Collaborative Virtual Prototyping

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The Department of Defense can no longer afford its present acquisition process. A naval research advisory committee recommended that a distributed simulation-based acquisition process approach be used to streamline acquisition and product support throughout all life cycle phases. Collaborative virtual prototyping (CVP) is the application of advanced information technology in the design, modeling, analysis, simulation, manufacturing, testing, and logistics to support the life cycle development of a system. The Applied Physics Laboratory supported the Naval Air Systems Command in conducting a study to determine the state of the art and state of practice of CVP technologies in the aircraft and electronics industries. The study found that commercial firms are using CVP technologies to maintain their competitive edge in world markets, and defense firms are rapidly adopting CVP technologies to remain competitive. Where CVP has been applied, cost savings of at least 20% have been realized while time to market has been reduced. The challenge now is for DoD acquisition officials to modify their processes to maximize the benefits of these emerging technologies.

INTRODUCTION

Since World War II, U.S. military superiority has been based on our technological advantage, which has been supplied by a defense-unique industrial base. This advantage was plainly demonstrated during Desert Storm where Tomahawk cruise missiles, laser-guided bombs, F-117 stealth fighters, and many other advanced weapons systems dominated the battlefield. As we approach a new millennium, our military strategists anticipate similar engagements in “lesser regional conflicts.” Indeed, our entire defense planning process is geared toward such a model, one in which technology is expected to play an ever-increasing role. In the past, the United States achieved technological superiority through large fiscal investments, rigorous specifications and standards, and a lengthy acquisition process. The Department of Defense realizes it can no longer afford its present acquisition process and is advocating major reforms to bring about fundamental change to the business practices that have sustained our industrial base. Secretary of Defense William Perry best described the current situation at a 1995 briefing: “The DoD’s acquisition process is not sufficiently streamlined, flexible, agile, efficient, timely, or effective.” Clearly we must find new ways to design, produce, and operate our future weapons systems at a fraction of the cost we now pay, and once again, the DoD leadership is looking at technology to find a solution.

In the early 1990s, several panels were formed to examine the acquisition process including various Defense Science Board studies, the Director of Defense for Research and Engineering (DDR&E) Technology for Acquisition Reform Study, and a 1993 Army Science Board study. All concluded that advanced distributed modeling and simulation technologies, combined with integrated product and process teams, could be used to support acquisition reform. In June 1993, Anita Jones, Director, DDR&E, established the Acquisition Task Force on Modeling and Simulation, whose final report states:

> Both industry and DoD representatives expressed the desire to perform more "integrated functional analysis" during the acquisition process. "Integrated functional analysis" generally encompasses analysis that considers the impact of decisions, trade-offs, and risks both within and across acquisition functional disciplines. Industry's effort to adopt Concurrent Engineering and Integrated Process and Product Development (IPPD) practices demonstrates the trend toward such analysis.[1]

In the summer of 1994, realizing that the future Navy would be a much smaller force with a reduced budget, the Naval Research Advisory Committee (NRAC) was convened to review the current utilization of modeling and simulation within the Department of the Navy. The challenge handed to the committee was to find a more efficient and less costly way of defining requirements, evaluating solutions, and refining system designs. The committee identified the phrase "distributed simulation-based acquisition" to include advanced distributed simulation (used in man-in-the-loop exercises) and simulation-based design/manufacturing (for engineering simulations). In their final report, the NRAC concluded the following:

> The panel believes that the tools embedded in Advanced Distributed Simulation (ADS) and Simulation Based Design and Manufacturing (SBD/M) provide a capability that can revolutionize the acquisition process. A new Distributed Simulation Based Acquisition (DSBA) process promotes end-to-end verification of requirements matched to design, manufacturing, and supportability, and it facilitates cost and performance trades for the complete life cycle, from pre-concept feasibility studies through development and training. The distribution of the common data base, and interactions with live and virtual simulations, are as valuable to training as they are to confirming operational requirements. DSBA also provides a mechanism to continually support user (operator/tester) involvement in needs, evaluation and training, and facilitates integrated product and process definition throughout the life cycle. If properly implemented we should be able to "try before buy," using distributed interactive simulation to solve many of the problems that usually are first evidenced only after hardware construct.[2]

Clearly these studies looked to modeling and simulation technology as the key to solving the affordability problem. Yet the DoD had been doing modeling and simulation for decades. What was the difference? We believe that two fundamental trends were synergistically merging to create a very powerful capability: (1) the ability to create a virtual prototype in digital form that captures the essential performance characteristics of the physical system, and (2) the ability to use networking technology to facilitate collaboration among experts who are geographically dispersed. We call this combination collaborative virtual prototyping (CVP)—the application of advanced information systems technology in the design, modeling, analysis, simulation, manufacturing, testing, and logistics to support the life cycle development of a system.

Collaborative virtual prototyping brings the best and the brightest talent from across the country into electronically integrated product and process development (IPPD) teams to concurrently engineer future systems. It enables all team members to continuously interact through electronic modeling and data exchange in a geographically distributed environment. CVP relies on high-fidelity physics-based models that allow increased insight into life cycle concerns and provide system-level testing before production through the use of validated model-based virtual proving grounds. Such technologies will accelerate eventual system production through the creation of virtual factories that permit detailed work flow analysis, workforce training, and accurate cost and time forecasts as well as the determination of equipment utilization rates. CVP can potentially allow technically superior systems to be developed at a much reduced cost and in less time. Most advocates believe a 20 to 25% concurrent reduction in acquisition cost and time to first article completion is possible.

Eighty percent of development costs and 70% of life cycle costs (LCCs) of a product are determined during its conceptual design phase. As a program moves from conceptual design into engineering and manufacturing development, the freedom to make changes is reduced and the knowledge about the system increases. A natural progression from soft to hard information increases as the acquisition program moves from preconceptual design to concept demonstration to engineering and manufacturing development. Figure 1 illustrates the problem by representing the knowledge gained during the development of a product versus the ability to change the design based on cost drivers. The use of CVP enables knowledge about the product, its performance, its producibility, and its ease of maintainability and operation to be obtained through modeling, simulation, and electronic prototypes as early in the conceptual design as possible. As shown in Fig. 1, CVP helps move the learning curve farther to the left, where there is a greater ability to influence the design and consequently where affordability is the greatest.

The Navy is examining the use of CVP and simulation-based acquisition to reduce costs and improve the performance of future systems. APL is supporting the Naval Air Systems Command (NAVAIR) in examining CVP technologies to facilitate development of next-generation support aircraft. This assessment is needed since current carrier-based naval mission support aircraft (S-3, E-2, ES-3, and C-2) will reach the end of their operational service lives between 2010

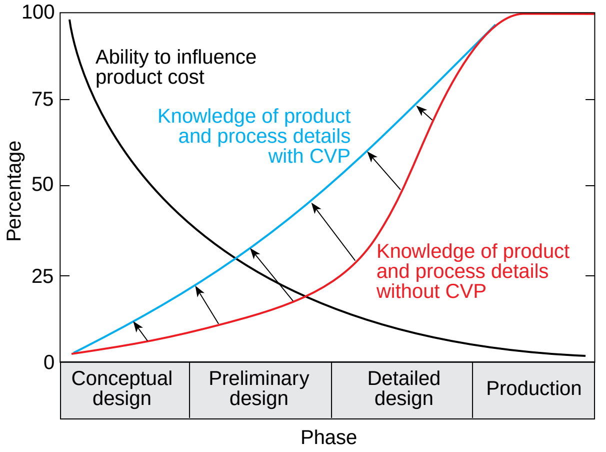

Figure 1. Cost versus product knowledge. Eighty percent of affordability decisions occur before detailed design; however, nearly all development costs occur during detailed design (CVP = collaborative virtual prototyping). (Figure adapted from one supplied by Lockheed Martin Tactical Aircraft Systems, Fort Worth, Texas.)

and 2015. For many of these airframes, mission obsolescence may occur sooner. A naval aviation affordability study, concluded in May 1993, determined that more restrictive budgets require a "neckdown" in the types of airframes, reduced flyaway unit costs, and reduced LCCs. A single airframe that can support multiple missions is highly desirable. Such an airframe would have to fly at high altitudes for long-range airborne surveillance and communications, fly at low altitudes for submarine acquisition and prosecution, and be able to shuttle supplies and personnel to and from a carrier battle group. CVP is an effective way to bring together the diverse engineering and manufacturing talents required to develop such a complex, multimission aircraft.

Several other government departments and agencies are developing tools and technologies that could be used as components of CVP. The Defense, Commerce, and Energy Departments, NASA, and the National Science Foundation are all developing new tools, integrating tools, developing advanced manufacturing processes, or conducting pilot programs for the CVP environment. Industry has adopted these new tools and business practices because they facilitate the development of higher-quality products in less time. CVP technologies allow U.S. producers to be competitive in the world market. For example, Chrysler has been able to reduce the development time of a new vehicle from 54 to 31 months, with staff reduced from 2000 to 600.

Figure 2 presents the approach taken for the APL-supported NAVAIR CVP study. Information on CVP has been collected in three areas: CVP technologies, enabling business practices, and benefits of CVP. The study areas were used to assess the maturity of CVP in both commercial and defense components of the industrial base. In all cases, the aircraft and electronics sectors have either invested heavily in CVP or are developing programs to integrate their tools and departments into a CVP environment. This article presents a summary of the NAVAIR/APL findings on exploiting the benefits of CVP.

CVP TECHNOLOGY

To apply CVP to the acquisition of large systems, many tools and technologies must be integrated. The CVP taxonomy depicted in Fig. 3 was derived from the Advanced Research Projects Agency (ARPA) Simulation-Based Design Project report[3] by the Lockheed

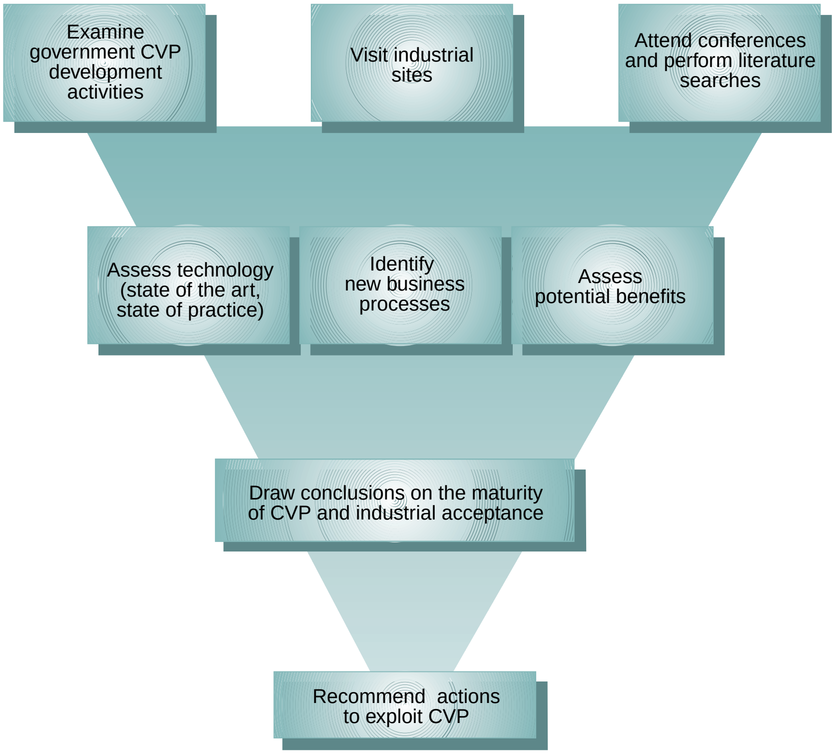

Figure 2. The Naval Air Systems Command collaborative virtual prototyping (CVP) study approach.

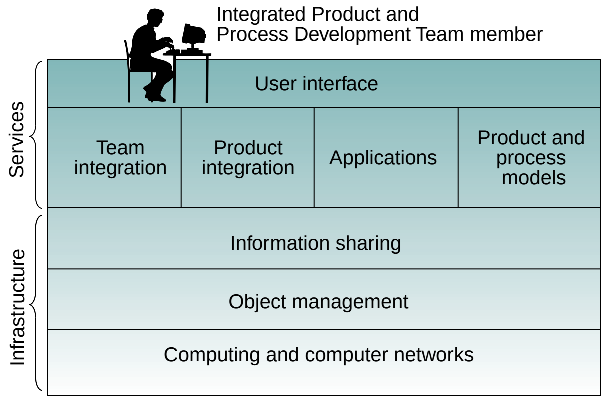

Figure 3. Collaborative virtual prototyping taxonomy.

Martin Missiles and Space Company in October 1994. The architecture presented in Fig. 3 has two elements: (1) services, which are tools and technologies that directly interact with the members of an Integrated Process and Product Development (IPPD) Team and (2) the infrastructure, which consists of the hardware and software that is transparent to the user (i.e., exists in the background but does not directly interact with the user).

The infrastructure is further divided into three major layers: information sharing, object management, and computing and computer networks. The lowest level, computing and computer networks, represents physical connectivity among computer resources. Within that layer exist high-performance computing centers, large data storage systems, system security, and the physical networks connecting organizations and processing capabilities. The next layer, object management, provides logical connection of data and information. Its components manage data, information, and models as objects that exist across the networked enterprise (the conglomeration of all participants). The object request brokers, object link embedding systems, and object database management systems are contained within this layer. The information sharing layer includes brokers and agents to locate and translate information, advertise services, and provide for subscription and notification of collaborative events.

The services layer has four components that interface with the information sharing layer in the infrastructure: team integration, product integration, applications, and product and process models. Each of these services has its own unique human/computer interface with members of the IPPD Team.

Team integration includes collaborative, multimedia, interdisciplinary information-sharing tools for proposing and making design changes with other team members. The second service provided by team integration is the assembling of application models or modules into megaprograms for performing physics-based analyses across disciplines. Technologies within product integration allow the user to interact with the product. The simplest of these are the solids models in the computer-aided design products, and the most sophisticated is a dome or the so-called CAVE, a room in which the user is immersed in a virtual world. Applications services consist of libraries of models for warfare, engineering design, production, cost, and risk analyses. The enterprise must devise means for accessing these models without the burden of generating new application-specific models that must be carefully maintained and take on a life of their own. The product and process model is a knowledge base and a virtual repository of information that is created for the product to be designed and produced. This electronic product and process model is the output of the IPPD Team. The ARPA Simulation-Based Design Team has coined the term "smart product model" to refer to the product and process model knowledge base.

Table 1 compares product model size estimates for different naval platforms. (Size estimates for an aircraft carrier and submarine were provided by Newport News Shipbuilding as a part of their simulation-based design effort for ARPA. Size estimates for the F-22 fighter were provided by Lockheed Martin Marietta, Georgia.) Objects are defined as the number of independent components constituting the platform. Data are the number of bytes that make up the object. Object sizes of 2 KB were estimated by the Simulation-Based Design Program. For complex objects, sizes could be orders of magnitude larger. The storage requirement needed to describe a relationship between or among objects is estimated to be the same for the description of an object (i.e., about 2 KB). For complex objects there would be many more relationships among objects than the objects themselves. Accurately representing the object relationships is one of the most beneficial aspects of CVP. These relationships are not fully

Table 1. Smart product model size estimates.

Model components	Aircraft	Submarine	Aircraft carrier
Objects (no.)	0.35×10^6	2×10^6	30×10^6
Data (bytes)	0.7×10^9	4×10^9	60×10^9
Relationships (bytes)	0.7×10^9	4×10^9	60×10^9
Total size assuming average of two versions/object (bytes)	2.8×10^9	16×10^9	240×10^9

understood until a physical prototype is assembled and is under test. Here again, 2 KB is a conservative estimate for a relationship that could be orders of magnitude larger for complicated systems. The total model estimate includes an average of two versions of each object while the model is in development. For an aircraft carrier, which is the largest naval platform, a smart product model could contain 30 million objects and require 240×10^9 bytes of storage. For an attack submarine, the number of independent objects is approximated at 2 million. A strike aircraft could contain 350,000 objects and require 2.8×10^9 bytes of storage. Today's optical data banks have capacities of several terabytes and could easily accommodate the estimated requirements.

Standards allow interoperability across the enterprise and are needed for every component of the taxonomy. Standards in information technology are being driven and developed by commercial open system requirements. Industrial consortia are assisting in the development of these standards. The Open System Foundation is fostering the distributed computing environment. The Object Management Group is contracting for the development of the Common Object Request Broker Architecture (CORBA), and Product Data Exchange Services, Inc., is promoting the Standard for the Exchange of Product Data (STEP).

Within the federal government, the National Institute for Standards and Technology (NIST) is responsible for Federal Information Processing Standards (FIPS). NIST is adopting a series of standards called Open System Environments; one of those standards is STEP.

The Defense Information Systems Agency (DISA) serves as the focal point for information technology standards within the DoD. DISA developed the Technical Architecture Framework for Information Management (TAFIM, DoD 8020.1-M), which is intended to guide the development of architectures that satisfy requirements across missions and functional activities. Use of the TAFIM is mandatory for DoD work. Additional information on the TAFIM can be obtained on the Internet's World Wide Web at http://www.itsi.disa.mil/cfs/tafim.html.

BUSINESS PRACTICES

To effectively implement CVP, both government and industry must adopt many cultural business changes. The NAVAIR/APL CVP study identified potential business practices that could help maximize the benefits of CVP. We present a few of the practices identified within the aviation industry in this section.

One of the largest tactical aircraft technology activities within DoD is the Joint Advanced Strike Technology (JAST) Program. One focus of the JAST Program Office is the development of technologies and business practices for an affordable next-generation triservice strike aircraft. Practices significant to CVP are extensive use of the Internet for communication among team members, use of electronic source selection, and adoption of associate contractor agreements.

JAST's use of the Internet for communications is a model for the entire Department of Defense. All unclassified program information is available including business plans, broad area announcements (BAAs) and meeting announcements, schedules, presentation materials, reports, newsletters, etc. This information is constantly updated and available on the World Wide Web. JAST contractors use the JAST home page to stay continually informed of program office activities.

JAST has also been using electronic source selection techniques for the preparation, evaluation, and awarding of contracts. With this CVP technology, the source selection process for JAST BAA 94-2 was reduced to 15 weeks; 9 weeks were reserved for proposal preparation, 4 for proposal evaluation, and 2 for final negotiation and award. To facilitate selection, limits are placed on the length and format of proposals. Paperless acquisition software tools are used to collect and evaluate proposals. Other tools are used to generate procurement and contracting documents. Additional features of the JAST Program include a bulletin board system to exchange contracts between the program office and award-winning contractors as well as electronic signature software.

Associate contractor agreements are contracts signed between the prime aircraft contractors and the technology development contractors. These agreements facilitate the exchange of design information between aircraft integrators and the component developers. Contracts among the aircraft primes and technology developers require these organizations to communicate information in the conceptual design phase to eliminate many of the integration issues that occur later in development.

Within NAVAIR, the PMA-299 Light Airborne Multi-Purpose System (known as LAMPS) Program Office is implementing a paperless, all-digital office. The PMA-299 virtual enterprise consists of the Chief of Naval Operations, NAVAIR, Navy laboratories, and contractors. Two networks support movement of information among participants. The first is a network in the Washington area linking NAVAIR and PMA-299 offices in Crystal City with the Pentagon. These links have video, audio, and digital data capabilities. A second link has been implemented to connect PMA-299 with the Navy laboratories and prime contractors. Interoperability is achieved through communications protocol and a common set of software to generate and retrieve information. To date, the network has been used primarily for administrative information and not to transfer electronic product data, but the infrastructure has been put in place to employ CVP for the development of the next-generation lightweight helicopter.

Figure 4 illustrates the way relationships are changing between large prime contractors and their suppliers. Shown is the average number of suppliers per company by sector for 1991, 1993, and 1995. Companies are grouped into three sectors: airframe, electronics, and engines et al. On average between 1991 and 1995, the number of suppliers decreased by half. Many of the suppliers are providing goods to all the companies, indicating that approximately half of the remaining companies are no longer supplying components for DoD aircraft applications. These companies have either diversified into other DoD markets, have increased or converted to more commercial operations, or have gone out of business. Figure 5 gives another view of the changing relationship between large prime defense contractors and their suppliers. The increase in information shared among the parties between 1989 and 1993 can be seen. Information is divided into six functional areas. In 1989, the primary types of data shared were production cost data and performance action improvement. By 1993, information sharing in all areas had increased, the largest increase being in performance improvement. Large primes are relying on fewer suppliers and are sharing more information with the remaining suppliers.

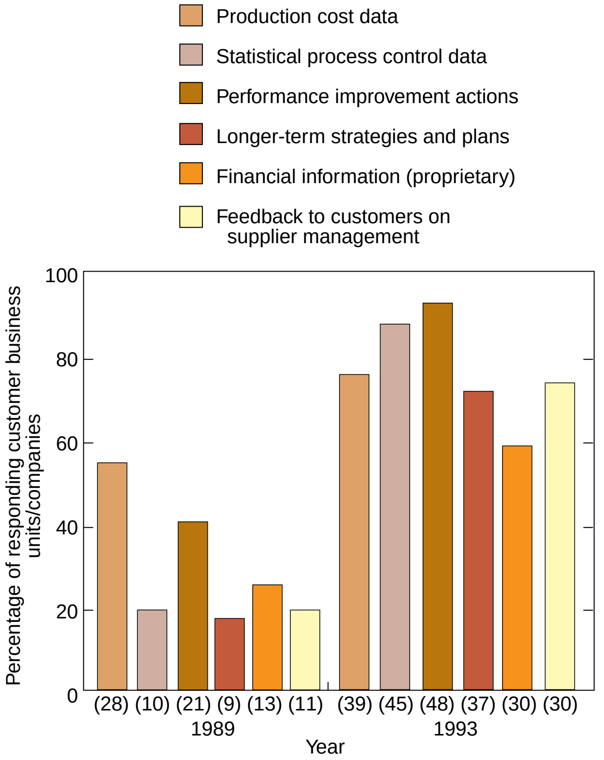

Figure 5. Supplier information shared with customer. Numbers in parentheses indicate number of responding business units. (Data supplied by personnel from Wright Patterson Air Force Base working for the USAF Manufacturing Technology Program.)

Vought Northrop Grumman Commercial Aircraft Division in Dallas, Texas, provides an example of how relationships with subcontractors are changing. Aluminum is a principal raw material for the construction of aircraft structural components. Vought electronically provides access to aircraft production information to ALCOA, a supplier of aluminum. It has become ALCOA's responsibility to supply material of the right size and quantity at a rate that matches Vought's production. This arrangement has dramatically reduced the size of procurement and expediting staff, has reduced the overall amount of labor and waste in cutting material to size, and has almost eliminated the need to carry large materials inventories.

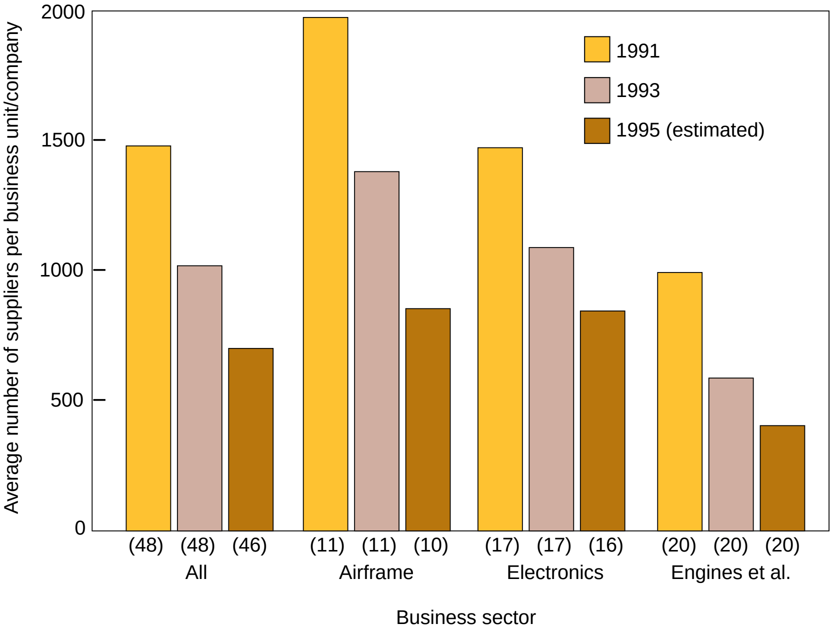

Figure 4. Average number of suppliers per business unit/company by sector. Numbers in parentheses indicate number of responding business units. (Data supplied by personnel from Wright Patterson Air Force Base working for the USAF Manufacturing Technology Program.)

The Lean Aircraft Initiative (LAI) is a Massachusetts Institute of Technology research project patterned after the highly successful Lean Automotive Initiative, which was used by the automotive industry to recapture the U.S. and world markets. This 3-year government–industry collaborative effort began in 1993 and focused on data, analysis, benchmarking, and implementation of lean aircraft principles. The following are the five elements of such an enterprise: (1) lean management, (2) lean customer relations, (3) lean supplier relations, (4) lean development, and (5) lean factory operations.

Figure 6 shows the framework used by the LAI to assess progress. This framework is centered around the cost of delivering a quality military aircraft, that is, the cost of compliance to government requirements, the cost of inefficiencies and errors, and the cost of value added. The cost of inefficiencies and errors is further subdivided into product development, factory operations, supplier systems and relationships, organization and human resources, and systematic and random errors. Progress is achieved when the cost of government compliance and the cost of inefficiencies and errors steadily decrease over time. Lockheed Martin Tactical Aircraft Systems has used these elements to continually reduce the price of the F-16 aircraft; the cost was reduced even though the number of units purchased sharply decreased.

Through interviews with personnel involved in Navy acquisition programs and through site visits to prime contractors, subcontractors, and universities, we identified a variety of barriers to CVP, namely, cultural, legal, and technological. New and innovative solutions to the legal and technological barriers are evolving, leaving cultural barriers as the major issue. Government managers must bring their programs in on cost, within performance requirements, and on schedule. However, program managers see CVP and related technologies as lacking maturity and consequently do not wish to make their efforts a part of the tool validation process. Decreasing cost or improving schedule, although commendable, is not generally considered worth the risk. This is in contrast to the view taken in the commercial sector where program managers and their teams are rewarded for program savings.

CVP technologies affect the workforce by automating the most people-intensive processes. Corporate management expects to achieve savings in personnel costs immediately. The potential impact on the workforce can be a significant barrier to acceptance.

In today's agile enterprises, subcontractors become associates and add value to the product. In such enterprises, information is rapidly and freely exchanged among associates. Ownership of data and intellectual property is often difficult to sort out. In other cases, a subcontractor may support multiple competing prime contractors. Ownership of digital information and intellectual property must be unambiguous. Not all subcontractors need to access information outside their immediate tasks. Limiting and controlling access to information is one method of protecting intellectual property in a distributed enterprise.

BENEFITS OF IMPLEMENTING CVP TECHNOLOGIES

Reforming or reengineering the acquisition process is a challenging and time-consuming task. CVP technologies can bring about fundamental change within the acquisition community and the real prospect of major cost and time-to-market reductions. However, before major changes are implemented, management generally requires a cost/benefit analysis. The approach used in the CVP study was to identify the benefits from existing applications of CVP technologies in commercial and Department of Defense aircraft programs. We present a few of the demonstrated benefits in this section; a more extensive list may be found in the CVP report.[4]

The JAST Program Office has made affordability a primary attribute of the next-generation triservice strike aircraft. Figure 7 presents an estimated LCC breakdown for the JAST aircraft, initially divided into research and development, production, and operation and service components. These stages are further broken

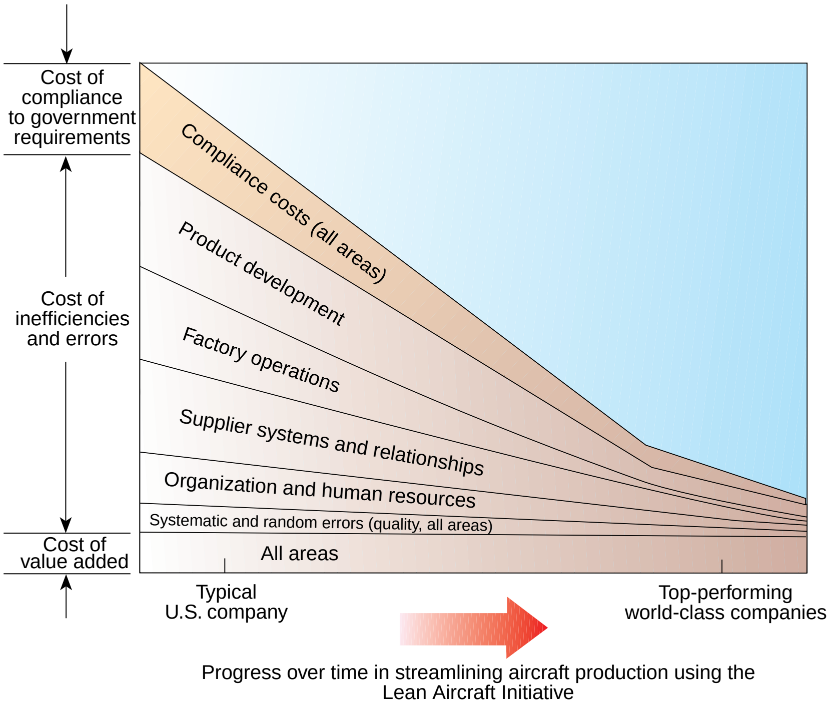

Figure 6. Framework for determining progress within the Lean Aircraft Initiative.

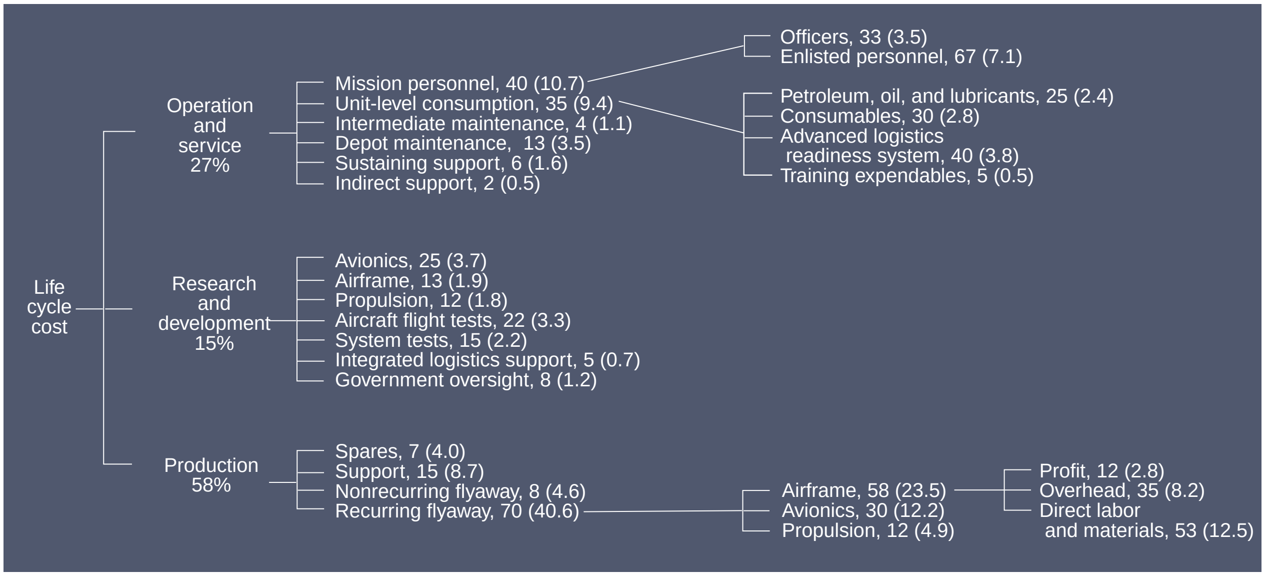

Figure 7. JAST life cycle cost components. Numbers represent percentages at that echelon; numbers in parentheses represent the percentage of total life cycle costs.

down into cost categories. Of the three major stages, production has the highest price tag at 58.0% of the total LCC. Within production, the recurring flyaway cost accounts for 70.0% of the cost of production and 40.6% of the total LCC. The flyaway cost can be split further into airframe, avionics, and propulsion costs. For the JAST aircraft, the airframe accounts for 23.5%, avionics for 12.2%, and propulsion for 4.9% of the total LCC. For the airframe, new materials and construction techniques help to reduce the LCC by about 12%.

The use of virtual prototypes is a major factor in new structures concepts and advanced production techniques. These prototypes can be used to perform structural analyses, assess producibility trade-offs, and generate numerically controlled machine code. Architectures, virtual system engineering, virtual environments, and software development tools are cost saving technologies for avionics. With these technologies, JAST estimates an LCC savings in avionics of 9 to 17%. For the support aircraft, avionics is expected to dominate the recurring flyaway cost structure, and a greater LCC cost saving could be expected.

McDonnell Douglas produces most of today's fixed wing aircraft (e.g., the F/A-18, T-45, AV-8, and C-17) for DoD. McDonnell Douglas is also a JAST weapons systems contractor teamed with Northrop Grumman and British Aerospace. The JAST Program, in conjunction with existing production, allows McDonnell Douglas to conduct pilot programs using current production assets.

The Design, Manufacturing, and Producibility Simulation (DMAPS) Program at McDonnell Douglas combines product, process, and simulation (CVP) tools into a virtual prototyping environment. The objective of the program is to reduce acquisition costs by 50%. The integration of these tools will result in a 33% reduction in design time, a 25% reduction in design personnel, a 50% reduction in manufacturing cycle time, and a 50% reduction in manufacturing personnel. DMAPS was used on the redesign of the tail for the T-45 trainer, which was performed in 30 man-months instead of the previously expected 100 man-months. The nonrecurring cost reduction was approximately 70%, and the estimated recurring cost reduction was up to 20%. The design included accurate cost estimates for production, verified aerodynamic loads and weights, three-dimensional solid feature–based files for enabling advanced fabrication techniques (composite lay-ups, high-speed machining, etc.), and an electronic visualization package for supporting IPPD Team decisions.

Within NAVAIR, the V-22 Action Team recently conducted an investigation of the savings and improvements realized from using electronic mock-ups in place of physical mock-ups. The team's findings are as follows:

- Significant monetary savings are achieved (about $22M) by reducing physical mock-ups.
- Schedule improvements result since time for the construction of physical mock-ups is eliminated.
- Electronic prototype remains current throughout the product life cycle.
- Electronic prototype is available for investigation and design of variants.
- First-time fit rates for tubes, wires, and ducting improve from 30–50% to 90%.

In addition, man-hours declined from 232,926 to 66,518.

APPLICATION OF CVP TECHNOLOGY

Industry has taken an intense interest in CVP. Companies like Ford, Chrysler, Caterpillar, and Boeing have manufactured products using virtual prototypes in design and analysis and as replacements for physical mock-ups. Aircraft firms that previously were not using virtual prototyping now see the technology as mandatory if they are to remain competitive.

Our conclusions and recommendations are the result of visits and discussions with leaders in the computing, aircraft, and electronics industries; a few of those general conclusions and recommendations are highlighted here.

The commercial sector is rapidly developing tools for distributed computing and virtual prototyping. World-class companies are procuring these tools and developing additional application-specific products. These companies see CVP technologies as their competitive edge in the world marketplace. CVP technologies have been applied to new products. Companies have seen significant reductions in time to market, improved quality, increased customer participation and satisfaction, and increased employee productivity.

The Departments of Defense and Energy are developing an infrastructure and a host of collaboration tools that should be available to new programs in the next 3 years. Programs planning on using CVP should become familiar with and leverage these development efforts.

Standards are the key element to all distributed enterprise activities. Without standards, electronic media cannot effectively be exchanged among members of the enterprise. The Department of the Navy must select information exchange standards to be employed across all programs.

Most existing models and simulations needed to perform warfare analysis have not been developed to operate in a distributed computing environment. Effective use of these models requires in-depth knowledge of their assumptions and constraints. Procedures must be developed to permit developers/operators of these models to use them in a distributed computing environment.

Investments must be made to develop and maintain effective DoD warfare analysis models. Selection of common models to be used across the Departments of Defense and the Navy will reduce investment costs and will make more capable models available to all users.

Producibility is an LCC driver. Again, approximately 80% of the LCC of a new product is determined during the conceptual design phase. Models for advanced manufacturing processes are needed for all phases of product development, but especially during conceptual design. There are a number of advanced manufacturing programs within the Departments of Commerce and Energy as well as within NASA. The Navy should leverage these programs to provide the processing models needed for its programs.

Incorporation of the customer as a member of the IPPD Team significantly reduces the development time since non–value added activities can be minimized. Rapid trade-off decisions made by the consumer help to focus the team's activities.

The Navy and DoD should investigate the benefits of using commercial business practices in revolutionizing the acquisition process. Forming partnerships with industry, as well as understanding and reacting to cost-driving procurement actions, can significantly reduce expenses.

The Applied Physics Laboratory is investing in rapid prototyping, conceptual design and visualization tools, advanced distributed modeling and simulation facilities and techniques, and warfare analysis models. These capabilities should help sponsors develop new systems in a CVP environment.

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