White Paper

Simulation-Based Acquisition at Lockheed Martin

February 20, 1999

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1.0 Introduction

The purpose of this white paper is to provide a more comprehensive description of how customers are using SGI® technology to improve product development and reduce manufacturing cost. This white paper describes two important programs at Lockheed Martin, the F-22 and the Joint Strike Fighter, and how SGI systems have been used there as an integral part of designing high-performance products while simultaneously driving down cost. The content of this white paper has been approved for external release by Lockheed Martin's communications group. Joe Stout, director of communications for Lockheed Martin Fort Worth, and Sam Grizzle, the F-22 communications manager at Lockheed Martin Marietta, have provided the final approval.

2.0 Company Background

Lockheed Martin is one of the leaders in developing military aircraft for the U.S. government, with a long list of products such as the F-111, the F-16, the F-22, and the Joint Strike Fighter. In recent years, the company has invested in a great number of digital tools and technologies that enable it to advance aircraft development while reducing cycle time and cost.

The original version of the F-16 was the last military aircraft program at Lockheed Martin that was designed using classic drawing boards. In 1976 Lockheed California developed a CAD application called CADAM, and engineers in Fort Worth, Texas, began to use CADAM in the final stages of the F-16 design. At this point CAD design was still really only a mechanical drawing package—not 3D solid models—but it was a major step toward digital design. By the early 1980s Dassault Systemes had developed CATIA®, a 3D solid modeling package that is used today predominantly by aerospace and automotive companies. The historical shift to true digital design came with the development of the F-16 XL. Lockheed Martin made the decision that this aircraft would be completely computer designed. Engineering and manufacturing teams were quite skeptical, but as manufacturing began to assemble the plane, excitement grew. All but one fastener fit, and that minor error was caused by a design change that was done outside the system.

Beginning with the F-22 air superiority fighter aircraft in the mid-1980s, multiple forces pushed Lockheed Martin to further incorporate virtual product development. For example, today's workforce is much more flexible. This workforce variability helped Lockheed Martin develop methods that made engineers disciplined in how they work and maintain information yet still allow for creativity. In 1995 Lockheed launched its Virtual Product Development Initiative (VPDI), taking the next leap in digital design. Lockheed's goal was for everyone involved in new product development to have the information they needed, as well as the most current iteration of the design.

3.0 Joint Strike Fighter (JSF) Background

In 1996 Lockheed Martin won a 51-month concept demonstration contract for the JSF, the next generation of jet fighters. In this initial phase of the program, Lockheed Martin will design, build, and flight-test two demonstrator aircraft. Future production will include approximately 3,000 aircraft, at a cost of $70 billion over 30 years. It will include the cost of not only building the fighters but all upgrades, maintenance, and training. The final contractor selection will be made in 2001 by the U.S. Air Force and U.S. Navy.

The JSF program consists of four customers and three different designs. The Navy will be looking for a plane capable of landing on aircraft carriers, the Air Force will require conventional take-off and landing criteria, and the Marines and the British Royal Navy will be looking for landing capabilities similar to those of the Harrier.

The Lockheed Martin team consists of three companies: Lockheed Martin, British Aerospace, and Northrop Grumman.

4.0 Virtual Product Development Initiative (VPDI)

The U.S. government mandated that affordability be a major factor in making the final contractor selection for the JSF. In 1996 Lockheed Martin Tactical Aircraft Systems (LMTAS) began a five-year program that would transform how aircraft are developed. This grew out of the recognition that revolutionary change was needed in the product development process to achieve Lockheed Martin's objective of a 50% cost reduction in development and production and a 30% reduction in maintenance time and cost.

VPDI began with a multidisciplinary team to identify processes, technologies (hardware and software), and integrated infrastructure to revolutionize product design. To ensure that the processes and technologies can truly reduce product development cost, an integrated infrastructure is critical. The team's approach was to use knowledge already developed in weapon systems, add new evolving technologies, and take advantage of commercially available software. As a result, several dozen tools have been developed for use throughout Lockheed Martin. Several of the VPDI tools were developed to take advantage of the significant graphics capabilities of SGI systems. For some applications the tools are run exclusively on SGI platforms. With SGI graphics capabilities, engineers are better able to visualize their designs and have real-time interaction with the 3D solid models.

During the first two and a half years the team evaluated the existing processes at LMTAS, as well as best practices at automotive, heavy industry, and other aerospace companies. In April 1998 VPDI recommended eight key high-payoff areas with which an integrated infrastructure should be created. These eight areas are:

- Product data management
- Relational design with exact solids, parametric, and geometric associativity
- Seamless data integration and model-based build-to-package release
- Design with cost objective: In the past, LMTAS would perform a parametric cost estimate after major design iterations. Parametric estimates between design iterations are still a part of the process; however, the parameters being evaluated address a much broader range of design and process considerations than has historically been the case. In addition, a key enhancement VPDI is introducing is the ability for the designers to assess the cost impact of a potential design change concurrent with other design and analysis activities so that they are able to treat cost as a design constraint during each design cycle. This capability not only affects material selection but process selection as well.
- Integration of design and analysis
- Integration of manufacturing and processes into the design: For example, the evaluation of different fabrication processes and material cost. There is also the evaluation of the factory flow of parts, making sure all aircraft parts arrive at the right place at the right time, as well as tooling, design, and assembly simulation.
- Integration of support process definition: These processes evaluate how the aircraft is serviced and refueled and how weapons are loaded. Through digital evaluation, engineers are able to create modular designs that minimize the time required to service the aircraft and consequently reduce the cost of aircraft maintenance. An excellent example of the benefits of virtual design was demonstrated using software from Deneb Robotics on SGI hardware. Designers using the digital model were able to see that the maintenance people had to put their hands over their heads to install the weaponry. What they gained using Deneb Robotics tools was to ability to view the maintenance task from the point of view of the maintainer, which revealed that the maintainer did not have an adequate line of sight to perform the task. Using Deneb's IGRIP software, the designers were able to identify the problem and change the design for more efficiency and safety.
- Integration of knowledge-based systems: Here the VPDI team took a three-tier approach. For example, they first would identify what causes scrap and rework. Second, they would interview the people currently performing the tasks and identify the most common reasons for engineering change. Third, they would develop a mechanism for capturing the knowledge and information and improving the process with a knowledge-based system.

The objectives for the selection of the above eight processes were as follows:

- Enable design for affordability: VDPI focuses on elimination of errors and physical prototypes, while ensuring a high level of fidelity and always includes physics-based information. Information is not based on a cartoon-like animation in which a physically impossible situation is made to appear real (such as a one-handed removal of a 500-pound component from an overhead rack), but rather is constrained by real-world limitations such as mass and inertia.
- Reduce development span: Digital technology allows for the evaluation of more alternatives and iterations for design optimization.
- Enable collaboration: Collaborating engineers wish to interact in real time with 3D representations of the parts they are designing (based on CAD models). Two engineers working in different locations using SGI workstations with QuickTime® video can create videos of the model. Then they can access the model via the Web and discuss the design with their counterparts. SGI systems can be used for this entire process.
- Change the way people work: This is why VPDI focuses so much on the process. Visualization capabilities make the process change much easier for designers and engineers.

"It is hard to miss the benefits," says Linda Poole, program manager for VPDI. "In some areas we are seeing reduction in cycle time and cost savings in the range of 70 to 80%. Engineers can change their design process through the visualization technology delivered by Silicon Graphics® systems. LMTAS has over 450 Silicon Graphics workstations, several Onyx2 systems, and Origin 2000 systems across multiple disciplines." According to Poole, "Several teams may design structures that work well by themselves but interfere with objectives of others. These visualization tools allow teams to see the impact of their work on the entire project before the design is firmly established, when mistakes will cost much more time and money." The teams will be able to view and interact with spatial analysis tools that can find and resolve flaws. Digital prototyping software from Engineering Animation, Inc., can be used in a secure environment across the Internet, so multiple sites can conduct collaborative design reviews. The VPDI system will be used not only by designers, but also by manufacturing and support engineers, ergonomics experts, suppliers, management, marketing, and customers.

5.0 Laser UT (Nondestructive Ultrasonic Testing System)

To develop its state-of-the-art Laser Ultrasonic test system, Lockheed Martin turned to best-of-class practices in the steel industry and made its own significant enhancements. The result is a Laser Ultrasonic Test (UT) System to replace its conventional water-coupled ultrasonic devices. The Laser UT Center is capable of testing large composite parts, up to 54 feet by 27 feet by 21 feet. The 10,000-square-foot facility is expected to provide a return on investment in the range of 30 to 60 times, saving hundreds of millions of dollars in manufacturing costs during the life of the JSF program.

Laser UT provides the capability to test complex-contoured aircraft parts made from graphite-epoxy composite materials. Composites are composed of layers of graphite-epoxy-impregnated materials that are cured under heat and pressure in an autoclave.

Ultrasonic testing is required to find voids and other potential flaws that could lead to part failure under conditions of structural stress. Because the Joint Strike Fighter will use a higher percentage of composites than previous fighters, it will require an unprecedented level of testing. For example, using current equipment, it takes approximately 24 hours to inspect a composite inlet duct built for the F-22 Raptor. This time will be cut to less than two hours with the Laser UT system. "In addition to reducing test cycle times by more than 90%, this cutting-edge technology virtually eliminates setup, simplifies operator interface, and provides design feedback to enhance affordability," according to Bob Rearden, vice president of production operations for Tactical Aircraft Systems.

The Laser UT system uses a two-pipe Silicon Graphics® Onyx2® supercomputer, visualization software developed at Lockheed Martin Tactical Aircraft Systems, and a gantry robot. The ultrasonic waves are translated into 3D solid models on the Silicon Graphics Onyx2 system. The inspector will then visualize the 3D model to determine the material flightworthiness of each composite part.

Only Onyx2 has the I/O bandwidth and ability to do the intense volume rendering required by this internally developed application. This system, in combination with a second system scheduled to come online in late 1999, established Lockheed Martin as the world leader in composite test technology.

6.0 Flight Simulation

Lockheed Martin has been a pioneer in flight simulation technology and has been instrumental in the development of today's full flight simulation. Originally, simulators were separate stovepipes (a separate computer for each function), a necessity due to limitations in the hardware. As SGI developed visual supercomputers, Lockheed Martin could place more and more functions on one system. Today the company can combine everything on one Onyx2 system. More functionality on one system means engineers don't need to worry about high-speed integration. This not only saves money but for the user it means no lag time. When multiple systems were used they also needed separate databases for each platform. Today, with one system, engineers need only one database. For example, out-of-the-window and heads-down displays can live in one database.

Matt Landry, junior manager for Simulation Programs, states, "The purpose of virtual reality is to save money and time by avoiding unnecessary prototypes, but if the technology is too difficult or expensive we've lost our advantage."

Virtual reality provides real benefits to the engineering community by allowing users to see how the design works in real-life conditions. Engineers can get valuable feedback from the pilots, and virtual reality can be used as a marketing tool to prospective customers.

The JSF program will run full mission simulation that requires full determination, high fidelity, and low lag. Lockheed Martin will test flight evaluation (handling quality) and provide tactical simulation (such as tactical software, weapons, etc.) and simulation for pilot training.

Flight simulation can even take place with multiple participating sites, in what is known as a Distributed Simulation Environment. Lockheed Martin demonstrated a full flight simulation with participation of four sites: Lockheed Fort Worth; Lockheed Missiles & Space in Sunnyvale, California; J Stars in Melbourne, Australia; and Northrop in Pico Rivera, California. All but J Stars ran the simulation on Silicon Graphics systems. With most locations running Silicon Graphics systems, Lockheed Martin was able to run the models locally, eliminating expensive long-haul networks and avoiding security issues.

Lockheed Martin has also developed fully immersive simulation environments, using a dome powered by an eight-pipe Onyx2 system with InfiniteReality® graphics. Projection into the dome comes from four outside projectors and provides a 360-degree view. The pilot sits in a center cockpit. To make this a real-time environment, Lockheed Martin had two major requirements. First, the computer hardware needed to be extremely fast (60 Hz, no lag), which is possible on the Silicon Graphics Onyx2 system. Second, in order to display a flat image on a curved surface distortion correction was required. Paradigm Simulation and SGI worked together to ensure distortion correction capability.

All companies competing for the JSF contract will use the same mission model (computer scenario with enemy, etc.) provided by the U.S. government. The Navy ACTEF (Air Combat Test & Evaluation Facility) selected Silicon Graphics systems and a flight file database from MultiGen as the facility standard to integrate all JSF models provided by defense contractors. The defense contractors must simulate their designs in this facility. Because of the common Silicon Graphics platform, the Lockheed Martin JSF team is easily able to integrate its design in the ACTEF facility and collaborate with the customer.

7.0 Lockheed Martin Marietta Simulation Lab

Lockheed Martin Marietta's F-22 Air Combat Simulation Integrated Product Team (F-22 ACS IPT) is responsible for developing a tool to help the Air Force determine the effectiveness of the F-22 as a weapon system. They must not only model the F-22 systems but also the other threat and friendly systems that interact with the F-22. They must model functions such as RF signals, infrared signatures, missile flyouts, ground radars, and AAA, AWACS, IFF, and RWR aircraft flight models that contribute to the overall F-22 system effectiveness. Developing aircraft avionics is more expensive than designing the airframe, making real-time cockpit simulation indispensable.

Today's jet aircraft avionics are unlike their predecessors that relied on "federated" avionics (separate radar, separate IR, separate IFF, separate weather and navigation, etc.). Now all information sources come together as needed and are coordinated in single displays. Fused data and integrated avionics require multifunction displays that put all relevant information together so the pilot does not have to switch back and forth to get the whole story. Many hours of simulation were required to develop the Pilot-Vehicle Interface. This was accomplished by putting Lockheed and Air Force pilots into simulators to resolve human factor development issues.

Added to this is the government's requirement of simulation-based acquisition (SBA). For example, in the F-22 program there will be flight testing, but the testing and evaluation of complex scenarios, unattainable in flight test, will take place in the Air Combat Simulation System. There are safety and security issues of flight testing that only simulation can overcome. The ACS IPT receives validated behavior/performance modeling data for missiles, adversary aircraft models, air defense systems, etc., and integrates them into the simulation. The original simulation requirements were to have 80 flying objects (aircraft, missiles) in a scenario with two F-22 fighters. This requirement has now grown to 200. Not only would this be impossible to produce physically, but it would be safer and more cost effective in a synthetic environment.

From the very start of the program in 1992, Lockheed Martin knew that the key requirements for all hardware and software would be portability, reusability, compatibility, flexibility, and scalability—with scalability being the most critical. Low-end development would have to interoperate with high-end systems in real time. "In 1992 we realized we had a requirement that was several years down the road for very high-end simulation," says Jim Spruell, staff engineer on the ACS IPT. Lockheed Martin knew that by the time it was ready to test the full system, much better hardware would be available than in 1992. So it developed a software architecture, based on Ada, that could be ported to future hardware. Spruell then formed a team that looked at various real-time hardware systems. When the SGI® Origin® 2000 system was delivered it had, by far, the best scalability of any platform. During the same time period, Silicon Graphics also upgraded the IRIX® operating system to have deterministic real-time capability.

Typically in development simulation, the scope of the program changes often (which nearly always means an increase in complexity and functions). By 1999 Lockheed's lab had a 32-processor Origin 2000 system and plans to add 32 more processors. The system was partitioned into one 16-processor and two 8-processor systems. Interestingly, it's not just scaling up that is required. In this case, scaling down is sometimes needed to allow parallel development and integration testing. This changeover can be done in less than one hour with a simple reboot. Scalability like this was unprecedented. With the addition of the second 32-processor Origin system, Lockheed plans to run with the 16-processor and the two 8-processor Origin 2000 systems, while keeping the 32-processor station intact as one system. Eventually Lockheed will configure the full 64-processor unit as one system that will be needed for full-scale testing.

What has also been important is the scalability between low-end workstations and high-end systems. According to Spruell, "This is a good example of technology insertion in which appropriate technology is applied to the problem at the appropriate time." In addition to the workstations and servers on location, the ACS IPT team will acquire two multichannel 360-degree flight simulator visual display systems driven by an Onyx2 InfiniteReality system (aka RealityMonster®) for two of their F-22 cockpits.

Spruell estimates that his organization has cut its development time and resources by a large amount through creation of a very good development and testing environment. The organization uses Indigo2™ and Silicon Graphics Onyx2 workstations to develop, unit test, and integrate the software in a non-real-time mode. The same code is then loaded onto the Origin 2000 systems and tested in real time without recompiling. Previous real-time simulation systems had different computers for development and execution. The real-time system was always the bottleneck during testing due to its lack of ability to perform parallel testing. Spruell states, "We couldn't do it with our current budget and staffing plan without the Silicon Graphics systems."

Simulations using SGI systems support new development changes in the product that is being simulated (the F-22, in this case). Air Force pilots flying the part-task simulators have validated completely new missions in the process. This information is then evaluated by the Air Force program office, which then generates new specifications for the aircraft (hence new specs for the simulator). Simulators equipped with Silicon Graphics systems also helped in the requirements definition and design of mission expansions. While the F-22 was originally designed purely for air superiority, its mission was expanded to include ground attack.

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3352 (06/28/2002) J14085