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BEST PRACTICES

Successful Application to Weapon Acquisitions Requires Changes in DOD's Environment

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The Honorable Rick Santorum
Chairman
The Honorable Joseph I. Lieberman
Ranking Minority Member
Subcommittee on Acquisition and Technology
Committee on Armed Services
Unites States Senate

As you requested, this report assesses whether commercial product development practices offer ways to improve the process used at the Department of Defense (DOD) to prepare weapon systems for production. It also determines how differences in commercial and DOD environments for developing new products affect the corresponding practices. We make recommendations to the Secretary of Defense and present matters for congressional consideration, all of which are intended to create the necessary environment to ensure DOD's future success in improving the transition of weapons from development to production.

We are sending copies of this report to other congressional committees; the Secretaries of Defense, the Army, the Navy, and the Air Force; and the Director, Office of Management and Budget. We will also make copies available to others on request.

This report was prepared under the direction of Katherine V. Schinasi, Associate Director of Defense Acquisitions Issues, who may be reached at (202) 512-4841 if you or your staff have any questions. Other major contributors to this report are listed in appendix II.

Henry L. Hinton, Jr.
Assistant Comptroller General

Executive Summary

Purpose

The Department of Defense (DOD) continues to state a need to modernize weapons for the armed forces at a faster pace within relatively level funds. It has a budget of over $40 billion in fiscal year 1998 to acquire and upgrade weapons, and may not reasonably expect to receive much more than that amount in future years. Therefore, it must find new ways to modernize more economically. The challenge of the Soviet Union has been replaced by a challenge to maintain weapons that have a leading technological edge; however, such technologies are increasingly being developed in the commercial sector. In this period of lessened tensions, DOD has an opportunity to revamp the practices it uses to acquire weapon systems, avoid the technological obsolescence that comes with 15-year and longer product development cycles, speed the pace of modernization in the face of budgetary pressures, and meet defense needs with sufficient flexibility. The practices employed by some commercial firms to reduce the time and money to develop new products—by as much as 50 percent—can illuminate ways for DOD to make similar improvements.

In response to a request from the Chairman and Ranking Minority Member, Subcommittee on Acquisition and Technology, Committee on Armed Services, GAO assessed whether commercial practices offer ways to improve DOD's process for transitioning weapons from development to production. Specifically, this report (1) compares DOD's practices for preparing a weapon system for production with best commercial practices, (2) determines how differences in commercial and DOD environments for developing new products affect practices, and (3) discusses environmental changes that are key to the success of DOD initiatives for improving the transition of weapons from development to production.

Background

Commercial firms make a distinction between product and technology development. Product development entails the design and manufacture of a product, such as an airplane, a car, or a satellite, as an end item for delivery to a customer. The basic features of product development include a definable market in terms of customer needs or wants, the ability to design a product for that market opportunity, the ability to produce that product, and the investment capital needed to fund the development effort. Technology development fosters technological advances for potential application to a product development. In DOD, the acquisition cycle for weapons includes technology development, product development, and production. Thus, the distinction between product and technology development on an individual program is much less clear.

Among the key sources of information GAO relied on in this review were individual DOD acquisition programs and several firms recognized as being among the best in developing and manufacturing new products. Much commonality existed among these firms' practices, even though their products spanned a range of technological sophistication. In this report, GAO highlights the best commercial practices in product development based on its fieldwork. As such, they are not intended to describe all commercial industry or suggest that commercial firms are without flaws.

Results in Brief

Commercial firms gained more knowledge about a product's technology, performance, and producibility much earlier in the product development process than DOD. Product development in commercial ventures was a clearly defined undertaking for which firms insisted on having the technology in hand to meet customer requirements before starting. Once underway, these firms demanded—and got—specific knowledge about a new product before production began. The process of discovery—the accumulation of knowledge and the elimination of unknowns—was completed for the best commercial programs well ahead of production. Not having this knowledge when demanded constituted a risk the firms found unacceptable. Immature or undeveloped technology could not meet these demands and was kept out of commercial product development programs; this technology was managed separately until it could meet the demands for product development.

In contrast, DOD programs allowed more technology development to continue into product development. Consequently, the programs proceeded with much less knowledge—and thus more risk—about required technologies, design capability, and producibility. The programs' discovery process persisted much longer, even after the start of production. Turbulence in program outcomes—in the form of production problems and associated cost and schedule increases—was the predictable consequence as the transition to production was made. Although DOD accepted more unknowns on its programs than commercial firms, it understated the risks present.

The commercial and defense environments created different incentives and elicited different behaviors from the people managing the programs. Specific practices took root and were sustained because they helped a program succeed in its environment—not because they were textbook solutions. The success of commercial product developments was determined when production items were sold. Until that point, the firm's

own money was at risk. Failure was seen as both clear and painful if the customer walked away. This definition of success, coupled with the realization that production startup was relatively close at hand, made production concerns a key factor in program start and subsequent decisions and provided strong incentives to identify risks both early and realistically. DOD programs began without needed technology in hand; rather, they were encouraged to include undeveloped technology. Because these programs ran much longer, production concerns did not play as big a role and were not as critical to success in the early stages. The definition of success was more complicated in DOD. During most of product development, success was defined as getting DOD and the Congress, as the customers, to fund the development annually. Optimistic assessments of performance and cost helped ensure this kind of success; realistic risk assessments did not.

Commercial practices for gaining knowledge and assessing risks can help produce better outcomes on DOD acquisitions. Indeed, DOD has several commercial-like initiatives underway, such as using cost or price as a means for forcing technology tradeoffs, that it believes are having promising results. For such practices to work on a broad scale, however, the DOD environment must be conducive to such practices. At least two factors are critical to fostering such an environment. First, program launch decisions must be relieved of the need to overpromise on technical performance and resource estimates. The pressure to amass broad support at launch creates incentives for new programs to embrace far more technology development than commercial programs. Although technology development clearly must be undertaken by DOD and supported by the Congress, its objectives, as well as what can be demanded of its knowledge and estimates, differ from those of product development. Second, once a program is underway, it must become acceptable for program managers to identify unknowns as high risks so that they can be aggressively worked on earlier in development. Currently, identifying a high risk on a DOD program is perceived as inviting criticism and the loss of funding. Studies sponsored by DOD and the defense industry call for the kinds of changes that could help shape a better environment for managing weapon acquisitions. The challenge for DOD and the Congress is to foster the environment that provides program managers with incentives for applying best practices.

Principal Findings

Leading Commercial Firms Attain More Knowledge Earlier in Product Development

To minimize the amount of technology development that occurs during product development, the companies GAO visited employ a disciplined process to match requirements with technological capability before the product development process begins. This process is grounded in production realities that demand proof that the technology will work and can be produced at an acceptable cost, on schedule, and with high quality. The companies bring proven technological knowledge to the requirements process in the form of current, high fidelity information from predecessor programs, people with first-hand experience on those programs, and new technologies deemed mature as a result of having "graduated" from a disciplined technology development and screening process. Also, they communicate extensively with customers to match their wants and needs to the firms' available technology and ability to manufacture the desired product. They do not stray far from their technological foundation.

For the programs GAO reviewed, DOD did not get as good a match between what customers require and what technology could confidently deliver. Even though DOD examines the potential for available technology to meet product requirements, it allows requirements to make technology reach beyond what is proven. DOD has less knowledge about the ability of the design to deliver required performance and be produced at this point in the program than commercial firms. The knowledge that the match has been achieved between requirements and technology is often not attained until testing is completed, late in development or after production begins. Commercial and DOD decisions made on a lightweight aircraft material—aluminum lithium—are illustrative of the differences between the two sectors. Boeing had initially decided to use the alloy on its 777-200 aircraft but rejected its use early in development because it was expensive, its manufacturing processes were not well understood, and its availability was limited. DOD accepted these risks and used the alloy on the C-17 aircraft. The alloy is now being phased out of the program as some of its unknowns became actual problems.

Before the halfway point of product development, the commercial firms GAO visited achieved near certainty that their product designs would meet customer requirements and had gone a long way to ensure that the product could be produced. Both DOD and commercial firms hold a critical design review to determine whether the design is mature and essentially

complete for production purposes. Engineering drawings, which document the schematics of the product, along with its performance, required materials and production processes, comprise much of the source material for the critical design review. Commercial firms typically had over 90 percent of these drawings available for the review. In comparison, the C-17 program had less than 60 percent and the F-22 program less than one-third of the drawings available for the review. Over one-fifth of the C-17's drawings became available after production began, and the aircraft experienced a number of problems in production as difficulties with the design were worked out. Several key technologies are still unproven on the F-22, and some will not be proven until after 40 aircraft have entered production. Nonetheless, the risks of proceeding with the rest of development as planned at the time of the critical design reviews for both programs were deemed acceptable.

The companies GAO visited reached the point at which they knew that manufacturing processes would produce a new product conforming to cost, quality, and schedule targets before they began fabricating production articles. Reaching this point meant more than knowing the product could be manufactured; it meant that all key processes were under control, such that the quality, volume, and cost of their output were proven and acceptable. The DOD programs demanded less proof of a design's producibility. The C-17 program began production in 1989 and still has less than 13 percent of its key manufacturing processes in control. The F-22 program is currently faring better than the C-17: the contractor believes it has almost 40 percent of its key manufacturing processes in control, 2 years before production is scheduled to begin. However, the program does not plan to have all key processes in control until about 4 years into production.

Differences in Military and Commercial Practices Reflect Different Environments

The commercial firms GAO contacted launch a product development only when a solid business case can be made. The business case basically revolves around the ability to produce a product with the right features to meet the market opportunity on schedule, with limited investment capital, and at a predictable unit cost so that the product will sell well enough to make an acceptable return on investment. Because success is determined in production, the business case for launching a program considers production realities and builds in natural curbs to overreaching for performance, cost, or schedule. A company demands considerable proof that the product will fulfill all of the business case factors and then provides full support for the program to succeed. The business case

provides a very solid decision-making framework from the outset and throughout the program. Commercial companies build relatively short cycle times, keyed to meeting market demands, into their decisions to begin a product's development. These short timeframes, together with the responsibility for protecting the business case, encourage program managers to identify risks and enable them to say "no" to pressures to accept unknowns. The companies are conservative in their estimates and aggressive in reducing risk. The abundance of reliable data and experienced people from predecessor programs provides a solid factual basis for defining unknowns and assessing risks.

Because DOD launches programs earlier, the knowledge commercial firms insist on is generally not available for a DOD program until years later. Some knowledge, such as high-fidelity information from numerous closely related predecessor programs, is simply unavailable. Even though less information about a new DOD product development is available at the time of launch, the competition for funding requires detailed projections to be made from the information that does exist. Although DOD is attempting to ease the technical requirements of programs, a new product development must possess performance features that distinguish it from either the systems to be replaced or rival candidates. Consequently, aspiring DOD programs are encouraged to include performance features and design characteristics that rely on immature technologies. Untempered by knowledge to the contrary, the risks associated with these technologies are deemed acceptable. Production realities, critical to matching technological capabilities with customer requirements on commercial programs, are too far away from the DOD launch decision to have the same curbing effect on technology decisions.

In this environment, risks in the form of ambitious technology advancements and tight cost and schedule estimates are accepted as necessary for a successful launch. Problems or indications that the estimates are decaying do not help sustain the program in subsequent years, and thus their admission is implicitly discouraged. An optimistic production cost estimate makes it easier to launch a product development and sustain annual approval; admission that costs are likely to be higher could invite failure. There are few rewards for discovering and recognizing potential problems early in the DOD product development, given the amount of external scrutiny the programs receive. The behavior of tolerating unknowns and not designating them the same risk value as in the commercial environment is manifested in the DOD environment because there is little incentive to admit to high risks before it is

absolutely necessary. This is not to say that DOD program managers and other sponsors act irrationally or with bad intentions. Rather, they see the programs under their purview as aligned with the national interest and do what they believe is right, given the pressures they face.

The Right Environment Will Be Key to the Success of DOD Initiatives to Improve Weapon Acquisitions

DOD has embarked on several acquisition reform initiatives that draw lessons from commercial practices. These initiatives include using cost or price targets as vehicles for forcing requirements or technology tradeoffs, evaluating contractors' past performance as a factor in selecting sources for new contracts, removing specifications that told contractors how to design or build a product in favor of specifying what performance was required of the end item, and using multidisciplinary teams to make decisions and tradeoffs on individual weapon systems. DOD reports that programs are showing potential reductions in cycle time and staff resources as a result of these initiatives. DOD has also recently set up a funding reserve to offset unexpected cost growth to mitigate the effect of unknowns on programs. In past acquisitions, changing the mechanics of a weapon's development, without changing aspects of its environment that determine its incentives, did not produce desired results. Nonetheless, DOD's current initiatives could help the transition of weapons into production if the environment for launching programs and appraising risks can be changed to better approximate the commercial environment.

Studies sponsored by DOD and the defense industry call for changes that could help shape such an environment. A May 1996 study by the Defense Science Board recommended replacing the current weapon acquisition process with one that emphasizes incremental technology advancement, coupled with much shorter product development cycle times. The study also noted that technology development should be aggressively pursued outside the realm of weapon system development programs. In April 1996, the National Center for Advanced Technologies also proposed a change in the DOD weapons acquisition process to reduce cycle time to the 3- to 5-year range by following an incremental technology advancement approach. The report noted that although concepts such as DOD's initiatives are constructive, there is no reason to assume that these concepts should succeed when previous good ideas did not.

A December 1994 study by the Defense Systems Management College made several recommendations to create an environment for weapon systems development to encourage realism in reporting program status. A significant recommendation is that the individual military services transfer

control of their acquisition organizations and people to the Under Secretary of Defense for Acquisition and Technology. The study noted that the Under Secretary would then be empowered to reward candor and realism in reporting through the use of assignments and promotions.

Recommendations

GAO makes several recommendations to the Secretary of Defense. These recommendations are intended to (1) ensure that sound standards for the timing and quality of production-related knowledge are applied to individual programs, (2) separate technology development from weapon system programs to enable DOD to meet higher knowledge standards on those programs, and (3) use decisions on individual weapon systems to foster the right environment for identifying risks early and send the right message to other programs concerning what practices will work in that environment. These recommendations appear in full in chapter 5.

Matters for Congressional Consideration

Because of its critical role in creating the environment for what constitutes program success and which practices will work, the Congress may wish to consider supporting the Secretary of Defense's efforts to create such an environment through changes to the acquisition process that provide program managers clear incentives for gaining sufficient knowledge at key points in weapon acquisition programs. The best commercial practices described in this report suggest what may constitute "sufficient" levels of knowledge. If DOD takes steps to manage technology development efforts outside the bounds of individual weapon system programs, the Congress may wish to consider providing the funds needed for such efforts. The Congress could also help create the right incentives on individual programs by favorably considering DOD funding requests to mitigate high risks early in a program and cautiously considering late requests for funds to resolve problems that should have been addressed earlier.

Agency Comments

DOD agreed with the report and all of the recommendations. A discussion of DOD's actions appears on pages 75-77. DOD's comments appear in appendix I.

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Abbreviations

AIM	Air Intercept Missile
CAIV	cost as an independent variable
CATIA	computer-aided three-dimensional interactive application
CDR	critical design review
DOD	Department of Defense
EMD	engineering and manufacturing development
GAO	General Accounting Office
IPT	integrated product team
JDAM	Joint Direct Attack Munitions
SPC	statistical process control

Introduction

The Department of Defense (DOD) continues to state a need to modernize weapons for the armed forces at a faster pace within relatively level funds. It has a budget of over $40 billion in fiscal year 1998 to acquire and upgrade weapons, and may not reasonably expect to receive much more than that amount in future years. Therefore, it must find new ways to modernize more economically. The challenge of the Soviet Union has been replaced by a challenge to maintain weapons that have a leading technological edge; however, such technologies are increasingly being developed in the commercial sector. In this period of lessened tensions, DOD has an opportunity to revamp the practices it uses to acquire weapon systems, avoid the technological obsolescence that comes with 15-year and longer product development cycles, speed the pace of modernization in the face of budgetary pressures, and meet defense needs with sufficient flexibility. When dealing with some similar problems, the best commercial firms have focused on the early stages of the product development cycle to speed up product developments, get them into production sooner, and achieve cost goals.

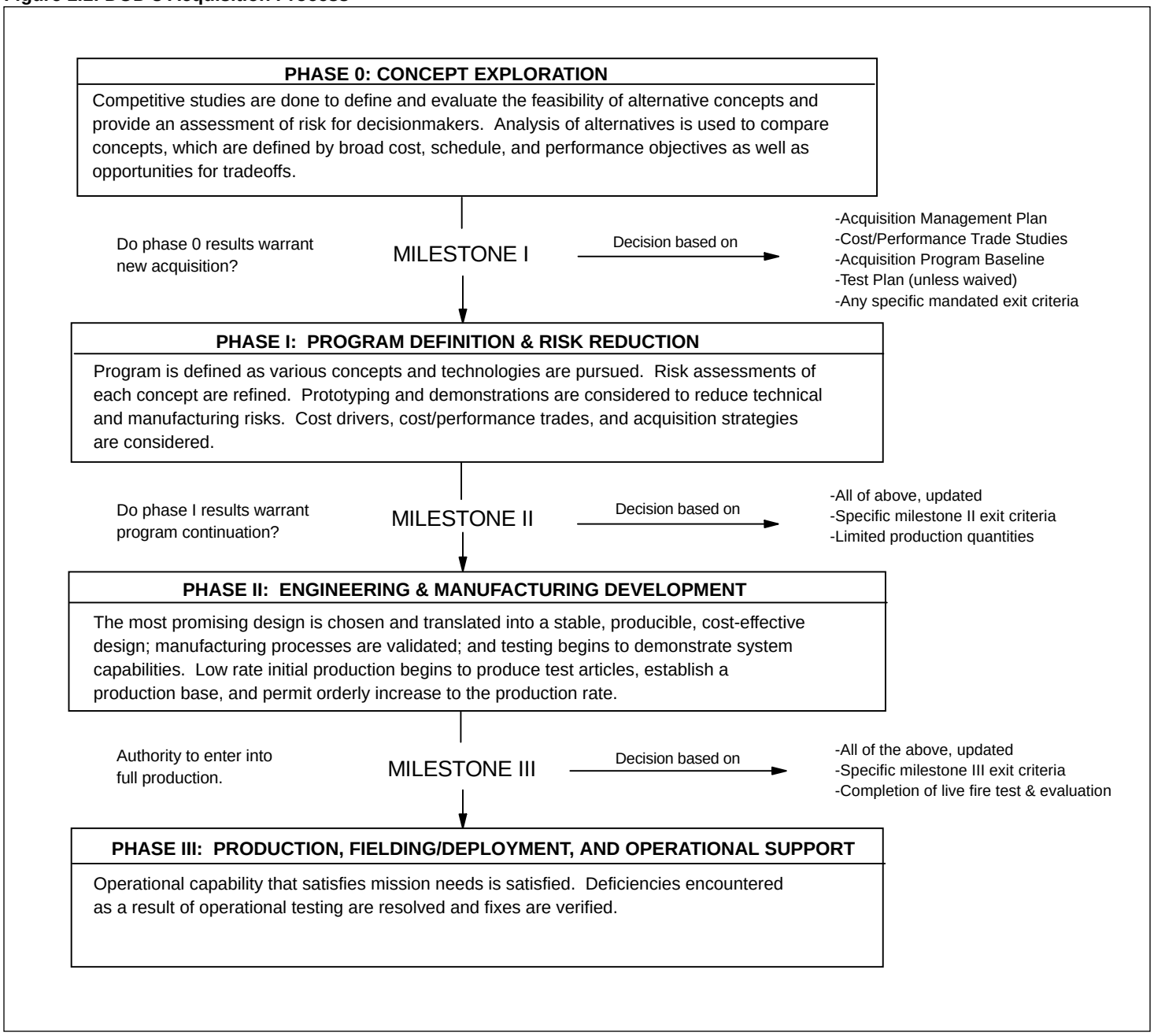
Product Development in the Commercial and Defense Sectors

For commercial firms, developing a product entails the design and manufacture of an end item, such as an airplane, car, or satellite, for delivery to a customer. The basic features of product development include a definable market in terms of customer needs or wants, the ability to design a product for that market opportunity, the ability to produce that product, and the investment capital needed to fund development. Product development is therefore very concerned with production realities and cost and schedule targets. It is distinct from technology development, which furthers the advancement of technology to see if it has potential application to a product. For example, a firm that makes satellites may study new materials and their properties to see if they can reduce the weight and size of solar array batteries, thus improving a satellite's carrying capacity. If the technology can be perfected and is feasible to use, it is ready to be included in a new product development. More failures are expected in a technology development, since it is a process of discovery that deals with many unknowns.

In DOD, the same functions take place on the weapon systems DOD develops, but they occur within the broader context of the acquisition cycle. The entire cycle includes technology development, product development, and production. DOD's development process is designed to manage a program through sequential phases, all followed by major milestone decisions in which decisionmakers approve or disapprove the

acquisition strategy for a program and its move into the next phase based on progress made as presented by the program manager. The phases of the acquisition cycle, as shown in figure 1.1, are: concept exploration; program definition and risk reduction; engineering and manufacturing development (EMD); and production, fielding/deployment, and operational support. The concept exploration phase decides what kind of weapon, if any, is the best solution to a military need. A new program actually starts with the program definition and risk reduction phase.

Figure 1.1: DOD's Acquisition Process



Source: DOD.

Within the acquisition cycle for a given weapon system, technology development, product development, and production activities take place over a number of years. The delineation of these activities is not always clearly discernable. Thus, even though the product development activities described for the commercial sector would occur largely in a weapon's EMD phase, technology development and production activities also occur in this phase. Likewise, some product development activities for a weapon system take place during production. The acquisition process is embodied in DOD's Regulation 5000.2, Mandatory Procedures for Major Defense Acquisition Programs, which was revised in 1996. In addition, DOD's 1985 Manual 4245.7-M, Transition From Development to Production, contains risk-reduction guidance based on best practices.

At any given time, DOD has hundreds of products in various stages of development and production, each with a program manager from one of the three services or other procuring agencies within DOD. Although DOD maintains oversight for all of these acquisitions and controls their funding, the actual management practices employed are specific to the program, the contractors, and the relevant government organization. We have issued a number of reports on weapon system acquisitions since the 1970s.

The program manager and staff for a new product's development in either sector face a formidable task. They are responsible for balancing the requirements for the product's performance against its established cost and schedule targets. This responsibility includes preparing an acquisition strategy for funding, testing, and manufacturing the product and ensuring that the strategy is carried out. Throughout the development process, the program manager is expected to identify and manage high-risk areas, which means making decisions about tradeoffs among cost, schedule, and performance to deliver a product that will satisfy the customer. The program manager and staff must therefore have expertise in many areas, such as estimating techniques, the budget process, simulation, testing, engineering, logistics, and production. The program manager is the one person who ultimately must know whether there is a match among financial, time, and personnel resources provided by upper management and what the product development effort can deliver. In product development, the financial investment is substantial and the stakes are high; program failure is not taken lightly.

The Case for a Smoother and Faster Development to Production Cycle

Products that proceed more quickly and smoothly through development into production require lower financial investment costs to develop. Also, a smoother and faster process enhances the product's impact on customers or users and benefits the producer by providing improved profitability and market share. Commercial firms that have been recognized as industry leaders have significantly reduced the time it takes to complete the product development cycle. They have put new products into production more quickly within unit production cost targets and improved the products' performance features and quality. For example, Boeing will reduce development time by 40 percent on its 777-300 airplane compared with its 777-200 development, Hughes develops satellites in 26 months and will soon reduce the time to 12 months, and Chrysler has reduced its new vehicle development times from over 5 years to less than 30 months.

If DOD made reductions of the same magnitude in the time it takes to develop a weapon, it could reap similar benefits. A compelling reason for DOD to pursue such reductions is to resolve long-standing difficulties in controlling cost and schedule outcomes of major weapon system programs. According to cost and schedule data from 93 major acquisitions started since 1975, the acquisitions overran original schedule estimates by an average of 24 percent. Recent DOD studies have concluded that weapon system development programs typically overrun costs by 20 to 40 percent and that acquisitions average 16 to 18 years. A 1993 Rand study concluded that there had been no improvement in controlling cost growth on the average weapon system. These results have persisted despite the implementation of various initiatives to mitigate cost risk and growth, including significant risk management guidelines DOD instituted in 1985 to improve the transition to production.

Another reason for DOD pursuing faster and smoother development to production cycles is to lower its investment costs, enabling the services to modernize at a faster pace within existing funding levels. According to DOD, modernization in recent years has been sacrificed to improve readiness in the forces. DOD believes that modernization should proceed more quickly and wants to increase the annual investment in procurement by $20 billion, but such increases have not materialized. Shorter development cycles would also help mitigate the possibility that technology will become obsolete while a weapon is still in development. Technological obsolescence has become a significant challenge for DOD acquisition programs whose developments span many years. Finally, faster

product developments would deliver improved products and better capabilities to the military forces sooner.

DOD recognizes the importance of reducing product development costs and cycle times. DOD's 1996 Technology Area Plan recognizes that the prevailing acquisition environment made affordability and rapid cycle times for acquisition of new systems key to maintaining an appropriate mix of systems and forces that are ready to respond to the defense missions of the future. The plan recognized that short cycle times invariably create cost reductions that would have clear implications for readiness and modernization. It also noted that world-class commercial companies have demonstrated overall product development and production cost reductions as well as cycle time reductions of about 50 percent. The plan states that, despite the major differences in products and requirements, cost and cycle time savings in that same range are feasible for military programs as well.

DOD is attempting to improve the product development process by introducing acquisition reform initiatives that mirror world-class companies' product development practices. DOD believes that these initiatives will result in better outcomes. A recent Defense Science Board study[1] concluded that the research and development phase of military systems should be revamped and should adopt best commercial practices. The aerospace industry has also offered suggestions based on commercial practices for improving DOD's development process for weapons as a basis for change.

Objectives, Scope, and Methodology

The Chairman and the Ranking Minority Member, Subcommittee on Acquisition and Technology, Senate Committee on Armed Services, requested that we examine various aspects of the acquisition process to identify best practices that might be useful or should be strengthened. This report covers one aspect of the acquisition process, the transition from development to production. Our overall objective was to determine whether commercial practices offer ways to improve DOD's product development process as it relates to the transition to production. Specifically, this report (1) compares DOD's practices for preparing a weapon system for production with best commercial practices, (2) determines how differences in the commercial and DOD environments for developing new products affect specific practices, and (3) discusses

[1]A Streamlined Approach to Weapon Systems Research, Development and Acquisition: The Application of Commercial Practices, a Report from the Defense Science Board Task Force on Defense Acquisition Reform, May 1996.

environmental changes that are key to the success of DOD initiatives for improving the transition of weapons from development to production.

Even though we selected firms with product lines of varying complexity, we did not concentrate only on firms whose products had the most in common with weapon systems. Such an approach would have limited our ability to include firms recognized as the best at getting new products into production. In our analysis, we concentrated on the criteria and knowledge used to support product decisions. Although the approach from product to product may vary, the basic processes and standards the best commercial firms applied to product decisions were consistent. We were limited in our ability to obtain and present some relevant data that commercial companies considered proprietary in nature. This information included funding amounts for investing in product development or for recurring production costs; the exact number and cost of changes to engineering drawings on a product; and specific costs of scrap, rework, and repair on products.

To determine historical cost and schedule outcomes on past DOD acquisitions, we examined Rand's database of Selected Acquisition Reports for over 200 acquisitions since the 1960s. To determine current DOD policy and practices and identify new initiatives, we interviewed and obtained documents from officials of the Office of the Secretary of Defense in Washington, D.C. For information from acquisitions on specific risk management practices and results, we interviewed officials and reviewed acquisition and risk management documentation from the following two major DOD acquisition programs, which are in different stages of the process:

- The C-17 aircraft, an air refuelable, four-engine jet transport, is being developed by McDonnell Douglas Corporation (since acquired by Boeing). It received full-rate production authority in November 1995. The Air Force estimates the cost to develop and produce 120 C-17 aircraft at about $43 billion, amounting to a program unit cost of $358 million. Procurement unit cost is estimated by the Air Force at $298 million.
- The F-22 fighter, the next-generation air superiority fighter, is being developed by Lockheed Martin Aeronautical Systems Company. It is currently in EMD. The Air Force estimates the cost to develop and produce 339 F-22s at about $62.2 billion, amounting to a program unit cost of $183 million. Procurement unit cost is estimated at $127 million.

We also reviewed the following newer DOD acquisition programs that have implemented some of DOD's acquisition reform initiatives; because these programs are newer, our review was more limited:

- The AIM-9X Sidewinder Missile, a joint Navy/Air Force, launch-and-leave air intercept missile, is being developed by Hughes Corporation. The program is currently in EMD. The services estimate the cost to develop and produce 10,049 AIM-9X missiles at about $3.2 billion, amounting to a program unit cost of $320,000. Procurement unit cost is estimated at $264,000.
- The Joint Direct Attack Munitions (JDAM), a joint Navy/Air Force tail kit to be attached to a 2,000-pound free-fall bomb and converting it to a guided munition, is being developed by McDonnell Douglas Corporation (since acquired by Boeing). The JDAM program is currently in EMD. The services estimate the cost to develop and produce 87,500 JDAM kits at about $3.39 billion, amounting to a program unit cost of $38,700. Procurement unit cost is estimated at $32,900.

To understand the product development process and best practices from the commercial sector, we conducted general literature searches and focused those searches as the assignment progressed. We also met with several experts in the area of product development, including representatives of Indiana University, Bloomington, Indiana; the University of Michigan, Ann Arbor, Michigan; and the Navy's Center of Excellence for Best Manufacturing Practices, College Park, Maryland. On the basis of our literature searches and discussions with experts, we identified a number of commercial firms as having innovative development processes and practices that resulted in successful transitions to production. We developed a data collection instrument to assist us in gathering uniform, quantifiable measurements about each firm's product development process and practices and the results they accomplished. We visited the following commercial firms, all identified in our literature searches, and followed the same agenda with each one:

- Boeing Commercial Airplane Group (airplane manufacturer), Everett, Washington;
- Chrysler Corporation (automobile manufacturer), Auburn Hills, Michigan;
- Cummins Engine Company (engine manufacturer), Columbus, Indiana;
- Ford Motor Company (automobile manufacturer), Dearborn, Michigan;
- Honda Motor Company (automobile manufacturer), Raymond, Ohio; and
- Hughes Space and Communications (satellite and spacecraft manufacturer), Los Angeles, California.

Our report highlights the best commercial practices in product development based on our fieldwork. As such, they are not intended to describe all commercial industry and practices or suggest that commercial firms are without flaws.

We conducted our review between October 1996 and September 1997 in accordance with generally accepted government auditing standards.

Knowledge at Key Junctures Is Critical to a Successful Transition to Production

Product development can be characterized as the reduction of risk and resolution of unknowns through the acquisition of knowledge. Compared with the DOD programs we reviewed, commercial firms gain more knowledge about a product's performance, producibility, and ability to meet customer requirements much earlier in the product development process. The best firms will not launch a new product development unless they have high confidence that they have achieved a match between what the customer wants and what the firms can deliver. The firms' keen knowledge of their technological capabilities and limitations frames the design features they are willing to offer. Before the midway point in product development, the firms attain enough knowledge to ensure that the product works. By the end of product development, but before fabrication of production items begins, commercial firms prove that their production methods will yield the desired volume and quality of the product within the desired unit cost. Throughout product development, the firms adhere to their own proven standards as to what constitutes an acceptable level of knowledge. By the time actual production begins, few risks or unknowns remain.

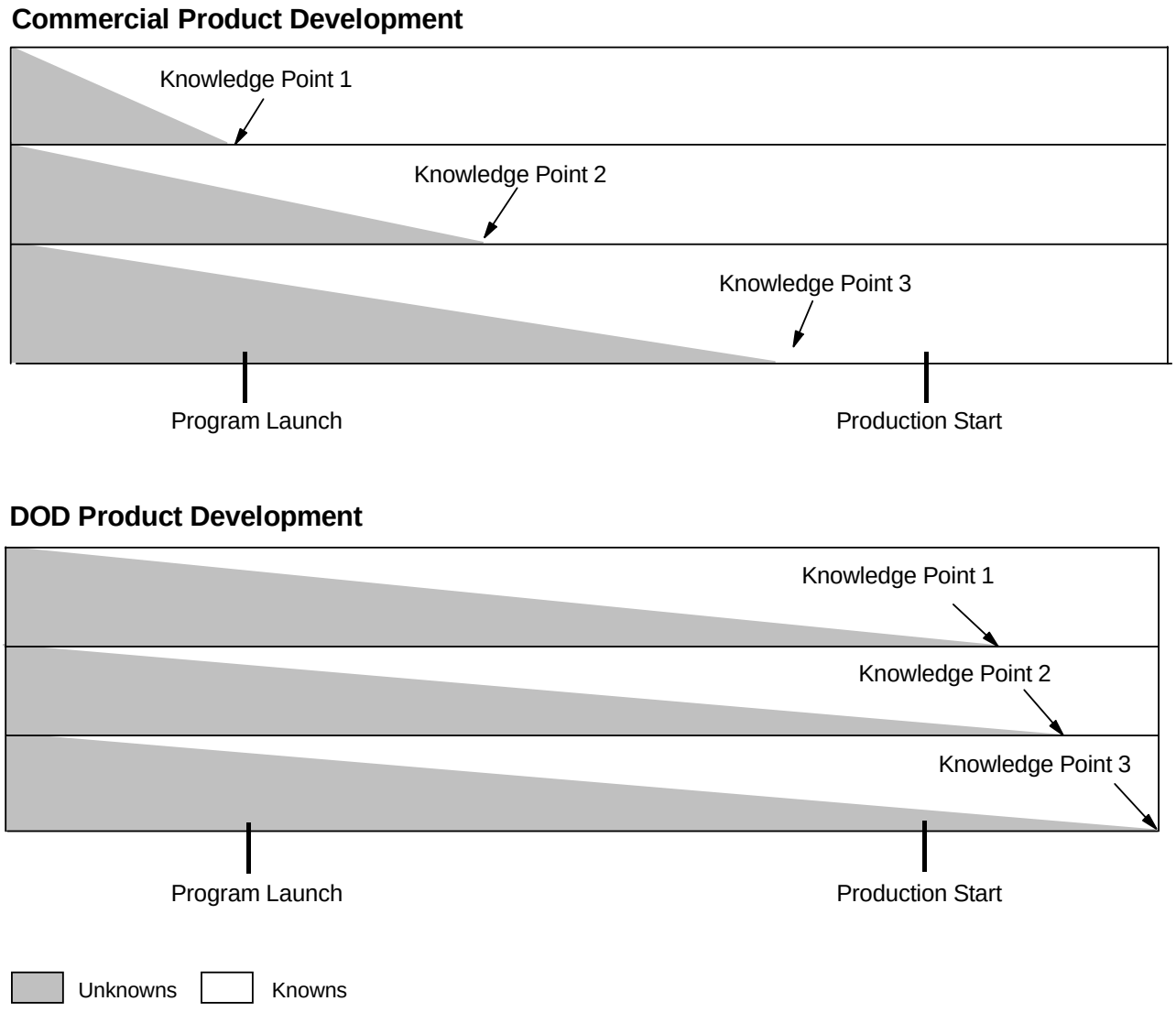
The DOD programs we reviewed allowed more technology development to carry over into product development. Consequently, they proceeded through product development with much less knowledge about required technologies, design capability, and producibility than the commercial firms we visited. Two programs—the C-17 and the F-22—did not or will not attain the same level of knowledge of the design's ability to perform or be produced until late in development or early production. Attaining the match between product design and customer requirements will not be certain until testing is completed late in development, a practice that is not acceptable in commercial product developments. Proof that production methods can yield the desired volume and quality within the desired unit cost will occur after production begins. As a result, the DOD programs tend to have more unknowns and greater risks to manage when production fabrication begins. DOD's review mechanisms tended to overstate knowledge or understate risks, as borne out by problems or unknowns discovered later in product development. Two programs we reviewed—JDAM and the AIM-9X—have attempted to make a closer match up front between demonstrated technology and customer requirements. They are thus in a better position to gain critical knowledge sooner in the remainder of their development phases.

Commercial Firms Develop Knowledge Sooner in the Product Development Cycle

The successful management of cost, schedule, and performance risk in transitioning a new product from development to production is related to how soon full knowledge about key dimensions of the product is attained. In this sense, knowledge is not the same as information. Knowledge, in this context, means that program managers and decisionmakers have reached virtual certainty about an aspect of the product being developed, such as a critical manufacturing process. It is the inverse of risk. Information is essential to attaining knowledge, but not all information produces the same level of certainty. For example, a study that shows a new manufacturing process should work does not produce the same degree of certainty that actual use of the process on another product does. For the purposes of comparing commercial and DOD product development cycles, we have characterized the point at which virtual certainty of some aspect of a product is achieved as a "knowledge point."

The commercial and military programs we reviewed did not all follow the same processes or steps in their development cycles. However, at some point, full knowledge was or will be achieved about a completed product, regardless of what development approach was taken. Knowledge on product developments can be broken down into three points or junctures: when a match is made between the customer's requirements and the available technology; when the product's design is determined to be capable of meeting performance requirements; and when the product is determined to be producible within cost, schedule, and quality targets. Program launch or start is the point at which organizations define a product's performance, cost, and schedule estimates and commit to making the financial investment needed to complete development and bring the product into production. Figure 2.1 illustrates the three knowledge points and the differences between the commercial and military product developments in terms of when they attain knowledge.

Figure 2.1: Comparison of Three Key Knowledge Points for Commercial and Military Product Developments



Knowledge Point 1: Knowledge that a match exists between technology and requirements.
Knowledge Point 2: Knowledge that the design will work as required.
Knowledge Point 3: Knowledge that the design can be produced within cost, schedule, and quality targets.

Because military programs tend to start product development with more unknowns, it takes them additional time, sometimes until well after production begins, to actually discover and capture enough solid information to attain full product knowledge and thereby virtually eliminate risk. The programs continue to resolve risks about the performance of the product design and its producibility after they begin production. Commercial firms attain full product knowledge before fabrication of production units begins.

Decisions made in matching requirements with technology have a direct impact on what is required to reach subsequent knowledge points. Synergy exists when a decision early in product development, such as establishing product requirements, reduces the amount of unknowns that have to be resolved before full knowledge of product design performance and producibility is attained. Conversely, a decision to reach for a technological advance can increase the effort required to attain full design performance knowledge, which, in turn, can delay the attainment of producibility knowledge.

Knowledge Point 1: Requirements and Technological Capability Are Matched

To minimize the amount of technology development that occurs during product development, the commercial companies we visited employ disciplined processes to match requirements with technological capability before product development begins. The process reflects production realities and demands proof that the technology will work and can be produced at an acceptable cost, on schedule, and with high quality. The companies bring solid technological knowledge to the requirements process in the form of current, high-fidelity information from predecessor programs, people with first-hand experience on those programs, or new technologies deemed mature as a result of having “graduated” from a disciplined technology development and screening process. In addition, the companies communicate extensively with customers to match their wants and needs to the firm’s available technology and its ability to manufacture an appropriate product. They do not stray far from their technological foundation. In the commercial world, this process is sometimes referred to as Quality Functional Deployment, a technique used to convert complex or unclear customer requirements into design and manufacturing requirements.

For the programs we reviewed, DOD did not get as good a match between customer requirements and the technology that could be confidently delivered. Usually, the individual services identify a need for a capability

and translate that need into specific weapon performance objectives and thresholds. Even though DOD examines the potential for available technology to meet product requirements, it allows requirements to drive technology and make it reach beyond what is proven. DOD has less knowledge than commercial firms—in the form of predecessor programs, people with experience on those programs, and technology maturity—about the ability of the design to deliver required performance and be produced at the point it starts a program. The knowledge that the match has been achieved between required performance and the capability of technology is often not attained until after production begins, when operational testing is completed.

Commercial Practices

We found examples of best commercial practices for matching requirements to technology at Boeing, Hughes, and Ford. Boeing communicated with the airlines to set achievable requirements for the 777-200 airplane and tested the design early. Hughes used a technology development process that graduated new technologies from concept into a product development program, enabling the firm to make what it saw as quantum performance increases with mature technologies. Ford uses its technology deployment process to separate immature technology from a new product's development. It enforces a decision point in product development in which new technology must show proof that it will meet cost and performance expectations to be accepted onto a product's development program.

Boeing established requirements for the 777-200 airplane after extensive communications with several airlines over an 18-month period before beginning product development. Originally, the airlines thought that a 767 derivative would serve their purposes. However, during the course of discussions, Boeing and the airlines realized that a "family" of airplanes that would provide the airlines' range and payload flexibility was required. During that time, Boeing matched customer's needs to its technological capability using an airline working group made up of airline representatives to establish market and product requirements and extensive performance testing to these requirements. Boeing tested all of the airplane's various systems together as a single, integrated entity in simulated flight conditions very early in product development. In addition, Boeing completed an initial design review that ensured the design's performance, identified all risks, made plans for their resolution, and selected a final configuration.

The diligence Boeing applied to matching requirements and technological capability on the 777 was a practice that resulted from painful experiences on two predecessor programs. On one program, Boeing had erred on the side of proposing too many new technologies and design features on a new aircraft design. Boeing halted the program before the launch point, after one airline customer complained that it contained "too much technology for technology's sake." In retrospect, Boeing was relieved because the design contained too much risk to make the sound business case needed for the launch decision. On another program, Boeing had erred too much on the side of allowing customers to add requirements after program launch. This program was completed, and aircraft were delivered; however, delays occurred in the development phase due to reworking the design, and the early production aircraft experienced problems with reliability rates. The requirements process for the 777-200 applied the lessons learned from both programs. Figure 2.2 shows the Boeing 777 airliner.

Figure 2.2: Boeing 777 Airliner

Lessons learned from previous programs helped Boeing match technology with requirements before launching the 777.

Source: Boeing Commercial Airplane Group.

Because of early communication and testing, Boeing met the airlines' requirement with plans for a family of airplanes in the medium-lift category that would meet the airlines' needs in a timely manner. The 777-200 model was first, followed by models that would increase capacity and range. Boeing also found that it could meet requirements for the 777-200 using mostly existing technologies. When new technologies were needed, such as digital avionics and advanced materials, they had to be demonstrated with laboratory testing, simulation, and modeling before

introducing them to the development program. Boeing also decided against some new technology on the 777 as the result of its matching of requirements to capability. For example, Boeing originally designed the airplane using a new, lightweight material—aluminum lithium—for some portions. However, at the design review that preceded the start of development, manufacturing members on the design/build team argued that the material was expensive and hard to find and that the fabrication processes for it were not yet fully understood. Despite the increase in weight that would result, the team decided against using the material. Boeing made the customers aware of the problem and worked with them to reduce the weight. Ultimately, the final 777-200 configuration was 1,500 pounds under its originally proposed weight.

According to Hughes Space and Communications, its newest product, the HS-702 satellite, was a quantum leap in satellite technology. It provided twice as much power and capacity as its predecessor; however, it was made with mature technology. Hughes used its technology development process to demonstrate new technology before inserting it into the HS-702's development. Specifically, it uses Technology Roadmaps to prioritize technology against business needs and corporate strategies, and investments are made accordingly. Product development managers will not use the resultant technology until it proves capable of meeting product performance, cost, schedule, and quality requirements and manufacturing processes are in place and in control.

Hughes identified three technologies it considered high risk when it began development of the HS-702 satellite: the gallium arsenide solar cells and solar concentrators, the xenon-ion propulsion system, and the deployable radiator needed to radiate additional heat resulting from the increased power. The new solar cell and propulsion system technologies had been through the corporate technology development process and had been applied on predecessor programs, so there was significant knowledge about them at the outset. The deployable radiator was high risk because Hughes did not believe it had the technology for this capability. Hughes found a Russian supplier that was already producing the required technology, greatly reducing technical risk. At Hughes, technology that is not proven through predecessor programs or the development process is not allowed onto a new product. For example, Hughes wanted to include lithium ion batteries and advanced receiver technologies on the HS-702 satellite to decrease weight and improve its capacity and power, but it did not include them because these technologies had not met cost, schedule, performance, and quality targets.

Ford reduces risk from new technology during product development with its Technology Deployment Process. This process prioritizes, matures, and introduces new or emerging technologies for product development, reducing risk from the time the concept is proposed to its ultimate implementation on a new product. During this process, technologists agree to deliver new technology to vehicle centers for product development. Managers of product development are customers to technologists and can agree or refuse to sponsor technology, which creates a shared understanding of deliverables between the technologist and the product manager. Each technology project has a concept readiness milestone, which includes a demonstration of the hardware and its required manufacturing processes, as well as testing and analysis results. Also, each technology has an implementation readiness milestone, which includes proof that the technology is ready for product development with identified and manageable risks. At this point, the new technology's cost, schedule, and quality targets must be met.

Ford enforces a "Wall of Invention" at the start of each new product's development. Beyond this point, no new technologies or design features are allowed to be added to the vehicle. From then on, the product manager takes responsibility for successfully developing and producing the new vehicle. Product managers are veterans of previous production programs, and their production knowledge makes them very discriminating in deciding what new technology will be allowed onto the vehicle.

DOD Practices

DOD programs did not attain a match between technology and requirements at the time of launch. DOD accepted varying—but consistently higher—degrees of technological risk on four of the product development programs we reviewed. Technologies ranged from comparatively high-risk advances for the F-22's avionics and low observability to low-risk advances for mostly off-the-shelf components being used to develop the AIM-9X missile and JDAM. The C-17 program was developed using mostly existing technology, with some demanding features required of the airframe design. DOD practices for matching product requirements to available technology on the AIM-9X and JDAM appeared to do a better job of reducing risks.

The F-22 development program has reduced risk from new technologies across most of its key design features through extensive, high-fidelity modeling and analysis. However, the program's product development includes new low-observable materials, avionics, and propulsion

technology whose performance is undemonstrated and raises some concern about producibility. Low observability is one of the F-22's most important characteristics and is dependent on many factors, such as the shape of the airframe, its flight characteristics, and airframe materials and coatings. Although the program has done pole model testing of the aircraft to determine whether it meets its low-observability requirements, the aircraft includes 10 newly developed derivatives of existing materials that are important to its low-observability feature. The materials will have had 3 years of flight testing before they are applied to the first production aircraft; however, the performance and maintainability of these materials cannot be completely verified until radar signatures can be tested in varying climates. This testing is scheduled to be completed 2 years after production begins.

Similarly, much remains to be proven on the F-22's avionics technology before it is certain that the technology is a match for the performance requirements. The avionics software features a level of integration not previously achieved in a fighter. One major technical challenge is perfecting the way in which various avionics subsystems will interface. The program has incorporated a series of risk reduction activities designed to mitigate these software integration problems. For example, it has defined and replicated all of the avionics interfaces at this point in development, but this testing will not prove that the various subsystems will interact in identifying and prioritizing threats. The program has begun testing in an avionics integration laboratory and on a flying avionics test bed mounted on a Boeing 757 and will further test the avionics capabilities for prioritizing threats at very high densities and conditions once the test facility is ready. However, until that type of testing and flight testing begin to produce results—in 1999 at the earliest—there are significant unknowns concerning the capability of integrated avionics on the F-22. The program plans three incremental updates to the software, completing its development in 2002. By this time, Lockheed plans to have at least 40 production F-22s, an investment of at least $8 billion, finished or in the manufacturing process.

The F-22 engines have many advanced features to meet aggressive performance requirements. One such requirement is for supercruise—the ability to sustain supersonic speeds without the use of afterburners. Some of these advanced features resulted in components that are more difficult to produce than originally anticipated and are resulting in higher-than-planned recurring production costs. The producibility risk is largely driven by unknowns concerning the hollow fan blades, some

components fabricated from composite materials, the turbine exhaust case, and a few features of the exhaust nozzle. A product cost reduction process has been implemented to mitigate these risks, but program officials acknowledged that the user's overall performance requirements for the engines remain very challenging, and it is still unclear whether the engines will meet all of the requirements.

For the most part, the C-17 was developed using nondevelopmental items or commercial parts. However, performance requirements for short landing and takeoff, payload, and range required design innovations that significantly increased technical risk on the program. A new technology that added risk to the program was aluminum lithium, a new, unproven alloy that the program used for its strength and weight savings. The first production aircraft contained 2,200 pounds of the alloy. Its application was unsuccessful due to a lack of knowledge about the technology's characteristics. The program discontinued its use because of its potential to warp during handling, cracking and chipping during installation, the need to keep it separate from other materials, and concerns over sources of supply. It is being phased out of the program and the 51st production airplane will be free of it. The C-17 program replaced aluminum lithium with aluminum alloy 7050, a less expensive and easier-to-handle material with several sources of supply. Boeing made the same decision at the outset of its 777-200 development program based on similar conclusions reached by its design/build team. This is a good illustration of different knowledge standards applied in making design decisions. Figure 2.3 shows the C-17 aircraft.

Figure 2.3: C-17 Cargo Aircraft

Although the C-17 was developed mostly with nondevelopmental items and commercial parts, performance requirements significantly increased technical risk.

Source: DOD.

Also, the software development effort to meet avionics performance requirements turned out to be significantly more complex than the Air Force thought. When the C-17 development program began in 1985, for example, the Air Force had identified 4 subsystems with about 164,000 lines of code that had to be developed. By 1990, this number had increased to 56 subsystems and about 1,356,000 lines of code, including approximately 643,000 newly developed lines of code.

The JDAM and AIM-9X development programs have been more attentive to matching customer requirements with technological capabilities. Both programs chose designs that relied strongly on predecessor data, and both programs emphasized affordability as a key product requirement. JDAM used modified variants of proven product lines for its guidance component and global positioning system. It also used mature, existing components from other proven manufacturing processes for its own system for controlling tail fin movements. The designs for the battery and the tail housing both use mature technology and will be built using mostly existing tooling and processes. The program office and contractor have been able to further minimize risk by conducting extensive development, qualification, and flight testing to demonstrate performance, quality, and reliability on some key subsystems.

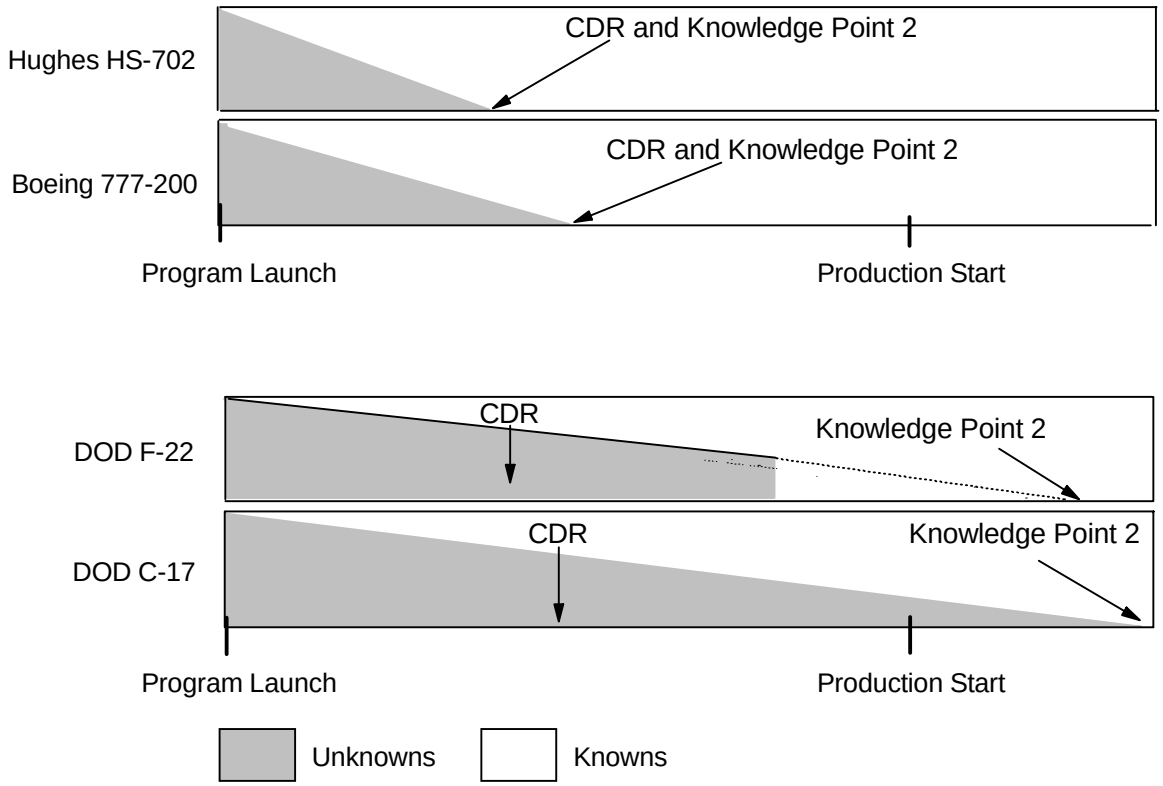
Except for its tracking technology, the AIM-9X air-to-air missile will use technology largely from manufacturing processes already in place or from the United Kingdom's Advanced Short-Range Air-to-Air Missile production program. For example, the sensor is currently being developed for the United Kingdom missile, and over 2,500 sensors will have been produced before the first AIM-9X is assembled. The AIM-9X airframe is adapted from a past Air Force flight test program and is made up of proven technology. The rocket motor, engine, warhead, and fuse are all taken directly from AIM-9M missiles and are already in production. The AIM-9X tracking system is the primary area of new technology. It is a sophisticated, computerized component that translates the light image obtained by the seeker into electronic signals that can be viewed by the pilot, discriminate against countermeasures, and guide the missile to a particular point on the target aircraft. It provides the seeker a wider, higher fidelity view in which to find targets. This new technology has been in development for some time and is made up of off-the-shelf components. Hughes believes this risk is manageable because of modeling and simulation that preceded the development program.

Knowledge Point 2: The Design Will Perform as Required

The completion of engineering drawings and their release to manufacturing organizations signify that program managers are confident in their knowledge that the design performs acceptably and can be considered mature. The drawings are critical to documenting this knowledge because they are not only precision schematics of the entire product and all of its component parts—they also reflect the results of testing and describe the materials and manufacturing processes to be used to make each component. Both DOD and commercial companies consider

the design to be essentially complete when about 90 percent of the engineering drawings are completed. Both sectors schedule a critical design review (CDR) to review the drawings, confirm the design is mature, and "freeze" it to minimize changes in the future. Figure 2.4 compares what knowledge, in the form of released drawings, was in hand at the time of CDR for the commercial and DOD programs we reviewed.

Figure 2.4: Comparison of When Commercial and DOD Programs Achieve Knowledge About Their Product's Design



Commercial Practices

The commercial firms we visited released over 90 percent of the products' engineering drawings at CDR. At that point—about midway through development—the firms had near certainty that their product designs

would meet requirements and had gone a long way to ensure that the product could be produced.

Boeing had full knowledge of the 777-200 design's capability at its final CDR. It began releasing engineering drawings after a preliminary design review when product development began in 1990 and completed this release process in 1992, less than 2 years later. CDR at Boeing is generally done by peer organizations, such as engineers from another program. Outside consultants are sometimes used. Boeing officials told us that, once the design drawings were released to the manufacturing process, they averaged less than two changes per drawing, well below their average on past programs and exceeding their goal for the 777-200 program. Once CDR was complete, Boeing strictly enforced the design freeze for the 777-200. For example, Boeing incorporated a customer requirement to include folding wingtips, along with the supporting bulkheads, into the 777 design at a cost of nearly $40 million. Later, the customer decided the folding wingtips were not necessary; however, Boeing left the bulkheads in the wings anyway because all of the engineering drawings were completed and the risk of introducing changes, even though the changes would have saved weight, was considered too high relative to cost and schedule targets.

Hughes, which designs both military and commercial satellites in the same facility, completed two design reviews for development of the HS-702. First, it passed an internal review to satisfy the corporation that its basic design was producible. Second, it reiterated design reviews on individual, customized satellites as they were ordered by customers. During the internal development process, Hughes began releasing engineering drawings at preliminary design review and completed releasing drawings at CDR, about 15 months into a 26-month product development process. Hughes' goal was to complete and release all engineering drawings at CDR; however, representatives told us the drawings were close to 95 percent released at that point.

Chrysler described several practices for ensuring mature designs. It uses information from predecessor products to quickly develop focused updates and innovative derivatives to existing products. This predecessor data, along with its use of platform teams, allows Chrysler to take advantage of existing information and expertise in new product developments. It is able to simultaneously develop and test the product's design and its required processes, which it described as true concurrent engineering at the right time. Chrysler uses prototypes to refine the

product and capture design knowledge early. It also employs a pilot production process and extensive testing facilities at its technical center to prove the design's performance and producibility before it is released to manufacturing facilities.

DOD Practices

The C-17 and the F-22 programs had less knowledge—in the form of test results or engineering drawings—about their designs than commercial companies did at the time they held their CDRs. The programs did not get or were not projected to get to the same level of completion on the drawings until later in the development cycle, which placed greater reliance on the lesser information available at CDR. This is important because the review is a major event that represents a point of departure from detail design to manufacture of the product. The risks of proceeding with CDR and the rest of development as planned are increased without the requisite drawings in hand. This was deemed acceptable for both programs.

The C-17 program had released 10,229 of its engineering drawings—56 percent—at CDR in August 1988, just past the midway point in development. After CDR, an additional 8,161 drawings were released, over 4,000 of which were released after assembly of the first production aircraft had started. We estimate that the C-17 program did not release 95 percent of its initial drawings until December 1991, more than 3 years after CDR and after seven production aircraft had been delivered to DOD. The C-17 encountered numerous technical problems during testing that resulted in redesigns, cost increases, and schedule delays. For example, flight tests in 1991 revealed that an innovative system of blown wing flaps—essential to the C-17's ability to fly steep landing approaches at slow speeds to access shorter runways—suffered heat damage and acoustical cracks. To correct this problem, the contractor had to completely redesign the slats to include titanium skin and substructure. This knowledge was not obtained until the program was at least two-thirds into development. Also, in 1992 both wings on the static test article failed at approximately 128 percent during a 150-percent limit load test and had to be redesigned.

Software development and management problems also contributed to C-17 cost and schedule problems. The Air Force lacked specific knowledge about software development problems as they occurred. The first C-17 aircraft achieved first flight 19 months later than planned and did not include many of the mission-critical software functions required for a fully

operational aircraft. Problems such as these caused completion of testing on the C-17 to be delayed by well over 1 year.

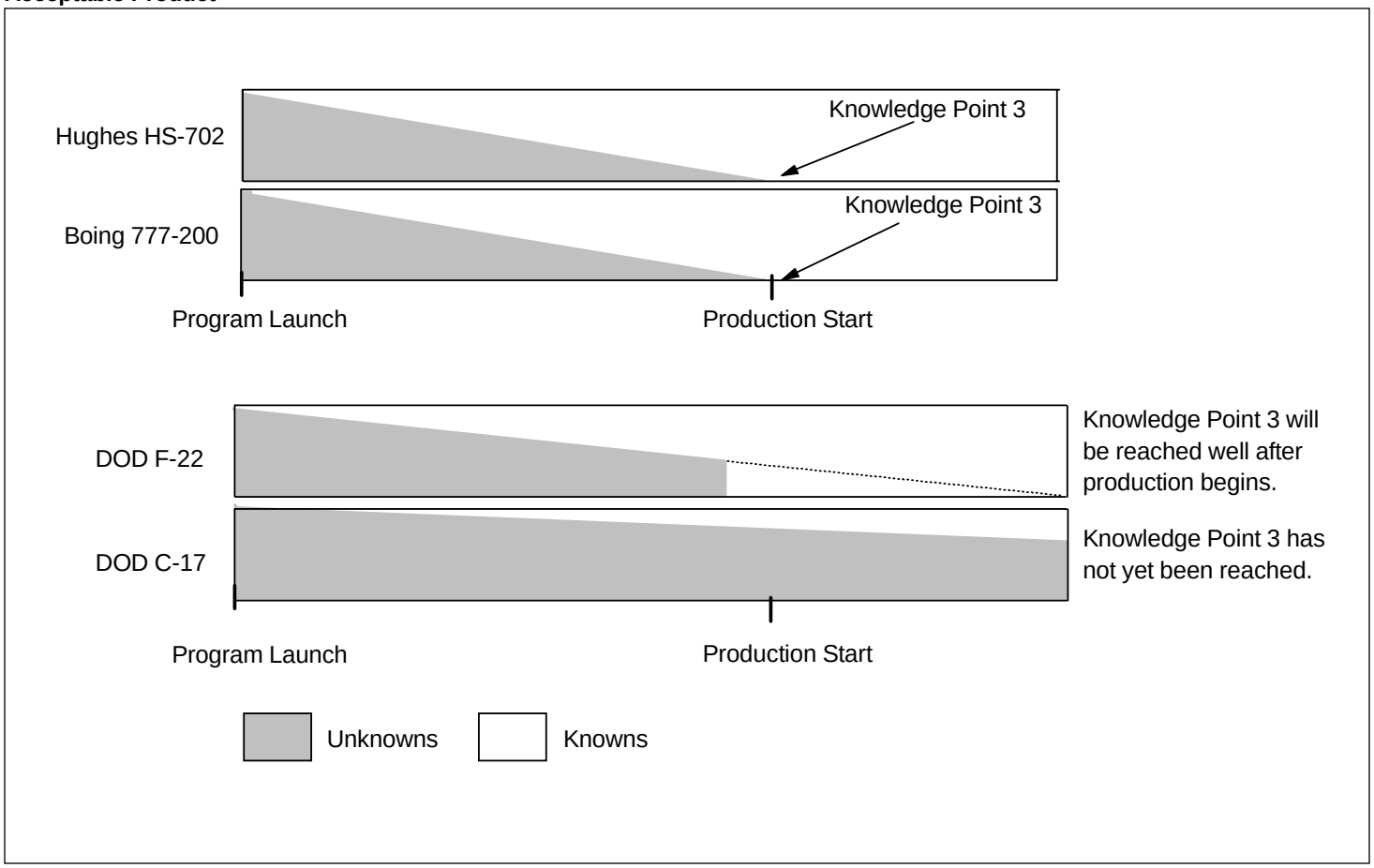
The F-22 program had released 3,070 initial structures and systems drawings, less than one-third of the eventual drawings, at its CDR held at the midway point in development. Since then, an additional 6,032 drawings have been completed and released. The drawing release process is not yet complete for the F-22, so we cannot determine if the program has yet released 95 percent of its drawings. F-22 production is scheduled to begin in June 1999.

Even though it is still too early to predict outcomes on the AIM-9X missile and the JDAM development programs, their prospects appear promising because they have chosen mostly proven technology from existing programs to achieve performance requirements. They appear to have robust, mature designs that will use manufacturing processes already identified and demonstrated to be stable or in control. JDAM held its CDR in August 1995. At that time, it had released 65 percent of its drawings. In addition, it demonstrated how the product would meet requirements using data, analysis, and a physical display of the product. The time it took to build up and load a JDAM was also demonstrated. AIM-9X has not yet held its CDR, but program officials indicated that they will have already built a prototype before CDR and hope to freeze the design based on that prototype.

Knowledge Point 3: Production Units Will Meet Cost, Quality, and Schedule Objectives

The companies we visited reached the point at which they knew that manufacturing processes would produce a new product according to cost, quality, and schedule targets before they began fabricating production articles. This meant more than knowing the product could be manufactured; it meant that all key processes were under control, so the quality, volume, and cost of their output were proven and acceptable. The C-17, in production for 7 years, still does not have all of its processes under control. The F-22 program is not scheduled to have all of its processes under control until the 4th year of production. The AIM-9X and JDAM programs appear to be doing better in this regard. Both programs are using the same approach as commercial firms to attempt to get their critical manufacturing processes in control before the programs enter production. Figure 2.5 illustrates the difference between the commercial HS-702 and 777-200 programs and the military C-17 and F-22 programs concerning when full knowledge about the production processes was achieved.

Figure 2.5: Comparison of When Commercial and DOD Programs Achieve Knowledge That Processes Can Produce an Acceptable Product



Commercial Practices

The commercial firms relied on existing manufacturing processes and statistical process control (SPC) data to achieve this knowledge in a timely manner and, in fact, had all their key processes under statistical control when production began. SPC is established by monitoring processes to see if they are consistently producing output that is within the quality standards and tolerances set for the overall product. Statistics concerning the quality of each process output are analyzed, and when the output is out of tolerance, process owners search for causes. Once a process is producing consistently high-quality output, the process is considered to be in statistical control, and inspections can be reduced. The knowledge gained using SPC is significant in transitioning from development to

production because it helps companies ensure that cost, schedule, quality, and reliability targets will satisfy the customer and the business case.

The ability to establish SPC for key processes before production began was the culmination of all the practices employed to identify and reduce risk. The criteria commercial companies had established throughout their product development processes forced program managers to prove that the product's design was capable and producible early in the process. For example, Boeing carried out more than 25 technical and manufacturing reviews during the development process leading up to production to ensure that the product's design was producible. Boeing identified computer-aided three-dimensional interactive application software (CATIA) and its design/build teams as crucial to ensuring that processes were in control and the transition to production went smoothly.[1] CATIA software allowed workers to share design and process information about the 777 in real time and different locations. Manufacturing engineers could check on a part's producibility at any time in the development process.

Hughes told us that it knew that all of the processes to manufacture the HS-702 were in control because the processes were either already in place from previous programs and under SPC or they had been proven to be in control before being released to product development by demonstrations during the corporation's overall technology development process. Figure 2.6 shows the Hughes HS-702 satellite. Ford had similar practices to Hughes, often demonstrating SPC on technology before it was inserted into a product development, even before production begins.

[1]CATIA allows designers and manufacturers the opportunity to view design drawings as three dimensional and provides real-time information to everyone in the process about the impact a change to a drawing will have on the overall design and manufacture of the product.

Figure 2.6: Hughes HS-702 Satellite

Hughes has achieved statistical process control on the low-volume HS-702 satellite before beginning production.

Source: Hughes Space and Communications.

Chrysler's use of platform teams, CATIA software, and its technical center all contribute to a smooth transition to production and ensure that processes are in control for every new product. Perhaps as important, synergy develops with a disciplined product development process that accumulates so much knowledge up to this point. All of the companies we visited agreed that knowledge about technology and design up front in the

process makes the control of processes possible and the transition to production smooth.

DOD Practices

The DOD programs we reviewed demanded less proof than commercial firms of a design's producibility before a product transitions to production. The C-17 did not achieve SPC on all key processes before production and will not reach that point until well into production. The F-22 is not slated to achieve control on all key processes until after production begins. Moreover, basic producibility problems were not discovered until late in the F-22's development and after production began on the C-17. These risks went unrecognized even though both programs had established criteria for ensuring that risks were acceptable and enough knowledge had been gained before proceeding to the next program phase. These exit criteria were light on production-related requirements, even at the decision point for proceeding with production. For example, the F-22 program's exit criteria for moving to full production does not require information from the final production readiness review until after the decision, and the C-17 program's exit criteria did not require proof of producibility. Neither set of criteria contained requirements about drawing releases nor the schedule for achieving control on key processes.

The C-17 program began production in 1989 with less than 13 percent of its key manufacturing processes in control, despite completing production readiness reviews that were intended to reduce producibility problems. The program has produced and delivered nearly 40 aircraft and has now identified 420 key manufacturing processes. Of those, only 56 are under statistical control. This inability to control manufacturing processes was caused, in part, by an immature design. For example, the C-17 program discovered major design changes of the wings, flaps, and slats were required after CDR, as prototype aircraft were being built. In addition to causing high rates of drawing changes, these late design changes caused problems on the production line. They necessitated costly changes to processes; forced the manufacturers to develop workaround plans that led to labor inefficiencies; and resulted in high rates of scrap, rework, and repair. The C-17 program estimates scrap, rework, and repair costs on the 34 delivered aircraft to be over $200 million.

The F-22 program is ahead of the C-17 at this point regarding SPC, perhaps due in part to its use of CATIA. Of 926 key manufacturing processes identified, almost 40 percent of its key processes are in control now, 2 years before production is scheduled to begin. Nonetheless, the

production preparations for the F-22 illustrate the limitation of a review mechanism when a substantial amount of knowledge is unattained. The program's initial production readiness review, held in 1995 when only about one-third of the engineering drawings were released, did not report any high risks in manufacturing or producibility, although clearly much was unknown at the time and drawing release was slower than called for by DOD guidance. In 1996, an independent team mandated by the Air Force reviewed the program and discovered numerous manufacturing and producibility problems, such as underestimated complexity in manufacturing processes, understated labor requirements for building the aircraft, immature definition of avionics flight test requirements, and concerns about software integration. These and other concerns led to increases to development and production cost estimates of $2.1 billion and $13 billion, respectively. Air Force officials believe that these additional costs can be offset by reprogramming existing funds and by implementing a number of cost avoidance measures in the future.

The JDAM program office completed manufacturing assessments at the prime contractor and all major suppliers in February 1997 in such areas as process controls and plant capacities. These assessments found that all of the production tooling was in place to build JDAM. The program office has identified 84 manufacturing processes that must be in control to meet the product's key performance characteristics and has achieved statistical control on 69 percent of the processes at this point in the program, about 1 year before full-rate production begins. The AIM-9X program is still very early in its EMD phase but has already identified all of the critical manufacturing processes that must be in control to meet the product's key performance characteristics. The contractor told us that all of those processes are stable at this point in the program, and most are in statistical control.

Although the F-22 program may not be characterizing and controlling its manufacturing processes as quickly as commercial firms do, it offers perspective on some of the strides that DOD has made in preparing weapons for production since the 1980s. In 1985, we reported that several weapons had encountered substantial problems in early production because they used hand-built development prototypes made in special shops by expert personnel.[2] Production articles were built in different facilities with different processes and people. There was no real transition to production, but rather a sudden shift from development to production.

[2]Why Some Weapon Systems Encounter Production Problems While Others Do Not: Six Case Studies (GAO/NSIAD-85-34, May 24, 1985).

One of the programs at that time, the F-16 fighter, had a much better experience. We noted that development prototypes were built in the production facility using as many production processes and people as possible. This made the transition to production much more gradual and was one of several factors that helped prepare the F-16 for production. Although the F-22 is attempting to make a bigger technological leap than the F-16 did, the development prototypes are being built in the production facility using some production processes and people.

Differences in Military and Commercial Practices Reflect Different Environments

The differences in the practices employed by the best commercial firms and DOD are not necessarily explainable by differences in tools, techniques, or talent. Rather, the differences in the actual practices reflect the different demands imposed on programs by the circumstances or environment in which they were managed. Indeed, the way success and failure are defined for commercial and defense product developments differs considerably, which creates a different set of incentives and different behaviors from the people managing the programs. Specific practices take root and are sustained because they help a program succeed in its environment. In this sense, practices are adopted because they work—not because they are textbook solutions.

In general, the success of a commercial product development is determined on the basis of production items sold; similarly, failure is clearly defined as the customer walking away and purchasing the product of a competitor. This definition of success, coupled with shorter cycle times, makes production concerns a main determinant in the initial business case to launch a commercial product development and in subsequent decisions to manage risk and make technology tradeoffs. This environment encourages the early identification of unknowns with realistic risk assessments so that risks are not allowed to jeopardize success. Strong incentives, both positive and negative, stress getting the product development right.

DOD product developments are launched much sooner—with greater technology, cost, and schedule unknowns—and extend much longer. Production concerns do not play as big a role early in these programs because production is so far off and thus is not as critical to success. The definition of success is more complicated in DOD. During most of product development, success is defined in large part as getting DOD and the Congress to fund the development on an annual basis. Optimistic assessments of design performance and cost help ensure this kind of success; realistic risk assessments for unknowns do not. By the time production nears, the risk of failure is much reduced because a vested customer is not likely to walk away.

Commercial Practices Are Driven by the Customer's Acceptance of the Finished Product

The commercial firms we contacted launch a product development program only when a solid business case can be made. The business case basically revolves around the ability to produce a product that will sell well enough to make an acceptable return on investment. The point of sale occurs after product development is complete; program success is determined in production when the customer buys the finished product. If the firm has not made a sound business case, or has been unable to deliver on one or more of the business case factors, it faces a very real prospect of failure. Production is a dominant concern throughout the product development process and forces discipline and tradeoffs in the design process. This environment encourages realistic assessments of risks and costs; doing otherwise would threaten the business case and invite failure. For the same reasons, the environment places a high value on knowledge for making decisions. Incentives favor identifying unknowns early, designating them an appropriate high risk, and aggressively eliminating them. Practices, such as achieving statistical process control before production, are adopted because they help ensure success.

Production Considerations Figure Prominently in the Program Launch Decision

For the commercial firms we contacted, the main focus of a product development program is to produce and sell the right product at the right time. The success of a program depends on the product's sales and not just on its successful development. Therefore, the business case for launching a program considers production realities and builds in natural curbs to overreaching for performance, cost, or schedule. Although the corporations demand considerable proof in the business plan that the product will meet market expectations, they then provide full support—including funding—for the plan to succeed. This provides a program with a very solid baseline from the outset that continues to serve as a good decisionmaking framework as the program progresses and problems arise. The day of reckoning—when program success or failure is realized—comes clearly and swiftly after development when the customer takes delivery of the product and is prominent throughout the product development process.

Boeing described the business case for the 777-200 product development as a "money wheel" that must be balanced across all of its factors. These factors include a market opportunity, a product whose technical features can satisfy the market, available investment capital, a cycle time short enough to get the product to market on time, and a unit production cost that will yield an acceptable return on investment. Boeing informed us that if any factor gets out of line, either through estimating errors or changing

conditions, the "wheel" will not turn, and profitability—and perhaps corporate reputation—could be lost. The program manager is judged by these standards, unlike in DOD.

Before Boeing committed to development of the 777-200, it first determined that a market opportunity existed for a family of at least 10,000 new, medium-lift airplanes and that the airlines would buy these airplanes at a certain unit price. The company then had to make the business case—that it could develop a product with the right features, in time to meet the market opportunity, and at an acceptable unit cost. Boeing did not commit to offer the new aircraft for sale until the commercial group's president presented solid evidence, on the basis of predecessor programs, testing, simulations, and analysis, to the board of directors that all of the business case factors were achievable. The board then approved investment of capital based on its assessment of the risk involved with meeting the business case. Boeing program officials pointed out, however, that it was not the board meeting that provided the incentive to get the business case right. Rather, they said that the commercial group president knew that the company's investment capital was at stake on such a major product development. An oversold business case would lead to failure and could have a devastating effect on the company's future. This had a very sobering effect on the people that constructed the factors in the business case and curbed the tendency to overstate the case.

Hughes presented a very similar scenario for the corporate decision to go forward with the development of the HS-702 satellite. Hughes was very comfortable with the level of technical risk at the outset because its technology development process had matured the required technologies before inclusion in the program. In fact, the biggest risk in its business case was ensuring that the market for the product was profitable. To resolve this risk, Hughes spent considerable time educating its customers about the benefits of the proposed program. Only after potential customers were convinced did Hughes have a solid business case for going forward with development.

The other companies we contacted—Chrysler, Cummins, and Ford—had similar frameworks established for making decisions about product development. Business realities, such as capital investment, cycle time, execution in production, and the customer's sensitivity to purchase price, created a high-stakes environment. The decision to begin a new development program was typically made at the highest corporate level. However, the business case, with all of its competing factors, provided a

framework and the incentives for program managers to make practical decisions about product development based on facts and data. This framework held the achievement of each factor as essential to success and committed the program managers to assess all associated risks realistically. Getting a program approved that embodied false or weak information was viewed as a failure because the customer might not buy the finished product. One commercial program manager informed us that his firm used to routinely underestimate the cost and schedule for developing a new product and overestimate its sales volume and profit margin. He described this practice as a "death cycle" that nearly bankrupted the company.

Shorter Cycle Times and Strong Incentives Foster Behaviors That Keep Programs on Track

Once a company decides to launch a product development, strong incentives—both positive and negative—serve to keep the programs on track. To meet market demands, leading commercial companies build relatively short cycle times into decisions to begin a product's development. Boeing's 777-200 went to production less than 5 years after development began, Hughes' HS-702 took about 26 months, and Chrysler developed its new sport utility vehicle in less than 30 months. These short timeframes make the day of reckoning, in terms of customer acceptance and return on investment, close at hand. Consequently, production—on time, at rate, at cost, and with quality—looms as a near-term reality that continues to greatly influence subsequent design and configuration decisions within the framework of the business case. The incentives that operate in the commercial environment encourage program managers to want risks identified early, be intolerant of unknowns, and not rely on testing as the main vehicle for discovering the performance characteristics of the product. By protecting the business case as the key to success, program managers are conservative in their estimates and aggressive in risk reduction. Ultimately, preserving the business case strengthens the ability to say "no" to pressures to accept risks or unknowns.

Boeing believes a number of factors serve as incentives to keep a program on track. First, because the fate of the program (and to a large extent the fate of the company) is in the hands of the program's design/build teams and their leaders, the incentive is for them to convince themselves that the business case is solid rather than to "sell" program estimates to corporate management. Second, the company's investment capital is fixed. Thus, development cost increases on any one program that can be absorbed are limited because, at some point, the overrun will hurt investment on other programs. Third, the program's ultimate performance becomes part of a

scorecard on the program manager's impact on corporate profitability. A failure that hurts the company financially will remain associated with the program manager and other people involved. Fourth, if the product does not live up to its performance characteristics (which include operation and support costs), the company will lose money on product guarantees. Finally, the program management staff understand that more is at stake than the program at hand; a serious miscue on one program can hurt the company's reputation and damage other programs as well.

Although these factors could be seen as negative incentives, Boeing's environment also provides strong positive incentives for keeping a program on track. The board approval to launch a product development is a commitment to completely develop and produce the item. There is no turning back unless something occurs that would cause a serious decay in the business case. The investment funding is approved up front, the corporation stands firmly behind the product development, and the program manager has control over the product's development process. When problems do occur, the corporate support does not waver, and problem solving takes place within a well-understood framework—anchored in the business case—for making tradeoffs. For example, Boeing realized early in the 777-200 program that investment costs would be higher than anticipated, largely due to cultural changes it was trying to accomplish with full use of CATIA and design/build teams. Boeing's approach to resolving the problem began with the premise that the contractual commitment to deliver the aircraft, with all of its features, on time, and at the same price, would be met. The problem was then limited to minimizing the increase in investment cost to keep the business case intact.

Boeing said that it is predisposed to identifying and solving problems early and paying the up-front costs to do it rather than accept the production cost consequences of the problems at the end. Its decisions on the use of aluminum lithium and the bulkhead for the 777-200 wing tip are demonstrative of behaviors that value minimizing production risks after a program is underway. Although the aluminum lithium could have been designed into the aircraft and offered performance improvements, it was rejected because of the unknowns it presented for material handling on the production line and for long-term performance under operational conditions. Similarly, Boeing could have taken the unneeded bulkhead out of the wing tip to reduce weight, but that idea was rejected because the redesign would have had a ripple effect on drawings and production preparations.

Chrysler officials discussed a similar environment for managing the product development process, emphasizing the need for discipline to come from within the program itself. Chrysler establishes a target unit price, specific performance objectives, and cycle time as part of the business case for each product's development. These factors are strongly enforced—within a fixed-price, firm schedule environment—as a discipline to manage risk and facilitate product tradeoffs. The platform teams operate under a "zero-sum" basis, meaning that if the price of one component is higher than expected, then savings must be found elsewhere. The platform teams are totally empowered to make all decisions concerning their product as long as periodic reviews by product assurance teams indicate that all of the performance objectives are being met. If the objectives are not being met, the team receives increased scrutiny and outside direction. This practice creates a strong incentive for product managers and platform teams to keep product risk to a minimum by using known product and process technologies and discovering problems as early as possible.

Chrysler explained an important aspect of the program manager's role is to say no to things, such as immature technologies, that may disrupt the product's cost, schedule, or performance targets. Chrysler believes that, without the "bottom line" discipline from the program manager, cost targets will not work. Any facet of product development that cannot be shown to be knowledge, rather than projection, is considered an unknown and designated a high risk. Design and production issues are thus equalized; a suspension component that can improve vehicle performance and reduce complexity will be rejected if the proposing team cannot provide proof that this component can be produced at the rate and cost called for by the business case. Figure 3.1 shows Chrysler's Plymouth Prowler.

Figure 3.1: Plymouth Prowler

Shortening product development cycles and other incentives help Chrysler managers identify risks and say no when necessary.

Source: Chrysler Corportation.

In this environment, every team member is considered to have high risk until each can demonstrate otherwise. Team members are encouraged to volunteer information early on risks or problems they are having because the other team members will step in to help, particularly if they have savings that can offset price increases. The team members know that if one of them fails, they all fail because the business case decays. They also know that if they help someone, they increase the willingness of others to help them. By the same token, the team member that withholds problems

until late in the development is ostracized for putting the entire team in a position to fail.

Ford officials believed that the product development environment at the firm had gotten to the point at which people treated the company's money as if it were their own. In our discussions with these officials, we discerned several factors that converged to keep estimates intrinsically sound during the product development process. These factors were: (1) the vast amount of predecessor data from previous product developments that can be used as a reality check for a new program's estimates; (2) the amount and quality of the information being generated for the program at hand, including the technique being used to generate data; and (3) the consequences of weak or overstated data on the program's success. Figure 3.2 shows the Ford Motor Company's Lincoln Navigator.

Figure 3.2: Lincoln Navigator

Ford reduced the amount of unknowns on the new Lincoln Navigator by limiting product requirements to proven technologies.

Source: Ford Motor Company.

The individual practices employed by commercial firms are consistent with the incentives of their environment. The high reliance on CATIA shortens cycle time and reduces risk by generating knowledge that

previously had to await the building and testing of physical articles. Insistence on having near 100-percent release of drawings at the CDR drives risks down as the production line is geared up. Achieving statistical process control before production begins helps create certainty that production costs, schedule, and quality will satisfy the customer. In short, these practices are adopted because they work by helping to ensure success in the commercial environment.

DOD Practices Reflect the Need to Succeed in Funding and Managing the Development Effort

DOD must make a defendable case before launching a program. The program's merits generally relate to providing a needed capability within the limits of affordability. DOD typically defines and launches a program years earlier in the process than a commercial product development, and thus the case for the product is made when much less is known about technology, cost, and schedule. In a very real sense, the point of sale begins much earlier on a DOD program and continues throughout development as the customer (DOD and the Congress) pays for the product on an annual installment basis from program launch. Success, then, for most of the product development cycle, is measured in terms of ability to secure the next installment. Because this approval must be won every year, it creates incentives to make the program's case look attractive.

By the time production begins, the customer is deeply invested and unlikely to walk away. As a result, success, in terms of program continuance, is substantially ensured before end items are produced. For these reasons, and because production is often many years from the launch decision, it is difficult for production realities and concerns to exert as much influence on a DOD product development. Instead, design features and performance are more dominant. More unknowns are accepted on a DOD program, and their attendant risks are often understated. This combination, which can be devastating to a business case, can work in a weapon development if it helps the program get launched and survive. Practices, such as deferring prove-out of key processes until production begins, are compatible with this definition of success.

Early Launches and Long-Term Programs Put Focus on Technology Development

For a major product development to be launched, DOD's acquisition guidance calls for a strong case to be made that includes a firm need, superior product performance, affordable cost, and feasible technology. A need can stem from several sources, including an increase in threat capabilities, the obsolescence of an existing weapon system, or the

potential for a new or expanded capability made possible by technology advances. Traditionally, needs for new weapons have been generated by individual branches within each service. In recent years, DOD has been experimenting with other vehicles for determining needs, such as advanced concept technology demonstrators to evaluate the utility of mature advanced technologies.[1] Once a need has been established, a product development vying for launch faces intense competition for initial funding.

A key distinction between DOD and commercial product developments is the timing of the launch. The launch decision on a DOD product development is often made years before that on a commercial product. In DOD, this decision is made when the program is approved to enter the program definition/risk reduction phase. The knowledge required to make the business case to launch a commercial product development is generally not available for a DOD program until well into the EMD phase. By way of analogy, the F-22 fighter program, 11 years after launch and about midway through the EMD phase, may now be at the point that it would be ready for launch in the commercial environment. Thus, when a DOD product development competes for launch funding, it is generally dealing with far greater unknowns than its commercial counterpart. Figure 3.3 shows an F-22 fighter plane.

[1]DOD defines advanced concept technology demonstrators as a means of demonstrating the use of mature technology to address urgent military needs. The demonstrators are not acquisition programs, but are designed to provide a residual, usable capability upon completion. If the user determines that additional units are desired, the additional buys would constitute an acquisition program.

Figure 3.3: F-22 Fighter Plane

The F-22, launched earlier than commercial products, needed significant advances in propulsion, low-observables, and avionics technologies to meet performance requirements.

Source: DOD.

Even though less information about a new DOD product development is available at the time of launch, the competition for funding requires detailed projections to be made from what information does exist. Although DOD is attempting to ease the technical requirements of programs, a new product development is encouraged to possess performance features that distinguish it from other systems. For example, the F-22 will be faster than the F-117 and stealthier than the F-15; the

RAH-66 Comanche helicopter will be faster, stealthier, and smaller than the AH-64 Apache. Consequently, aspiring DOD programs have incentives to include performance features and design characteristics that rely on immature technologies.

Untempered by knowledge to the contrary, the risks associated with these technologies are deemed acceptable. We have often reported on the subsequent realization of such risks in the form of problems later in the product development. In a 1993 study of seven weapon systems, Rand found that, despite policies to the contrary, the technology underlying several programs was clearly not fully developed and ultimately caused substantial difficulties.[2] Production realities, critical to matching technological capabilities with customer requirements on commercial programs, are too far away from the DOD launch decision to have the same curbing effect on technology decisions. Indeed, in support of the Defense Manufacturing Council, a multi-discipline team from industry and government pinpointed a major cause of acquisition problems in DOD as the imbalance between product goals and the maturity of engineering and manufacturing processes used to reach those goals.

Other pressures on DOD programs at launch make tough demands for knowledge that does not yet exist. A product development deemed worthy cannot be launched unless development and production funding is available over the right time period. The product's development and production cost, as well as timing, must fall within available funding. Because DOD relies largely on forecasts of cost, schedule, and performance that are comparatively soft at this stage, success in funding competition encourages the cost and schedule estimate to be squeezed into profiles of available funding. Additional product requirements, such as high reliability and maintainability, serve to make the fit even tighter.

Ultimately, the demands of successfully competing for launch funds make for a much different business case on a DOD product development. Compared with commercial programs, the DOD environment launches product developments that embody more technical unknowns and less knowledge about the performance and production risks they entail. These unknowns place a much greater focus on demonstrating and proving out technology during the remainder of product development than we found on commercial programs. Equally important, the DOD program is launched with customer funding. Even though the competition for funding will continue throughout the program's development, the point of sale begins

[2]Barriers to Managing Risk in Large Scale Weapons System Development Programs, Rand, 1993.

with program launch. When a commercial product development is launched, the customer's willingness to buy is still undemonstrated and thus remains a significant risk and a powerful incentive.

Incentives on DOD Programs Encourage Different Behaviors From Managers

As a product development proceeds in DOD, its success is still measured in terms of the funding it receives. Success translates into getting the funding requested each year; failure can mean anything from a significant funding cut to cancellation. In a sense, the day of reckoning for a DOD product development comes every year with the budget process. The most important issues facing the program at the time will dominate the attention of program managers and decisionmakers. These issues tend to be related to the successful demonstration of technology. In contrast, the day of reckoning for commercial programs is later in the program cycle: at the sale of the produced item. The business case with the production conclusion sustains the commercial product development's focus through future decisions and problem solving. Again, shorter cycle times are key to sustaining this focus.

Unlike commercial programs, DOD programs do not receive full corporate support throughout development. Even though many individual programs compete for funding at any given time, competition also exists at the aggregate level, among the services for their portion of the budget. In addition, DOD programs face scrutiny by service executives, the Office of the Secretary of Defense, independent cost estimating and test agencies, audit agencies, and several committees and subcommittees of the Congress. Given this amount of competition and oversight, the detection of a problem on an individual program makes that program vulnerable to criticism and possible loss of funding support. Ironically, it is these same pressures that encourage overreaching at the time of program launch. This situation contrasts with that of the commercial product development, which enjoys full corporate support once it is launched; in turn, the program's estimates are kept realistic by the knowledge that the program's success may determine the firm's future.

The pressures and incentives in the DOD environment explain why the behaviors of managers and other sponsors of product developments differ from those in commercial programs. According to a 1994 study done for the Under Secretary of Defense for Acquisition, government program managers found their formal role of objective program management at

odds with their informal role of program advocates.[3] According to the study:

> "A feeling of responsibility for program advocacy appears to be the primary factor causing government managers to search aggressively and optimistically for good news relating to their programs, and to avoid bad news, even when it means discrediting conventional management tools that forecast significant negative deviations from plan."

In this environment, risks in the form of ambitious technology advancements and tight cost and schedule estimates are accepted as necessary for a successful launch. Problems or indications that the estimates are decaying do not help sustain the program in subsequent years, and thus their admission is implicitly discouraged. An optimistic production cost estimate makes it easier to launch a product development and sustain annual approval; admission that costs are likely to be higher could invite failure. There are few rewards for discovering and recognizing potential problems early in the DOD product development. For commercial product developments, an optimistic production cost estimate will mean failure of sales or profit; admission of cost increases early invites aggressive problem-solving behaviors to restore the business case. The behavior of tolerating unknowns and not designating them the same risk value as in the commercial environment is rational in the DOD environment because there is little incentive to admit to high risks before it is absolutely necessary, as long as the resulting estimates are accepted by DOD and the Congress. In fact, admitting risk may doom the program.

Behaviors toward testing follow a similar logic. On commercial product developments, much more is known about the product's performance at the beginning of development. Testing is used to confirm knowledge and identify weaknesses or limits in the product. It is consistent with a firm's anxiety to eliminate unknowns to preclude failure in production. DOD product developments are much more dependent on testing to discover technical performance characteristics and answer the question of whether the product will work. DOD tests serve more than the purpose of discovering or confirming performance characteristics—they are examinations on which the program must get good grades or face failure in the form of withdrawal of support. Good test results can help a program, whereas negative test results are equated with failure. Unknowns, then, present a safer course of action; if testing does not occur until late in the product development, forecasts of product performance will serve as the only information available.

[3]Critical Issues in the Defense Acquisition Culture, Defense Systems Management College—Executive Institute, December 1994.

Cycle time is an important determinant of what pressures the environment brings to bear on a product development. In a DOD product development, cycle times can be 10 to 15 years, whereas the tenure of a program manager is more likely to be 2 to 4 years. One senior commercial program manager informed us that it is unreasonable to expect that a program manager can truly focus on anything that is more than 3 years off; events beyond that timeframe are not powerful motivators. Thus, it is hard for production success to present the same reality for the first few managers of a DOD program and the decisions they are involved in. To some extent, DOD may attempt to counteract the disparity between the length of a program manager's tenure and that of the program being managed through formal reviews. Production readiness reviews are an example; they do not have a commercial counterpart because readiness for production is intrinsic to the commercial product development. The production readiness review does not provide the same incentives for success because it is also prey to the pressure to accept unknowns and assess them as tolerable risks. DOD's practices, which allow key production knowledge to be gained concurrent with production, are a logical consequence of the DOD environment. If problems arise in production, there is not nearly the risk of failure that a commercial product faces; by the time a weapon enters production, the point of sale to the customer has already occurred.

We did not attempt to make a formal comparison between the capabilities of DOD and commercial program managers. We believe that commercial program managers have one advantage in that they are likely to have more experience with repeated product developments than a DOD program manager. Aside from that advantage, we did not observe that commercial managers were somehow better or more ethical than their DOD counterparts. As we previously reported,[4] DOD program managers and other sponsors do not act irrationally or with bad intentions. Rather, they see the acquisition of the weapons under their purview as aligned with national interests. They do what they believe is right, given the pressures they face. The difference is that the definition of program success determines what is right, and success in the DOD environment is different from success in the commercial environment.

[4]Weapons Acquisition: A Rare Opportunity for Lasting Change (GAO/NSIAD-93-15, Dec. 1992).

Creating the Right Environment Is Key to the Success of Initiatives to Improve Weapon Acquisitions

DOD has embarked on several initiatives that draw lessons from commercial practices, such as cost as an independent variable (CAIV), integrated product teams (IPT), use of past performance data, and performance specifications. DOD has also recently set up a funding reserve to offset unexpected cost growth to mitigate the effect of unknowns on acquisition programs. These initiatives could have a positive effect on the transition of weapons into production if the environment for launching programs and appraising risks can be changed to provide the right incentives. Studies sponsored by DOD and the defense industry call for changes that could help shape such an environment. A 1996 study by the Defense Science Board Task Force on Defense Acquisition Reform calls for replacing the DOD acquisition process with a process that combines the best elements of practices from commercial and defense-unique activities. A major tenet of the recommended process is more emphasis on incremental technology advancement, coupled with much shorter product development cycle times. These themes are also echoed in a study by a National Center for Advanced Technologies task force comprised of defense firms.

Examples from past acquisitions serve as reminders that changing the mechanics of a weapon's development, without changing aspects of its environment that determine its incentives, may not produce desired results. DOD's guidance for preparing weapons for a successful transition to production, some of which is 10 years old, already has much in common with commercial best practices. Thus, the challenge for DOD and congressional decisionmakers may not lie so much in the "how to" aspects of product development as in creating the incentives—or the reasons why best practices will work for program managers.

DOD's Risk Reduction Policy Is Consistent With Commercial Practices

DOD 4245.7-M, Transition From Development to Production, a risk reduction policy manual written in 1985, provides metrics and tools for minimizing design and production risk during a product's development. In addition, DOD's new procedures for major defense acquisition programs contained in the new 5000 series of acquisition policies emphasize best practices in assessing and mitigating risk during development. Figure 4.1 shows DOD's main policy guidance on preparing weapons for production.

Figure 4.1: DOD Guidance on Preparing Weapons for Production

DOD has provided ample guidance to program managers on how to properly manage weapon system development to successful production.

DOD 4245.7-M contains templates that provide guidance for when and how to perform trade studies, design reviews, and producibility reviews. It contains criteria for trade studies that require an evaluation of new

technology before selecting it for a product's development and suggests that cost, producibility, and quality should be considered equally with performance. The templates also suggest that a CDR should be held when 95 percent of the product's design is complete in terms of engineering plans and drawings and that the design should be frozen and released directly after CDR. The templates also state that CDR results and critical drawing release schedules and approvals are essential data sources for design release. Finally, the templates suggest that (1) the effect of the design on current manufacturing processes should be measured during the design process, (2) any new manufacturing processes should be "proofed" during development to ensure producibility, (3) proofing simulates actual production conditions and environments, and (4) SPC data are considered essential program data sources for qualifying the manufacturing processes during product development.

DOD revised its 5000 series procurement policies in March 1996 with the intent of defining an acquisition environment that makes DOD a smart and responsive buyer of the best goods and services. Several themes described in the new 5000 series documents resonate with commercial practices:

- The commercial marketplace must be researched to determine its potential to meet system performance requirements and results documented in the initial operational requirements document.
- The acquisition process must consider both performance requirements and fiscal constraints as embodied in CAIV.
- Acquisition of commercial processes and practices provides rapid and affordable application of new technologies to meet DOD mission needs.
- Future acquisitions must take into account customary commercial best practices in developing acquisition strategies and contracting arrangements.
- A streamlined management structure and event-driven management process at DOD would emphasize risk management and affordability and would explicitly link milestone decisions to demonstrated accomplishments.

DOD's 5000 series documents emphasize the interrelationship between establishing requirements, managing the development process, and making funding decisions with the objective of translating users' needs into products with affordability as a key discriminator. The policy also emphasizes the consideration of producibility early in a product's development. It states that producibility is key to managing risk and that existing manufacturing processes should be capitalized on when possible.

It also states that production should not be approved until the design has been stabilized, manufacturing processes have been proven, and facilities and equipment are in place. DOD has emphasized that programs should meet users' needs with mature technology, when possible, by using demonstrations of technology and incremental or evolutionary product developments, thereby taking advantage of existing information about cost and performance.

DOD Initiatives Adapt Some Commercial Practices

DOD's more recent initiatives are intended to reduce the cost and duration of major weapon system acquisitions. In establishing the framework in which cost is considered an independent variable, DOD is attempting to make cost a prime reason for trading off performance requirements. Once cost and performance tradeoffs have been made, CAIV establishes cost as the overriding constraint for obtaining the needed military capability from the new system. For CAIV to work properly, program managers will need sufficient knowledge of technological capability and associated program development and production costs, along with a sound mechanism and forum for making tradeoffs. Whether tradeoffs are made will depend on the incentives in place to make them. DOD points to the JDAM as an example of how effective CAIV can be because use of this tradeoff technique reduced expected unit production prices from $40,000 to about $14,000 per unit. Figure 4.2 shows the JDAM.

As the program proceeds through development, the framework for making decisions is to be similar to the zero sum approach an auto manufacturer follows after establishing a price target for a new vehicle. Today, however, the career incentives for program managers in DOD are not consistent with those of the auto manufacturers.

Figure 4.2: Joint Direct Attack Munitions System

Use of cost as an independent variable and integrated product teams enabled the projected unit price of the JDAM to be reduced from $40,000 to $14,000.

IPTs are a means to integrate the development of a product and its manufacturing processes by using multidisciplinary teams that represent a variety of product functions, such as engineering, manufacturing, purchasing, and accounting. Traditionally, these functions have been separate organizations that tended to get involved sequentially in the product development process. Through IPTs, the functions are brought together to make tradeoffs that will optimize the design, manufacturing, and supportability processes for a weapon system. They are important to making techniques such as CAIV work. IPTs have analogies in Boeing's design/build teams and Chrysler's platform teams. Many defense contractors have already adopted the IPT approach. Several factors affect

the success of IPTs, including reasonableness of the program goals, the knowledge the members bring to the team, the authority the teams have to make tradeoffs to achieve the goals, and the right disciplines represented on the teams.

DOD has an initiative to use information on the past performance of a contractor to ensure that DOD has access to a globally competitive industrial base capable of supplying the best value goods and services. DOD believes that past contractor performance information is an important strategic tool that when properly used, will allow DOD to evaluate the risk of using poor or nonperforming contractors as well as the potential for using excellent contractors. This information will allow DOD to make better decisions during source selection. In the commercial sector, the use of past performance information for suppliers was generally found to be integral to improving product developments.

DOD has also made the decision to use performance specifications on weapon system developments. Previously, many military specifications told defense contractors specifically how they were to accomplish certain tasks. Performance specifications tell the contractor only what performance is desired of the end product and not how to get that performance. Again, there is a commercial analogy in the sense that customers are generally not concerned with how a product does something, such as get better fuel economy, as long as performance is as advertised.

DOD is tracking the effects of these acquisition reform initiatives on seven programs, designated as Defense Acquisition Pilot Programs. These programs were afforded early statutory and regulatory relief under the provisions of the Federal Acquisition Streamlining Act of 1994 to set the example for acquisition reform. JDAM is one of the pilot programs. According to DOD, the successful application of commercial practices enabled these programs to demonstrate significant improvements. DOD projects that acquisition programs that have benefitted from acquisition reform could reduce cycle time by 25 percent. Some of DOD's pilot programs have significantly reduced the amount of military specifications and standards. JDAM has eliminated all 87 of the military specifications and standards that were in its baseline contract in favor of commercial practices. A 1997 DOD report on the pilot programs credits the use of IPTs for reducing program office size and significantly decreasing government contract administrative hours. The same report states that the

improvements indicated by the pilot programs appear to be applicable across DOD.

DOD has recently set up a reserve of funds to be used to mitigate the effect of unforeseen technical problems that might threaten to upset an acquisition program's schedule. This initiative emerged from DOD's Quadrennial Defense Review, which stated that

> "complex, technologically advanced programs all bear some risk of costing more than planned. When unforeseeable growth in costs occurs, offsets from other programs must be found, which in turn disrupts the overall modernization program. Our programming process must provide sufficient flexibility in the form of program reserves to address this risk."

DOD plans to begin accumulating the risk reduction fund in fiscal year 2000 and expects it to grow to about $1 billion by fiscal year 2003. It will be accumulated through contributions from the Office of the Secretary of Defense and the services.

We have not evaluated this new funding mechanism or the way DOD plans to implement it. Nonetheless, DOD's use of the reserve has the potential for communicating to program managers which practices will be encouraged and which ones will not. For example, if the fund is used primarily to pay for problems that are revealed in late development or early production, the fund could reinforce existing incentives for not dealing with risks until they become problems. Conversely, if the fund is used to resolve risks early and preclude problems, it could encourage risks to be revealed earlier in programs.

Experience on Past Programs Underscores the Need to Match Technique With the Environment

A discussion of lessons learned or difficulties encountered on past weapon acquisitions must recognize that the DOD acquisition process has produced the best weaponry in the world. Nonetheless, the experiences of some weapon systems serve to point out the importance of making the environmental changes necessary for good practices to work. These techniques then will have the chance to offer better outcomes consistently in terms of cost, schedule, and performance.

In the 1980s, the Army attempted to acquire the Sergeant York Air Defense Gun using a strategy that included several features similar to those in the Defense Science Board's recommended process. These features included a competition between two contractors to use components based on

previously demonstrated technology and integrate them into a weapon system, coupled with the freedom to trade off flexible performance requirements to save costs and shorten cycle time. The resulting system failed in operational tests after it had entered the 4th year of production and was subsequently canceled. The risks associated with integrating the technologies had been underestimated, and the discovery process was protracted into production. The techniques to foster tradeoffs, reduce risks, and give the competing contractors the freedom to design the system did not, by themselves, change the Sergeant York's environment into one that encouraged the early discovery of problems.

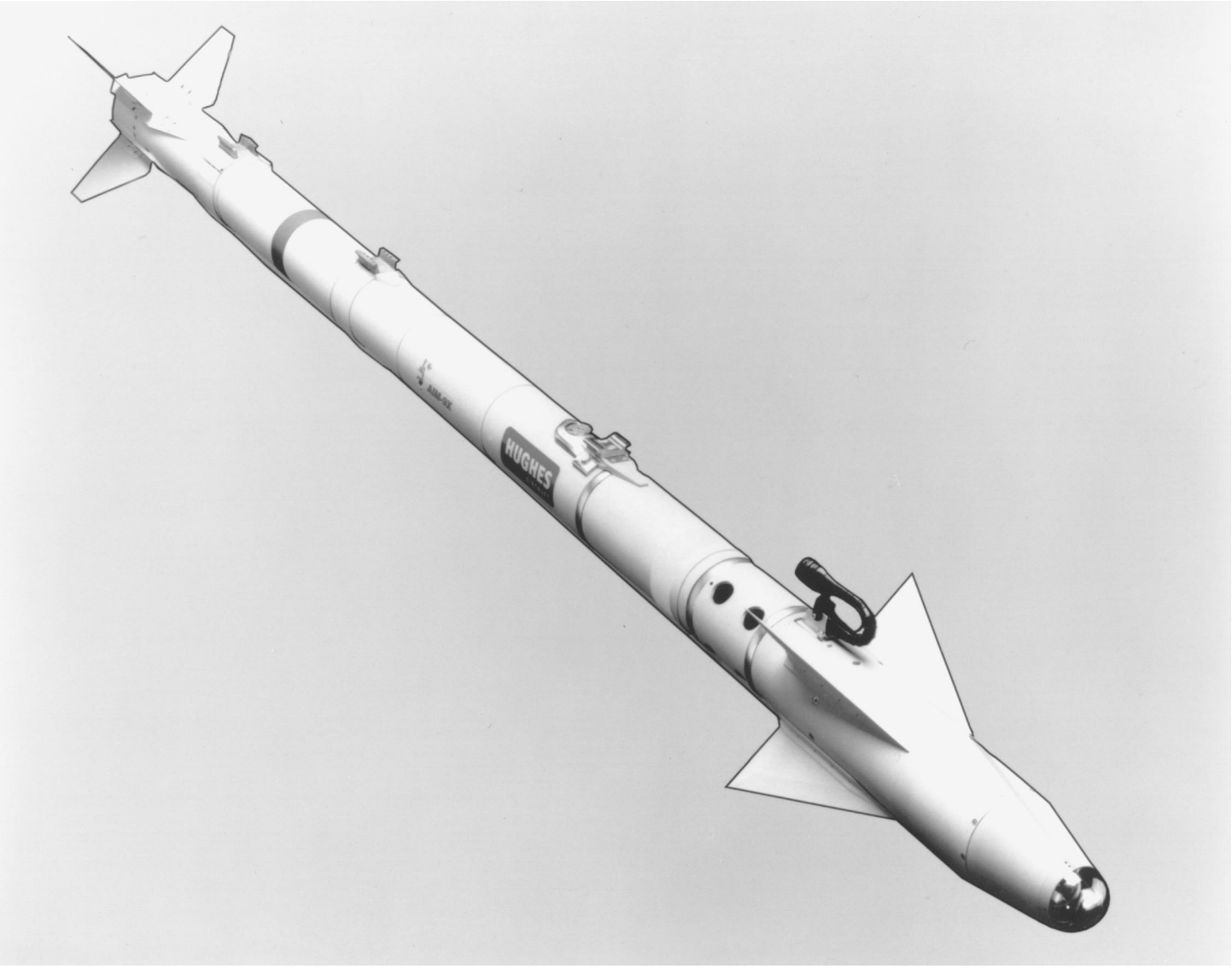
Fluctuations in funding cause perturbations in weapon programs and are a complication that poses less of a problem for the commercial firms we contacted. However, stable funding, by itself, will not ensure program success. In the 1980s, baselining a program was a technique aimed at enhancing program stability, whereby a program office "contracted" with top management to develop a system that met basic performance, cost, and schedule requirements in exchange for stable funding and minimal interference. The 1986 Packard Commission cited the B-1B bomber as an example of a baselined system. Despite enjoying stable funding and congressional support, the B-1B experienced significant performance shortfalls and continues to require substantial additional funding to correct these and other problems. Similarly, the F-117A program experienced cost increases, schedule delays, and substantial modifications despite stable funding, continuous congressional support, and streamlined management. In view of the many pressures that characterized the acquisition environment for these programs, stable funding and support did not prevent other problems, such as those stemming from ambitious performance requirements and concurrent schedules.

When a stated program goal is to trade performance for cost and operational support reductions, the acquisition process must encourage those tradeoffs. This was not the case for the Army's Comanche helicopter. This program was initiated in the early 1980s by senior Army management as a family of lightweight, multipurpose helicopters whose justification centered on practicality rather than the threat. The program was expected to replace a fleet of Vietnam-era helicopters with new helicopters that would be up to 50 percent less expensive to operate and support. Within these economical confines, the new helicopters were to offer as good a technical performance as was possible. However, specific requirements were subsequently developed through a performance-oriented requirements process. The program emerged as a

threat-based program to yield the next-generation, high-performance helicopter at a cost significantly higher than that of the Apache, the Army's most advanced and costly helicopter.

The lesson to be drawn from these experiences is not that a weapon's transition to production cannot be improved through the use of better practices. Rather, these experiences show that attempts to improve individual acquisitions require more than a new technique or approach; they also require the knowledge needed to make key tradeoffs and risk assessments, as well as the recognition by decisionmakers that such information provided early is critical to program success. We believe that the JDAM and AIM-9X have promise in this regard because they have utilized mostly existing technology in setting requirements and, when they did not use existing technology, have reduced risk through other means. JDAM represents a new munition built with mostly commercial parts, and the AIM-9X is an upgrade to an existing missile system that largely relies on its predecessor's technology. Moreover, the launch decisions for the JDAM and the AIM-9X missile have encouraged performance tradeoffs to save time and money. Figure 4.3 shows the AIM-9X missile.

Figure 4.3: AIM-9X Missile



Tradeoffs early in the program may enable requirements for the AIM-9X to be met with mature technologies.

Source: DOD.

The challenge for these programs will be to maintain their integrity during subsequent decisions as knowledge—and problems—are discovered. It also remains to be seen to what extent large programs, such as new tank or aircraft development programs, can apply these techniques in the perhaps higher pressure environment in which they will be managed. DOD's 1997 report on the Defense Acquisition Pilot Programs notes that, to fully achieve the benefits of acquisition reform, a complete cultural change must be affected. The report notes that despite significant top-level management emphasis on changing the acquisition process, cultural resistance to various reform initiatives has been encountered on both industry and government teams.

Recent Studies Promote Shorter Cycle Times and Other Environmental Changes

In May 1996, the Defense Science Board completed a study that concluded "force modernization at low cost and with short cycles—and with ability to draw on world-class commercial firms—requires a new weapons R&D [research and development] process." Some of the features of the process recommended by the study directly address key environmental differences we noted between commercial and DOD product developments. Specifically, the study recommended that DOD's process

- aggressively pursue high-risk technology before inclusion in a weapon research and development program;
- employ product solutions chosen jointly by the Under Secretary of Defense for Acquisition and Technology and the Vice Chairman of the Joint Chiefs of Staff;
- maintain competing alternatives for solutions throughout product design;
- make use of already developed next-generation technology, and concentrate on evaluations of existing subsystems as the building blocks for the concepts selected to meet the need;
- use flexible performance requirements with fixed-price and firm schedule requirements; and
- rely on competitive forces and price-based contracting versus regulations and cost-based contracting.

In the opinion of the Defense Science Board, adopting such an acquisition process would supply effective hardware in small quantities, producible and supportable at affordable cost, with cycle times reduced by one-half.

In April 1996, the National Center for Advanced Technologies also proposed a change in the DOD weapons acquisition process to reduce cycle time by drawing on lessons learned from successful military and

commercial programs. The center notes that concepts such as integrated product/process development and CAIV are constructive but that previous good ideas did not succeed. Its proposal for change calls for a new culture that relies on an affordable, incremental approach that could reduce product development cycle times by 3 to 5 years. The new culture features

- an incremental approach to performance, with a threshold or minimum performance for the initial battle group with incremental upgrades and
- requirements that would be managed through cost tradeoffs to keep performance and cost in balance, avoid grand designs, and mitigate risk.

The December 1994 study by the Defense Systems Management College, Critical Issues in the Defense Acquisition Culture, made several recommendations to create an environment for weapon systems development that encourages realism in reporting program status information. Perhaps the most significant recommendation is that the individual military services transfer control of their acquisition organizations and people to the Under Secretary of Defense for Acquisition and Technology. The study noted that, by doing so, the Under Secretary would then be empowered to reward candor and realism in reporting through the use of assignments, transfers, and promotions.

Conclusions and Recommendations

Conclusions

Product development in commercial ventures is a clearly defined undertaking for which firms insist on high levels of knowledge before starting. Once underway, these firms demand—and get—specific knowledge about a new product before manufacturing begins. The process of discovery—the accumulation of knowledge and the elimination of risks or unknowns—is completed for the best commercial programs well before production units are made. In our analysis, we characterized this knowledge in terms of three points or junctures: the match between requirements and technology, the ability of the design to perform as expected, and the ability to produce the product on time and at the right price. Not having this knowledge when demanded constitutes risks that the firms find unacceptable. Immature or undeveloped technology cannot meet these demands. It is essentially kept out of commercial product development programs because of the risks it poses to a product's price and schedule. Increases in price and schedule devalue a commercial product's worth. Immature technology is managed separately until it can meet the demands for product development.

DOD does not insist on the same level of knowledge when it decides to begin a weapon development program. In the DOD acquisition process, a clear delineation is not made between technology development and product development. In fact, programs are launched in the technology development phase, and the pursuit of new technology—the discovery process—continues through EMD and even into production. Not having the same level of knowledge as commercial firms explains much of the turbulence in DOD program outcomes as the transition to production is made. It is a predictable consequence that can be forecast early by the use of knowledge points or other metrics. DOD has had guidance in place that provides policies and metrics that have much in common with what commercial firms demand in terms of knowledge. However, the way the tools for implementing such guidance are used, such as CDRs and production readiness reviews, understates the risks present. Ironically, commercial firms that have weeded out unknowns and minimized the discovery process still identified some risks as high that needed to be resolved in their product developments. DOD programs, which accepted more unknowns and technical advances, did not assess risks as high.

Environmental differences underlie the differences in the product development practices we observed between the DOD programs and commercial firms. At the core of these differences are the definition of success and the time span of programs. In commercial programs, success is defined by the sale of production units to the customer; product

development activities exist only for production. Until the sale is made, the investment money of the product developer is at risk. Product development cycle times are short enough that production realities are a major factor in assessing and eliminating risk in the commercial sector. Behaviors, such as candor about risk and an intolerance for unknowns, and practices, such as ensuring design performance and demonstration of all critical production processes by CDR, are encouraged because they facilitate success.

In DOD, programs are launched with immature technology, product development cycle times are much longer, and production realities figure less prominently in early tradeoff decisions. Success is defined more as the ability to secure annual funding installments from the customer through the budgetary process to sustain the development effort. Thus, the point of sale essentially occurs when the program is launched. By the time production begins, the sale of the product has, to a large extent, already occurred. DOD's acceptance of unknowns and practices that understate risk are consistent with program success as defined in its environment.

Commercial practices for gaining knowledge and assessing risks can help produce better outcomes on DOD acquisitions. For such practices to work, however, the knowledge they produce must help a DOD program succeed in its environment. Thus, the DOD environment must become conducive to such practices. At least two factors are critical to fostering such an environment. First, program launch decisions must be relieved of the need to overpromise on performance and resource estimates. The pressure to amass broad support at launch creates incentives for new programs to embrace far more technology development than commercial programs. The objectives of technology development, as well as what is demanded of knowledge and estimates, differ from those of product development. Clearly, DOD has to develop technology, particularly the technology that is unique to military applications. However, by separating technology development from weapon programs, DOD could insist on higher standards for knowledge on its programs and get better results when those programs transition to production.

Second, once a program is underway, it must become acceptable to identify unknowns as high risks so that they can be aggressively worked on earlier in development. Commercial firms insist on knowledge measured against a criterion for assessing risk. Fixed prices and firm schedules help form the basis for such assessments. Firms then make decisions to preserve the business case by eliminating risks. The result is

discipline provided from within. In contrast, the identification of high risk is more likely to invite damage to the funding case on DOD programs. Unknowns are more likely to be accepted, and knowledge is more likely to be traded to preserve resource estimates. Releasing drawings behind schedule indicated the attainment of less knowledge about design and manufacturing on the F-22 program, but production readiness reviews did not identify any areas of high risk. It took an external team—discipline from outside—to assess production risks as having significant cost consequences.

Decisions made by the Office of the Secretary of Defense and the services to advance programs with significant unknowns or advance programs with known high risks but without sufficient resources, send signals to acquisition managers that current practices work and are acceptable. These decisions define what success means in DOD and what practices contribute to success. The newly created risk reserve could become one vehicle for signaling what behaviors and practices are encouraged on individual programs.

Recommendations

To close the gap between policy and practice, we recommend that the Secretary of Defense take steps to ensure that sound standards for the timing and quality of production-related knowledge are applied to individual weapon system programs and used as a basis for assessing production risks and for making tradeoffs. These standards, which can already be found to some extent in existing DOD guidance, should draw from commercial practices and could include the release of engineering drawings, identification of key production processes, demonstration of risky or new production processes, and achievement of statistical process control. Such standards could enable manufacturing representatives on IPTs to flag something as high risk if it would delay drawing release and the achievement of statistical process control beyond the standard of acceptability. Identifying the impact of such deficits in production knowledge could help program managers to say “no” to proposals to accept unknowns and could force tradeoffs in the design.

To make the environment for DOD product developments more conducive to the techniques used by commercial firms, we also recommend the Secretary of Defense redefine the point for launching programs as the point at which technology development ends and product development begins. This recommendation is made without prejudice toward the necessity of technology development but rather with the intent that

programs could be better managed if such development was conducted outside their purview. Thus, concomitant with defining the launch point later in the acquisition cycle must be the willingness of decisionmakers in DOD and the Congress to support research and development efforts that will advance technology and establish the basis for determining which technologies and subsystems have the mettle to meet the performance, production, and precision estimating demands of product development. If extenuating circumstances necessitate including technology development in a program, this should be recognized as a departure from sound practices, accorded a high risk, and funded and paced accordingly.

Finally, we recommend that on individual program decisions, the Secretary of Defense or his designee send the signals that create incentives for acquisition managers to identify unknowns and ameliorate their risks early in development. Incentives could take the form of a decision to fully fund one program's efforts to mitigate a high risk identified early or requiring another program in which risks are revealed late to absorb the associated financial consequences.

Matters for Congressional Consideration

Because of its critical role in creating the environment for what constitutes program success and which practices will work, the Congress may wish to consider supporting the Secretary of Defense's efforts to create such an environment through changes to the acquisition process that provide program managers clear incentives for gaining sufficient knowledge at key points in weapon acquisition programs. The best commercial practices described in this report suggest what may constitute "sufficient" levels of knowledge. If DOD takes steps to manage technology development efforts outside the bounds of individual weapon system programs, the Congress may wish to consider providing the funds needed for such efforts. The Congress could also help create the right incentives on individual programs by favorably considering DOD funding requests to mitigate high risks early in a program and cautiously considering late requests for funds to resolve problems that should have been addressed earlier.

Agency Comments and Our Evaluation

DOD concurred with a draft of this report and all of its recommendations (see app. I). DOD noted that, although it accepts technical risks to provide superior weapons that often differ from risks in commercial industry, it agreed that changes were needed in its environment to adopt practices that industry has used to become leaner and more flexible. DOD stated that

it was pursuing such practices through the Defense Reform Initiative, the National Performance Review Reinvention Center, Management Reform Memorandums, and numerous acquisition reform initiatives.

DOD also highlighted actions that it believes are consistent with our recommendations. Regarding redefining the point for launching programs, DOD noted that its EMD phase was equivalent to the commercial product launch and that it was taking steps to ensure that technology development was separated from this phase. DOD stated that, to create incentives for acquisition managers to identify unknowns and risks early in development, it had established goals for reducing program cycle time and obviating cost growth. DOD said it was striving to identify metrics to be used in assessing program risks and cited several existing sources for such metrics. In response to the matter that the Congress favorably consider DOD proposals for fully funding technology development efforts, DOD observed that full funding can, in some instances, reduce the flexibility needed to manage these risky efforts. DOD also provided technical comments, which we incorporated where appropriate.

As DOD takes actions to improve weapon system outcomes by better identifying and eliminating program risks early, we underscore the need for an environment that creates incentives for such actions to succeed. It was the right environment that gave rise to the excellent practices we found in leading commercial firms. Given the competitive pressures new programs face, a weapon system program that is started during the technology development phase (Program Definition and Risk Reduction) is encouraged to accept significant technological risks, which are not necessarily reflected in cost and schedule projections. When that program reaches the EMD point, it is difficult to back off of the original projections and put the program on a footing in which requirements, available technology, funding, and time are matched to finish development and start production. Yet, it is from that point on, despite the defense-unique technological risks previously accepted, that a weapon system program should have much in common with a commercial program, including the standards for knowledge that are demanded.

Likewise, once a program is underway, perhaps the clearest way of encouraging the right behaviors—specifically, program managers' and other decisionmakers' willingness to identify and deal with risks early—is through signals sent by individual decisions made on individual programs. Absent such incentives, mechanisms that already exist for identifying and reporting risks have not worked. While we support the search for

improved metrics for production-related knowledge, it is the effective application of good metrics that is more pressing. Such metrics should be applied to programs at key junctures in a way that will enforce standards for knowledge like those we found at commercial companies. We did not intend that providing full funding for technology development efforts should impede the flexibility needed to manage such efforts. We have clarified the wording on that matter.

Comments From the Department of Defense

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

ACQUISITION AND TECHNOLOGY

Mr. Louis J. Rodrigues
Director, Defense Acquisition Issues
National Security and International
Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Rodrigues:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, "WEAPONS ACQUISITION: Changes in DoD'S Environment Are Needed to Apply Commercial Practices," dated December 2, 1997 (GAO Code 707188/OSD CASE 1489). The Department concurs in the views expressed in the GAO draft report; however, specific comments concerning your recommendations and suggestions are enclosed. Technical comments to the report were separately provided.

The fundamental challenge in the acquisition of weapons systems is to provide warfighters the capability to maintain combat superiority while minimizing casualties which drives DoD to develop and acquire technologically superior weapon systems. DoD accepts the associated technical risk and manages it aggressively which often differs from that of commercial industry.

We share your view, however, that changes are needed in DoD's environment in order to adopt those business practices that American industry has successfully used to become leaner and more flexible. The Department is vigorously pursuing the adoption of such practices through the Defense Reform Initiative, the National Performance Review Reinvention Impact Center, as well as, issuing various Management Reform Memoranda to reengineer processes, and implementing numerous acquisition reform initiatives resulting in both regulation and policy changes addressed in the Acquisition Deskbook and the Federal Acquisition Regulations. In addition, our aggressive communication, education and training program is directed towards accelerating implementation of these new initiatives. Thank you for the opportunity to review and comment on the draft report.

Sincerely,

J. S. Gansler

A very thoughtful and helpful report.

Enclosure:
As Stated

GAO DRAFT REPORT - DATED DECEMBER 2, 1997

(GAO CASE 707188) OSD CASE 1489

"WEAPONS ACQUISITION: CHANGES IN DoD'S ENVIRONMENT ARE NEEDED TO APPLY COMMERCIAL PRACTICES"

DoD COMMENTS IN RESPONSE TO THE RECOMMENDATIONS AND MATTERS FOR CONGRESSIONAL CONSIDERATION

RECOMMENDATIONS

Now on pp. 74-75.

- RECOMMENDATION 1: The GAO recommended that the Secretary of Defense should take steps to ensure that sound standards for the timing and quality of production-related knowledge are applied to individual weapon system programs and used as a basis for assessing production risks and for making tradeoffs. (p. 10, p. 79/GAO Draft Report)

  DoD RESPONSE: CONCUR. The Department is constantly striving to identify metrics that can be used in assessing program risk of all types, particularly in the area of production. The Under Secretary of Defense (Acquisition and Technology) initiated an Enterprise Metrics Program in 1996 which led to establishing Year 2000 goals for reducing program cycle time and obviating program cost growth. In addition, there are numerous production and manufacturing courses available to the acquisition workforce through the Defense Acquisition University. Furthermore, the Acquisition Deskbook (available on-line) outlines production-related key attributes that the Program Manager (PM) should look for in assessing the extent and effectiveness of his/her program's efforts in designing for producibility.

Now on pp. 74-75.

- RECOMMENDATION 2: The GAO recommended that the Secretary of Defense redefine the point for launching programs as the point at which technology development ends and product development begins. (p. 10, pp. 79-80/GAO Draft Report)

  DoD RESPONSE: CONCUR. The Engineering and Manufacturing Development (EMD) phase is currently the Department's "product launch" equivalent. We acknowledge the need to "reinvestigate" whether we are stringent and precise in enforcing that technology development ends before this point in time. The Department has taken steps and will continue the efforts toward separation of technology development and product development through Advanced Concept Technology Demonstrations (ACTD) and technology maturation programs. The Department's Cycle Time Reduction Task Force is reviewing appropriate decision points for major defense acquisition programs as part of a larger effort to investigate alternative acquisition processes aimed at reducing the time to field recapitalized assets.

Now on pp. 74-75.

- RECOMMENDATION 3: The GAO recommended that the Secretary of Defense or his designee, on individual program decisions, send the signals that create incentives for acquisition managers to identify unknowns and ameliorate their risks early in development. (p. 10, p. 80/GAO Draft Report)

DoD RESPONSE: CONCUR. As a National Performance Review Reinvention Impact Center, DoD has established Year 2000 acquisition goals for reducing program cycle time and obviating program cost growth.

MATTERS FOR CONGRESSIONAL CONSIDERATION

- SUGGESTION 1: The GAO suggested that the Congress should support the Secretary of Defense's efforts to create an environment for program success through changes to the acquisition process that provide program managers clear incentives for gaining sufficient knowledge at key points in weapon acquisition programs. (pp. 10-11, p. 80/GAO Draft Report)

Now on pp. 74-75.

DOD RESPONSE: CONCUR.

- SUGGESTION 2: The GAO suggested that the Congress could help foster the right incentives by favorably considering DoD proposals to fully fund technology development efforts as well as mitigate high risks early in product development efforts. (pp. 10-11, p. 80/GAO Draft Report)

Now on pp. 74-75.

DOD RESPONSE: CONCUR. During technology development, however, some flexibility is also absolutely critical. Full funding can potentially straitjacket the technology development process by channeling dollars to those efforts which possess strong advocacy and 'clear promise,' thus shifting money away from less glamorous activities. If the promise is not borne out, which happens often in this risky enterprise, it should be possible to easily shift funds to other activities. Full funding, alone at this stage, will produce a sunk cost mindset and limit our options. What is also needed is a stronger linkage between the warfighting and development communities. One proposal is to build upon the successes of the Advanced Concept Technology Demonstration (ACTD) program, by initiating a number of 'Demonstrations,' collaborative warfighter-developer efforts which culminate in an operational demonstration of a specific capability. The warfighter's operational assessment would determine a need to acquire. This would necessitate a shift away from the serial development of requirement and system, towards a 'convergence' phase in which user and acquirer iterate on a particular need statement and its requirement. Focused demonstrations would (1) provide a target for the S&T community to 'shoot at,' and, perhaps more importantly, (2) procure an operationally useful and technically feasible system which could, if desired, be acquired on a larger scale following a milestone decision.

- SUGGESTION 3: The GAO suggested that the Congress should carefully consider requests for additional funds to resolve problems that should have been addressed earlier in weapon acquisition programs. (pp. 10-11, p. 80/GAO Draft Report)

Now on pp. 74-75.

DOD RESPONSE: CONCUR.

Major Contributors to This Report

National Security and International Affairs Division, Washington, D.C.

Louis J. Rodrigues
Paul L. Francis
Gordon W. Lusby
Maria J. Santos

Chicago Field Office

Michael J. Sullivan
Marvin E. Bonner

Office of the General Counsel

John A. Carter

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