physical prototypes that encounter unanticipated problems. By reducing the computational time from two to three weeks to just a few days, you can target potential failure points and identify surrounding components that can carry the load if something goes wrong, making the failure less catastrophic. Furthermore, product development and certification cycles will be reduced as this capability enables designers and analysts to perform rapid virtual testing and simulation of the part before it is built and tested."

Reduced run times on this project have demonstrated significant savings in time and cost. Using HPC, the AlphaSTAR engineers have been able to reduce the running time for the analysis of static and fatigue durability by a factor of four. When ramping up to a full vehicle simulation, the savings in HPC computation costs might amount to a whopping 40 percent.

About the Project

This project was created to demonstrate the business and competitive value of product simulation and analysis with HPC in the U.S. manufacturing industry, motivate usage of this innovation-accelerating technology throughout the DoD's supply chain, and identify technologies and partners that can help support an HPC infrastructure for the DoD supply chain base. It was led by University of Southern California's Information Sciences Institute (ISI), which solicited help from OSC to support an HPC Innovation Service Portal (ISP) pilot study taking existing DoD-focused problems, designing prototype computational solutions and evaluating both the technical challenges and potential benefits. Through its industrial outreach program, OSC contacted Ohio Polymer to recommend an engineering firm to support the ISP. Ohio Polymer recommended Composites DOC for its experience in design-optimization and prototyping of composite vehicle components. Composites DOC invited AlphaSTAR Corp to participate in this effort as a leading provider of innovative engineering and software solutions for high-power computing, durability, life and reliability assessment of structures made from advanced lightweight materials.

This project was supported by funding from the Defense Advanced Research Projects Agency (DARPA) under contract number FA8750-08-C-0184. DARPA is the central research and development office for the U.S. Department of Defense. DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security. For more information, see http://www.darpa.mil.

Complete information about the other pilot projects and case studies associated with this project is available at http://www.compete.org/hpc/darpapilots/.

This particular pilot with AlphaSTAR and Composites DOC was one of four such collaborations organized under this project and featured the collaboration of the following key partners:

- **TARDEC** is the U.S. Army's Tank Automotive Research, Development and Engineering Center, the nation's laboratory for advanced military automotive technology. See http://tardec.army.mil for more information.
- The **Ohio Supercomputer Center** provides supercomputing, research and educational resources to a diverse state and national community, including education, academic research, industry and state government. See http://www.osc.edu/ for more information.
- **University of Southern California (USC)—Information Sciences Institute (ISI)**, ISI is a world leader in research and development of advanced information processing, computer and communications technologies. A unit of the University of Southern California's Viterbi School of Engineering, ISI is one of the nation's largest—and most successful—university-affiliated computer research. See http://isi.edu for more information.
- **MSC.Software Corporation** is a global leader of simulation solutions that help companies improve quality, save time and reduce costs associated with designing and testing manufactured products. The company's NASTRAN software was a key part of this pilot. See http://www.mscsoftware.com/ for more information.
- **Vanderplaats Research & Development, Inc.** is the provider of Genesis software, a fully integrated finite element analysis and design optimization software package, written by leading experts in structural optimization. Genesis was used for control arm shape optimization in this pilot program. See http://www.vrand.com/Genesis.html for more information.

Council on Competitiveness
1500 K Street, NW, Suite 850, Washington, D.C. 20005 T 202 682 4292
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