Re-engineering with Confidence: The Critical Role of Physics-Based Simulation, and It’s Effect on Future U.S. Military Materiel Production and Procurement

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The following is a paper submitted to DefenseReview.com (DR) by ANSYS, Inc.'s marketing department. DefenseReview.com (DR) is therefore publishing it under corporate press release status. The reason we're publishing it is because we believe it covers important topics like military materiel manufacturing and procurement, and is interesting to us, even though it falls a bit outside DR's normal content, which is Mil/LE/civilian tactical technology.

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As we enter a period of declining military procurement and uncertain budgets in the West, the stakes for military programs and associated defense contractors have rarely been higher. With large quantities of battle-hardened equipment returning from theater and aging equipment in need of refurbishment or replacement, suppliers that can meet the military’s need for payload, performance and protection balanced against cost and time targets stand to gain substantially—not just from immediate contract awards, but from billions of dollars of follow-on work. Those programs, program managers and contractors that fail against the key performance indicators of time, budget and quality face a very uncertain future.

Smart Engineering Adds Quantifiable Value

Winston Churchill is often quoted as stating, “Gentlemen, we have run out of money. Now we must think.” A recent reference was by retired U.S. Air Force Lieutenant General Lawrence Farrell in a discussion of the national debt’s effect on defense budgets [1]. This sentiment rings especially appropriate in the face of today’s cross-domain recapitalization and refurbishment programs. For example, the Army has a fleet of 160,000 Humvees requiring modernization. The plan is to upgrade a portion of the fleet to high-performance, blast-survivable vehicles and replace the rest with brand new trucks.

This initiative is drawing a great deal of attention, as the winner of the refurbishment contract could gain billions in additional work down the road, not just from the Army but the Marines as well. But the question is whether the existing fleet can be modernized for less than the cost of new trucks.

Colonel David Bassett, Army program manager for tactical vehicles, believes that the answer to this challenge lies in engineering. “Industry has learned that there is no silver bullet. It’s about smart engineering. We think the companies that understand that are going to be postured to compete effectively [2].”

Smart engineering would, presumably, allow projects to be completed in shorter timeframes on smaller budgets, without compromising the desired quality and performance of the end product. But what contributes to smarter engineering? What techniques and characteristics differentiate smart engineering from engineering approaches that fail to achieve time, cost and quality goals?

Research by the Aberdeen Group measured the performance of more than 620 engineering companies against key performance indicators, such as time, cost and quality, to identify what strategies distinguished best-in-class firms from the rest. The differences in performance were clear [3].

Assessing the most highly differentiated strategies between the best-in-class firms and laggards, Aberdeen Group found that the systematic use of physics-based engineering simulation tools early in the engineering process was a standout factor.

Specifically, Aberdeen concluded that best-in-class companies:

- Meet quality targets 91 percent of the time, compared with a 79 percent industry average
- Meet cost targets 86 percent of the time, compared with a 76 percent industry average
- Launch on time 86 percent of the time, compared with a 69 percent industry average

This assertion has also been proven beyond doubt in a three-year study performed by the U.S. Department of Defense [4]. The study found that “for every dollar invested (in software and computing infrastructure to support simulation), the return on investment is between $6.78 and $12.92.”

The Many Roles of Physics-Based Simulation Tools

Physics-based simulation tools harness the power of computers to solve the fundamental equations of physics. Designers and analysts can use the software to create and test virtual representations of components, subcomponents and complete systems (or very close approximations, at least) so they can determine the performance envelope without actually building anything. Design risk can be better quantified as a design moves from stage to stage, and off-design points can be examined to ensure that the end design is robust and meets requirements. What's more, performance can be assessed at nonstandard design points, so performance against future threats can be determined in advance.

Physics-based simulation can be deployed in a wide variety of areas to make engineering and design processes more efficient and effective. The case studies that follow highlight just a few of the ways that technology can be valuable to critical military re-engineering programs.

Case Study: Developing a Safer, Lighter Ejector Seat in 14 Months

The military's advanced concept ejection seat, ACES II, is one of the most successful aircrew escape systems in U.S. Air Force history, credited with saving more than 450 lives since its introduction in 1976. Goodrich Aircraft Interiors and Concurrent Technologies Corporation faced the daunting task of re-engineering this proven design in the next-generation ACES 5 seat for integration into the F-35 Joint Strike Fighter (JSF). The new seat was to be optimized to:

- Enhance aircrew safety
- Reduce maintenance downtime
- Reduce weight
- Integrate with the F-35 cockpit

However, the biggest challenge was developing and delivering an entirely new seat structure in less than 14 months.

The design and analysis was split into three phases. First came conceptual design development, in which engineers designed the seat structure to meet functional requirements, while physics-based simulation verified that the structure was sound and weight was optimized by considering each component individually. During the second phase, a physics-based simulation of the entire seat system was created. A single linear static structural analysis of the seat could be solved in less than 30 minutes. This rapid turnaround time allowed the engineering team to quickly evaluate various what-if design scenarios. They conducted more-detailed submodeling on critical areas to ensure that the structure would not fail in extreme conditions.

After 10 months of development, the third and final phase began. Five prototype seats were built for testing, with the first ejection test of the ACES 5 F-35 JSF seat occurring just 14 months after project initiation. The seat performed flawlessly the first time. According to Park Cover, Jr., Concurrent Technologies' senior mechanical engineer, "This extraordinary outcome was the result of a great deal of teamwork between Goodrich and Concurrent Technologies and would have been unattainable without using physics-based engineering simulation software [5]."

Case Study: Tracking Part Wear to Reduce Service Costs

Component fatigue assessment is often based on a standard load duty profile. In reality, the exposure of a component or system varies widely depending on the mission. The duty profile method of calculating fatigue frequently results in parts being serviced and replaced sooner than necessary, and maintenance performed more often than required. This adds cost and unnecessary equipment downtime. To develop a more effective, condition-based maintenance scheme for jet engine parts, one jet manufacturer coupled physics-based simulation tools with historical part performance data, in-service equipment monitoring and in-house codes.

The result is a system that accurately tracks and predicts component life consumption in fighter jets. At the end of each mission, load data from an aircraft is sent to a server that automatically matches this data with the individual engine parts. The system uses structural and thermal calculations within physics-based simulation software from ANSYS to determine the life consumption of engine parts. ANSYS structural mechanics technology has been found to deliver very accurate results in revealing stresses and temperatures for each mission. The system has allowed jet owners to avoid unneeded expenses and replace parts that have exceeded what the standard duty cycle would advise, ultimately enhancing reducing costs and improving safety [6].

Case Study: Gauging Stress and Vehicle Durability in Minutes

Designing rugged utility vehicles requires engineers to balance durability against time and cost. E-Z-GO, a U.S.-based Textron company, develops durable, high-performance vehicles for a variety of off-road uses, from golf carts to personnel carriers.

E-Z-GO engineers had just one week to redesign a utility vehicle frame to eliminate a bend that was causing manufacturing difficulties. The team relied on ANSYS Mechanical™ for its powerful and flexible design optimization capabilities, using the software to optimize loads and achieve the desired stress level in the redesigned frame. A number of load cases from physical tests were used, including static rolling, braking over bumper, wheeling in a pothole and cornering. Senior Project Engineer Jing Heng Wen was pleased to see that “the finite element analysis model behaved just like the real vehicle in terms of stress and strain on the frame, yet the analysis took only 30 minutes to run.”

Based on the results of the finite element analysis, fatigue life estimation and durability testing, the new utility vehicle frame design was released for production. The new design demonstrated reliability and durability that were at least equal to the previous design, but the manufacturing problem was solved. This approach substantially reduced engineering costs and helped E-Z-GO get the new design into production faster [7].

Case Study: Solving Rapid Antenna Placement with High-Performance Computing

As electronics systems improve and communications and antenna demands increase, retrofitting new systems onto existing equipment can pose significant challenges. Engineering questions such antenna cositing need to be addressed. Traditionally, using physics-based tools to identify solutions in large, electrically complex structures such as ground, air and marine vehicles has been a time and memory challenge.

New techniques, such as multiprocessing and domain decomposition, are resulting in significant improvements in solution time — as much as a speedup factor of 10. In one example, simulations using a 350 MHz antenna mounted on an F-35 Joint Strike Fighter could be completed in a fraction of the time it would take before. What might have been a very difficult problem yesterday is now quite possible [8].

Case Study: Maximizing Load Cycles while Minimizing Brake Pedal Weight

Pratt & Miller Engineering is globally recognized as a force in motorsports and high-level engineering. When the team discovered premature cracking on its brake pedal faces in a particular design configuration, they took notice. Investigations revealed that this was caused by mechanics repositioning the brake pedal face in response to driver preference. Fortunately, engineers discovered the problem before any accidents occurred.

Because the original pedal design had not accounted for any aftermarket modification, Pratt & Miller engineers set out to redesign this critical component. The goal was to greatly increase fatigue life without compromising performance. Simply overengineering the part was not an option, as weight is a vital consideration in the auto racing world.

To speed the redesign, the Pratt & Miller team employed structural mechanics simulation using ANSYS Mechanical software as well as fatigue analysis. The team evaluated a variety of options within the ANSYS Workbench™ environment, which allows users to set up structural mechanics models as much as three times faster than other FEA software. ANSYS DesignXplorer™ software performed automated design iterations to determine the lightest-possible design without exceeding material limits.

The engineering team checked the redesign and found that it greatly improved fatigue life — well over 1 million minimum load cycles. The original design predicted a life of 16,567 cycles, while the redesigned pedal has a predicted life of more than 10 million cycles.

The new design is now in production and on the track. By using physics-based engineering simulation tools, the engineering team increased confidence in getting the redesign right first time — in effect, outpacing the competition by designing a lightweight part with a lower target fatigue life factor [9].

Engineering Provides the Critical Edge

There's no question that budgets and development cycles will continue to be squeezed. The time and costs associated with physical testing of individual components and complete systems is a luxury military clients can no longer afford — particularly when it comes to retrofitting and upgrading existing assets to address ever-changing threats and environments.

Fortunately, using physics-based simulation to measure performance, calculate preferred options, determine appropriate materials, and troubleshoot problems virtually has proven itself to be a reliable, efficient alternative. Engineers can now balance competing needs — aerodynamics and stealth, weight and mobility, comfort and protection, and more — by reviewing a range of scenarios in minutes, making it fast and easy to identify and move forward with the optimal solution.

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About the Author

Robert Harwood, Ph. D., is the aerospace and defense industry marketing director at ANSYS., Inc., which develops engineering simulation software and technologies widely used by engineers, designers, researchers and students across a broad spectrum of industries and academia.

ANSYS, Inc. is one of the world's leading engineering simulation software providers. Its technology has enabled customers to predict with accuracy that their product designs will thrive in the real world. The company offers a common platform of fully integrated multiphysics software tools designed to optimize product development processes for a wide range of industries, including aerospace, automotive, civil engineering, consumer products, chemical process, electronics, environmental, healthcare, marine, power, sports and others. Applied to design concept, final-stage testing, validation and trouble-shooting existing designs, software from ANSYS can significantly speed design and development times, reduce costs, and provide insight and understanding into product and process performance. Visit www.ansys.com for more information.

Side Bars

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Attributed to Winston Churchill

"There is no silver bullet. It's about smart engineering."

Colonel David Bassett
Program Manager for Tactical Vehicles U.S. Army

"This extraordinary outcome would have been unattainable without using engineering simulation software."

Park O. Cover, Jr.
Senior Mechanical Engineeer
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“The finite element analysis model behaved just like the real vehicle in terms of stress and strain on the frame, yet the analysis took only 30 minutes to run.”

Jing Heng Wen
Senior Project Engineer
E-Z-GO

Captions for Graphics and Image

Physics-based simulation, used early in the design process and deployed systematically in the organization, is a key defining factor of smart engineering.

The ACES 5 seat performed flawlessly the first time.

The ACES II ejection seat carries a pilot out of the aircraft.
U.S. Air Force photo by Staff Sgt. Bennie J. Davis III.

Load data on fighter jet components is recorded after each mission. ANSYS structural mechanics technology has been found to deliver very accurate results in revealing stresses and temperatures for each mission.

E-Z-GO utility vehicles haul materials over rough terrain.

Geometry of the original frame (above); redesigned frame showing welds (below)

Mounting option for a 350 MHz antenna on an F-35 Joint Strike Fighter, along with the resulting radiation pattern

Brake pedal crack with simulation of equivalent stresses