United States Government Accountability Office

GAO

Report to Congressional Committees

September 2006

BEST PRACTICES

Stronger Practices Needed to Improve DOD Technology Transition Processes

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GAO-06-883

September 2006

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Stronger Practices Needed to Improve DOD Technology Transition Processes

Highlights of GAO-06-883, a report to congressional committees

Why GAO Did This Study

The Department of Defense (DOD) relies on its science and technology community to develop innovative technologies for weapon systems, spending $13 billion on basic, applied, and advanced technology research. Several GAO reports have addressed problems in transitioning technologies to the acquisition community. This report, which was prepared under the Comptroller General's authority to conduct evaluations, compares DOD's technology transition processes with commercial best practices. Specifically, GAO identifies technology transition techniques used by leading companies and assesses the extent to which DOD uses the techniques.

What GAO Recommends

GAO recommends that DOD strengthen its technology transition processes by developing a gated process with criteria to support funding decisions; expanding the use of transition agreements, relationship managers, and metrics; and setting aside funding for transition activities. DOD generally agreed with GAO's recommendations with the exception of adopting process-oriented metrics and setting aside funding for transition. It cited ongoing initiatives it believes address several of the recommendations. GAO believes DOD's actions to date are incomplete and all recommendations warrant further attention.

www.gao.gov/cgi-bin/getrpt?GAO-06-883.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Michael J. Sullivan at (202) 512-4841 or sullivanm@gao.gov.

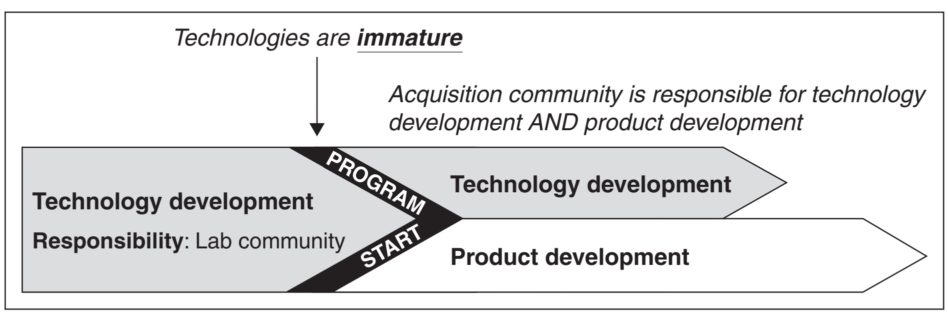
What GAO Found

Leading commercial companies use three key techniques for successfully developing and transitioning technologies, with the basic premise being that technologies must be mature before transitioning to the product line side.

- **Strategic planning at the corporate level**: Strategic planning precedes technology development so managers can gauge market needs, identify the most desirable technologies, and prioritize resources.
- **Gated management reviews**: A rigorous process is used to ensure a technology's relevancy and feasibility and enlist product line commitment to use the technologies once the labs are finished maturing them.
- **Corroborating tools**: To secure commitment, technology transition agreements solidify and document specific cost, schedule, and performance metrics labs need to meet for transition to occur. Relationship managers address transition issues within the labs and product line teams and across both communities. Meaningful metrics gauge project progress and process effectiveness.

Not only does DOD lack the breadth and depth of these techniques, the department routinely accepts high levels of technology risk at the start of major weapon acquisition programs. The acquisition community works with technologies before they are ready to be transitioned and takes on responsibility for technology development and product development concurrently, as shown in the following figure. A defined phase for technology transition is not evident. These shortcomings contribute significantly to DOD's poor cost and schedule outcomes.

Path That DOD Follows for Technology Development and Product Development



Source: DOD (data); GAO (analysis and presentation).

A stark contrast exists between DOD's and private industry's environments for developing technology. The numerous examples of DOD programs that have incurred cost overruns, schedule delays, and reduced performance serve as reminders that inserting a few best practices and changing the mechanics of technology transition processes without changing the environment that determines incentives may not produce better outcomes.

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Abbreviations

DARPA	Defense Advanced Research Projects Agency
DDRE	Director, Defense Research and Engineering
DOD	Department of Defense
RDT&E	research, development, test, and evaluation
S&T	science and technology
TRL	technology readiness level

Accountability * Integrity * Reliability
United States Government Accountability Office
Washington, DC 20548

September 14, 2006

The Honorable John W. Warner
Chairman
The Honorable Carl Levin
Ranking Minority Member
Committee on Armed Services
United States Senate

The Honorable Duncan Hunter
Chairman
The Honorable Ike Skelton
Ranking Minority Member
Committee on Armed Services
House of Representatives

The Department of Defense (DOD) relies on the technological superiority of its weapon systems and armed forces to protect U.S. interests at home and abroad. The DOD science and technology (S&T) community is tasked with ensuring that technologies are mature when DOD's acquisition community takes over and integrates the technologies into weapon systems. In fiscal year 2006, DOD plans to spend approximately $13 billion[1] in its science and technology efforts to develop technologies that are as innovative as stealth and global positioning were when they were first developed. In doing its work, the S&T community must strike a balance between meeting the short-term needs of today's warfighters and the long-term needs of future years' warfighters. Achieving this balance is made more challenging because of the need to keep pace with or exceed the pace of innovation and to counter technologies developed by potential U.S. adversaries.

Although the United States has produced the best weapons in the world, its acquisition programs often incur cost overruns, schedule delays, and performance shortfalls that undermine DOD's buying power. This dilemma is due in part to DOD's difficulty transitioning technologies from a technology development environment to an acquisition program. Because

[1]This represents the amount of money Congress authorized DOD for basic research, applied research, and advanced technology development.

the acquisition community frequently pulls technologies too early, it takes on the additional task of maturing the technologies—an activity that is the primary responsibility of technology developers—at the start of an acquisition program.[2] The start of a program ushers in a high-cost, delivery-oriented phase in which the acquisition community is supposed to be focused on integrating subsystems and working on system development and demonstration. DOD has continued to allow the acquisition community to take over this task before the S&T community considers the technologies ready for transition. Numerous GAO reports have addressed the problems of proceeding with immature technologies and have explained what leading commercial companies do to ward off such problems.[3]

This report examines DOD's technology transition processes through the prism of best practices. Specifically, our objectives are to (1) identify techniques that commercial companies use to transition mature technologies before the start of product development and (2) assess the extent to which DOD is using these techniques. We also describe how the environments at private companies and DOD differ with regard to technology development. The overall effort to hand off and integrate mature technologies is referred to in this report as technology transition. Also in this report, the private sector acquisition community is generally referred to as a product line or business unit. GAO has prepared this report under the Comptroller General's authority to conduct evaluations on his own initiative as part of a continued effort to assist Congress in overseeing DOD's technology and acquisition investments.

In conducting our work, we interviewed lab and product line managers at four leading commercial companies—Boeing, IBM, Motorola, and 3M—to identify processes for successfully transitioning mature technologies. These companies develop a variety of products such as the 787 airplane, network servers, integrated radio communications and information solutions, and fuel cell technology for cars, buses, trains, homes, and businesses. We also conducted interviews and collected pertinent

[2]GAO, *Defense Acquisitions: Assessments of Selected Major Weapon Programs.* GAO-06-391 (Washington, D.C.: March 31, 2006).

[3]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes.* GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999) and *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes* GAO-01-288 (Washington, D.C.: March 8, 2001). Other best practices reports are listed in the Related GAO Products section at the back of this report.

documents from each of DOD's military services and the Defense Advanced Research Projects Agency (DARPA), which is the central science and technology organization for DOD. We compared commercial and DOD practices to identify potential areas for improvement. Appendix I includes additional details about how we performed our review, which was conducted from June 2005 to July 2006 in accordance with generally accepted government auditing standards.

Results in Brief

Successful transition in leading companies starts with strong strategic planning followed by a structured technology development process led by research labs and supported by tools that pave the way for a smooth handoff to the product line. Strategic planning is considered a precursor to transition and allows managers to identify market needs so the company can quickly adapt its technology portfolios to meet those needs. A gated technology development process continually tests for relevancy and feasibility of technologies and gauges the commitment of product line managers to accept them. Once a technology is ready to transition, management and funding responsibilities gradually shift from the lab to the product line. By the end of transition, but before product development starts, the technology is validated as mature enough for use in the intended product. Companies highlighted three tools to facilitate transition: technology transition agreements, relationship managers, and metrics. The agreements put in writing the technology and business-related expectations, such as specific cost, schedule, and performance characteristics that labs must demonstrate. The agreements also may require documenting manufacturing costs or specifying whether certain lab scientists will be loaned to the product line to provide continuity in technical knowledge. Relationship managers communicate across the labs and product lines to address transition issues. Last, metrics gauge the effectiveness of the technologies and the process itself. These tools require the active involvement of the labs and product lines to ensure successful transition of technologies to new products.

Over the past several years, DOD has taken steps to improve its transition processes, but it lacks many of the techniques that are hallmarks of leading companies' ability to transition technology smoothly onto new products. From a strategic perspective, the department lacks strong influence at the corporate level to guide the department's technology investments. In addition, DOD does not use a gated process with criteria that would allow lab and program managers to know when a technology is ready to transition. Consequently, technologies are often not ready when needed and acquisition programs pull the technologies into their programs too early, leading to inefficiency during product development and cost and schedule increases. We found that DOD has taken some positive steps to aid technology transition. They hold promise, but must be accepted, improved, and replicated significantly more than currently to have a positive impact. For example, each of the military services has established boards to select and oversee some of their technology projects and has elevated the importance of meaningful metrics. They are also using technology transition agreements. However, use of these agreements thus far has been low. With regard to improving communication, DARPA is using relationship managers to address transition issues. And the Office of the Secretary of Defense has initiated a number of new programs, including the Joint Capability Technology Demonstration program, which requires the S&T and acquisition communities to work more collaboratively earlier in the acquisition process.

The environment and incentives of private world-class companies differ dramatically from DOD's. Despite these differences, the practices used by commercial companies can help DOD make better progress in transitioning technologies to weapon programs. Private companies operate in a competitive environment that demands speedy delivery of innovative, high-quality products to satisfy market needs or the company will go out of business. DOD has a variety of "customers" and complex relationships that often hinder the chief technology officer at the corporate level from providing the type of strategic leadership found at successful companies. DOD puts pressure on itself to develop many new technologies. And because competition for funding is fierce, the technologies described with many superlatives for speed and lethality tend to get more attention than others do. We previously reported that to secure funding, DOD program managers frequently make overly optimistic promises to the warfighter about technologies' cost, feasibility, risk, and delivery schedule.[4] The challenge for DOD and congressional decision makers lies not only in the "how to" aspects of technology transition but also in creating stronger and more uniform incentives that encourage the S&T and acquisition communities to work together to deliver mature technologies to programs.

We are making recommendations that DOD strengthen its technology development and transition processes by developing a gated process that

[4]GAO, *Best Practices: Better Support of Weapon System Program Managers Needed to Improve Outcomes*. GAO-06-110 (Washington, D.C.: Nov. 1, 2005).

includes a transition phase and identifies criteria that can be used to support funding decisions. In addition, we are recommending that DOD expand the use of transition agreements, relationship managers, and metrics. We also recommend that DOD set aside a portion of research and development (advanced component development and prototypes) funds for the S&T community to manage the transition of technologies to acquisition programs.

DOD concurred with our recommendations to develop a gated process for developing and transitioning technology and to expand the use of technology transition agreements, although we do not see its plans as fully responsive. DOD partially concurred with the recommendation to include additional metrics in technology transition agreements, stating that it recently developed metrics to gauge manufacturing readiness and that other metrics should be applied on a project-by-project basis. DOD also partially concurred with expanding the use of relationship managers, stating it already uses written documents to facilitate communication. However, DOD agreed that more time should be devoted by staff at the execution level on transition activities. We continue to believe that additional person-to-person communication needs to take place at all levels within the S&T and acquisition communities to supplement the written agreements. DOD did not concur with our recommendation to adopt more process oriented metrics because it believes that other processes it plans to mature over the next 4-5 years will capture these metrics. We believe the metrics DOD wants to use will not allow the department to analyze its investment portfolio and make adjustments appropriately. Finally, DOD did not agree with our recommendation to set aside a portion of its 6.4 budget activity funding, known as advanced component development and prototypes funds, for the S&T community to manage for the transition of technology. DOD does not believe the S&T community should have additional resources to mature technologies to the point of successful transition to programs. We found otherwise in the commercial world and believe DOD's approach to funding technology development and transition is flawed.

Background

Mature technologies are pivotal in developing new products. Without mature technologies at the outset, a product development program will almost certainly incur cost and schedule problems. Effectively managing technology as a separate process from product development can improve the potential for on-time product delivery at reduced cost. Leading companies know this and have established disciplined processes to prioritize their technology investments based on market needs, eliminate technologies that are not relevant or feasible, balance technology push and customer pull, and then transition technologies to product development efficiently. Overall, effective management of technology facilitates the delivery of new, innovative products to the user in less time. While DOD is very aware of the need for new advanced technology in its weapon systems, it has not always been effective in transitioning mature and relevant technologies to product development.

Development of DOD's new weapon systems depends on two distinct phases: technology development and product development. DOD relies on its S&T community to identify, pursue, and develop new technologies that improve and enhance military operations and ensure technological superiority over adversaries. This includes the development of technologies for new weapons programs as well as those that will be inserted into existing systems. The acquisition community takes these new technologies, develops weapon system programs, and delivers the products—that is, the weapon systems—to the warfighter. Table 1 shows technology-related activities that take place during technology development and product development, who performs the work, fiscal year 2006 funding, and overall goals.

Table 1: DOD's Two Development Phases with Technology-Related Activities

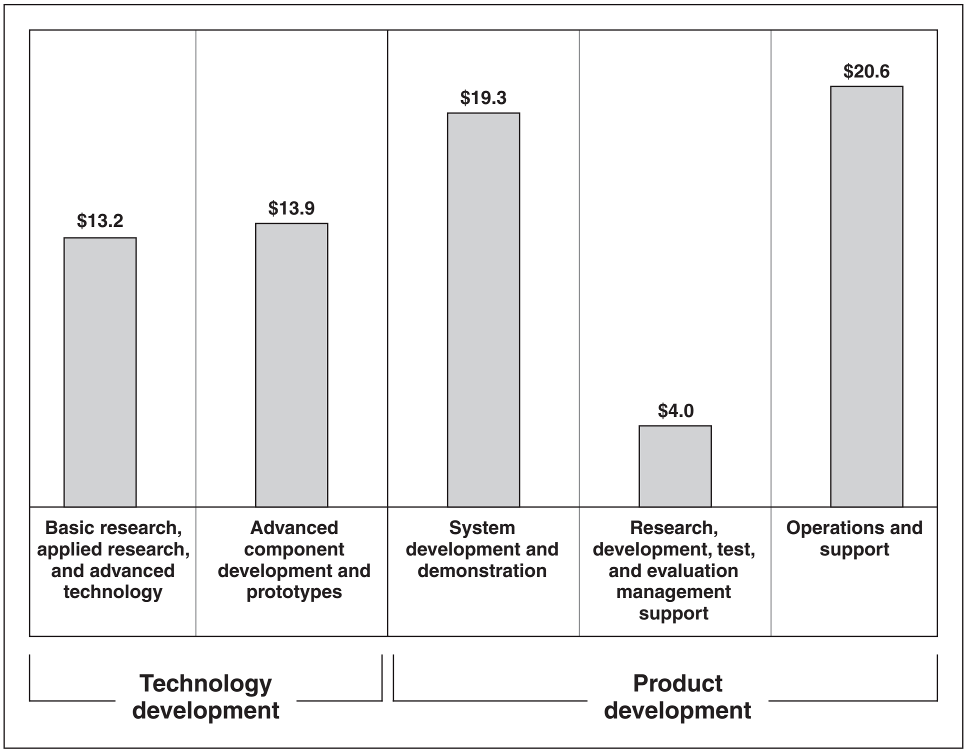
Technology development phase	Product development phase
Activities: identify, fund, develop, and manage new technology projects that warfighter needs	Activities: integrate, demonstrate, support, and upgrade technologies on weapon systems
Who does the work: government, industry, and academic technologists	Who does the work: prime developer, industry supplier, and acquisition community's development lab engineers
2006 funding: about $13 billion	2006 funding: about $58 billion
Goal: demonstrate a technology or subsystem in a relevant environment	Goal: develop and deliver weapon systems to the warfighter

Source: DOD (data); GAO (presentation and analysis).

Note: Activities listed under the product development phase focus solely on technology maturation and do not include other activities that the acquisition community is responsible for, such as overall design and manufacturing.

DOD uses research, development, test, and evaluation appropriations to fund its technology activities. The budget is divided into categories that generally follow a sequential path for developing technologies. Figure 1 shows the amount of money DOD spends in each category. (App. III contains additional details about the budget.)

Figure 1: Fiscal Year 2006 Categories for DOD Research, Development, Test, and Evaluation Budget (dollars in billions)



Source: DOD (data); GAO (analysis and presentation).

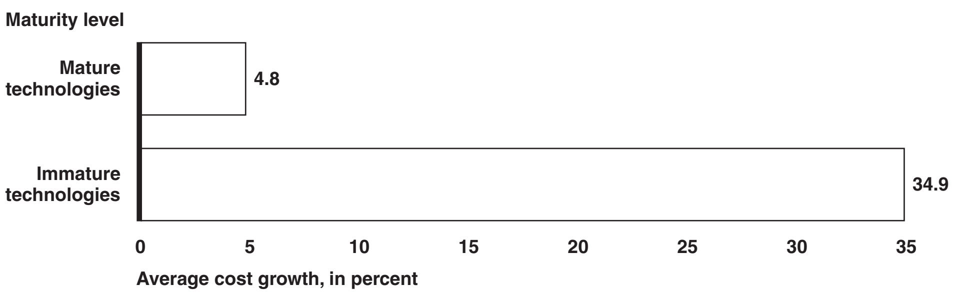
The S&T community controls the budget for basic research, applied research, and advanced technology development. The budget category of advanced component development and prototypes involves testing and evaluating prototypes of systems or subsystems in a high-fidelity or realistic environment before product development starts. DOD officials say it is assumed that either the S&T community or the acquisition community could carry out this work, but traditionally the acquisition side prevails. After this point, additional technology-related activities are completed as part of product development under the authority of the acquisition community, namely, the program manager for a weapon system.

Prior GAO reports have said that DOD launches new weapon programs with immature technology. We found this inability to mature the technology before the start of product development to be a major contributor to weapon system cost and schedule growth. In our March

2006 review of 52 major DOD weapon programs, we found that 90 percent of the programs started with immature technologies[5]. More than half of the programs were working with immature technologies at design review, when DOD acquisition policy expects the design to be stable. And by the time production began, one-third of programs still did not have mature technologies.

Not surprisingly, we found that DOD research, development, test, and evaluation cost estimates increased dramatically for programs having immature technologies at program start. Figure 2 shows the average cost growth of DOD programs we reviewed when technologies were mature and immature at program start.

Figure 2: Average Program Research, Development, Test, and Evaluation Cost Growth from First Full Estimate (sample of 52 DOD weapon programs)



Source: DOD (data as of March 2006); GAO (analysis and presentation).

Programs that started with mature technologies have averaged a modest 4.8 percent cost growth above the first full estimate, whereas programs that started with immature technologies have averaged about 35 percent cost growth. Some programs experienced significantly greater cost growth. A consequence of this cost growth is that the services typically deliver weapon systems late, have to reduce quantities to stay within cost estimates, shift funds away from other projects to make up for added costs, or some combination of the three. For example, the Air Force has incurred a 189 percent growth in the cost per aircraft for its F/A-22 tactical aircraft program, in large part because of technology maturation issues. In response, the Air Force has reduced the quantity of F/A-22 aircraft it plans to procure by 72 percent from 648 to 183 to offset escalating costs. In the case of the Space-Based Infrared System High satellite, technology and

[5] GAO-06-391

design components matured late in development, contributing to research, development, test, and evaluation cost growth and four Nunn-McCurdy unit cost breaches[6]. Instead of purchasing five satellites, the Air Force now plans to buy three at a program acquisition unit cost of about $3.4 billion, a 315 percent increase.

Leading Companies Rely on Strategic Planning, a Gated Process, and Tools to Transition Needed Technologies

To successfully develop and transition technologies from their labs to their product lines, leading commercial companies depend on three key techniques:

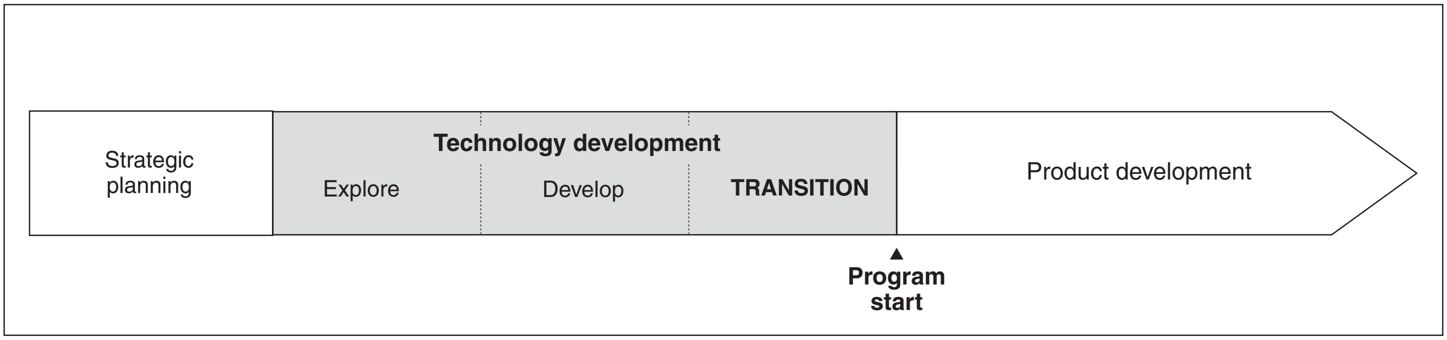
- strategic planning at the corporate level;
- a gated management review process that ensures a technology's relevancy, feasibility, and transition readiness; and
- effective tools to solidify commitment, address transition issues, and gauge project progress and process effectiveness.

Overall, corporations are incentivized to follow these critical techniques because the opportunity cost of not meeting customer demand is late delivery and lost revenues and market share for the company. Through rigorous adherence to these practices, leading companies increase chances of eventual success because the strategy for developing the technology fits the company's objectives, commitment is strong for incorporating the technology, and only after the technology is considered mature enough for use in a certain product does product development begin. Because the cost of developing new and breakthrough technologies can be high, funding typically comes from the corporate level rather than from a single product line unit, enabling the company's product lines to manage only product development risk, not technology risk as well.

The central focus of this report is on how the lab and the product line communities work together to solidify the final steps of technology transition. Figure 3 depicts the general flow of technology development and where technology transition resides in the process.

[6] 10 U.S.C § 2433 establishes the requirement for unit cost reports if certain thresholds for program costs are exceeded (known as unit cost or Nunn-McCurdy breaches). DOD is required to report to Congress and, if applicable, certify the program to Congress.

Figure 3: General Flow of Process Leading Up to Technology Transition



Source: GAO analysis and presentation of leading companies' practices.

This report touches briefly on strategic planning, which precedes technology development. As the lab community identifies and develops high-priority technologies during the technology development phase, product line managers develop the business case for a new product by identifying the market potential of the new product and using systems engineering to set product requirements. This report does not focus on these product line activities or on product development.[7]

Strategic Planning Is a Critical Precursor to Successful Transition

Strategic planning—the effort to identify desirable technologies and prioritize resources—is an important early step in a company's ability to eventually deliver the highest-priority technologies to various product lines. Leading companies organize their research and development activities into technological "thrusts", or competencies that represent the core markets of their businesses. 3M and the other companies we visited undergo strategic planning at least annually, and this process enables corporate management to conduct portfolio analysis, identify long-term market needs, and match the projects in each thrust area to market needs. Eventually, managers determine which projects appear to be relevant and feasible, which ones are applicable for which products, whether the right projects are getting the right resources, whether the company wants to be first to market, and whether the final products should be released to the marketplace as soon as possible or several years down the road. Managers may decide to establish new thrust areas as new ideas come to light, rely on outside suppliers for some technology, or hire new people to fill

[7]Numerous GAO reports address issues surrounding product development. See Related GAO Products at the end of this report.

technology voids. Projects that no longer are relevant or feasible are eventually terminated. This type of strategic planning is critical to ensuring that the right technologies ultimately transition to the right product line in an economical and timely way.

Each company we visited funds technology differently, however, all ensure that funding for early technology projects is protected at the corporate level and not immediately beholden to product lines. 3M, for example, has 17 technological thrust areas, and the projects are directly funded with seed money from the corporate level. IBM receives the majority of its funding from the corporate level. IBM labs also receive and manage funding from product lines for specific projects. Both Motorola and Boeing require business units to fund a portion of lab costs each year based on their historical usage of lab resources, but the labs have freedom to use those funds in line with corporate strategy. Decisions are made at least annually on the composition of projects in the portfolio so it includes the most relevant and feasible projects.

Leading Companies Use Gated Reviews to Validate Readiness for Technology Transition

After technology projects are selected for funding, they enter the development "pipeline" where a gated process is used to manage and oversee technology exploration, development, and transition. At each gated review, lab managers assess technology progress and ensure that certain criteria are met before technologies can enter the next stage of development. The final phase is dedicated to technology transition activities. The number and names of the gates vary by company, but the type of information collected and knowledge obtained are similar. For example, 3M uses a three-gate process, Boeing has a four-gate process, and Motorola has a five-gate process. Regardless of where the funds came from—a corporate or a product line unit—labs are responsible for managing, overseeing, and using the money to fund technology projects until the projects have transitioned to a product line. Figure 4 generally depicts the technology development gates that companies use, lists types of deliverables expected during each gate, and shows who provides funding.

Figure 4: Generalized Depiction of Deliverables and Funding under Gated Process

TECHNOLOGY DEVELOPMENT GATES		
Explore Technology ideas and concepts are being explored	**Develop** Technology development activities are underway	**Technology transition** Technology is ready to transition from lab to product line team
Review ▲	*Review* ▲	
Deliverables • Technology is consistent with overall business strategy • Technology is promising and is likely to meet needs for potential product lines • Lab identifies potential products where technology can be used • Key cost, benefit, risk, marketing, manufacturing, and life cycle management issues are identified • Scalability approaches are identified • Technologies considered to be intellectual property are identified	**Deliverables** • Technology is consistent with technology strategy and other relevant strategies • Labs have high degree of confidence the technology will work • Product line team agrees that the technology will meet its needs • Technical requirements are identified • Cost, benefits, and risks are quantified • Scalability approach is selected • Strategies for addressing intellectual property rights are selected	**Deliverables** • Technology project complies with technology strategy • Technology is sound • Technology meets product requirements • Cost, benefit, and risks are well understood • Technology can be scaled to a magnitude appropriate for practical application • Product line team agrees technology is ready • Intellectual property rights methods have been pursued • Technology is demonstrated in an operational environment • Technical documentation is ready to be given to product line team
Funding • Corporate management funds projects that are relevant for meeting specific product line needs and projects that lab managers believe are necessary for the company to meet future market needs	**Funding** • Corporate management funds projects that are relevant and feasible; in some cases, product lines may provide matching funds for labs to develop specific technologies	**Funding** • Corporate management funds activities related to technology transition, including developing a prototype that is demonstrated in an operational environment; in some cases, product lines may provide matching funds

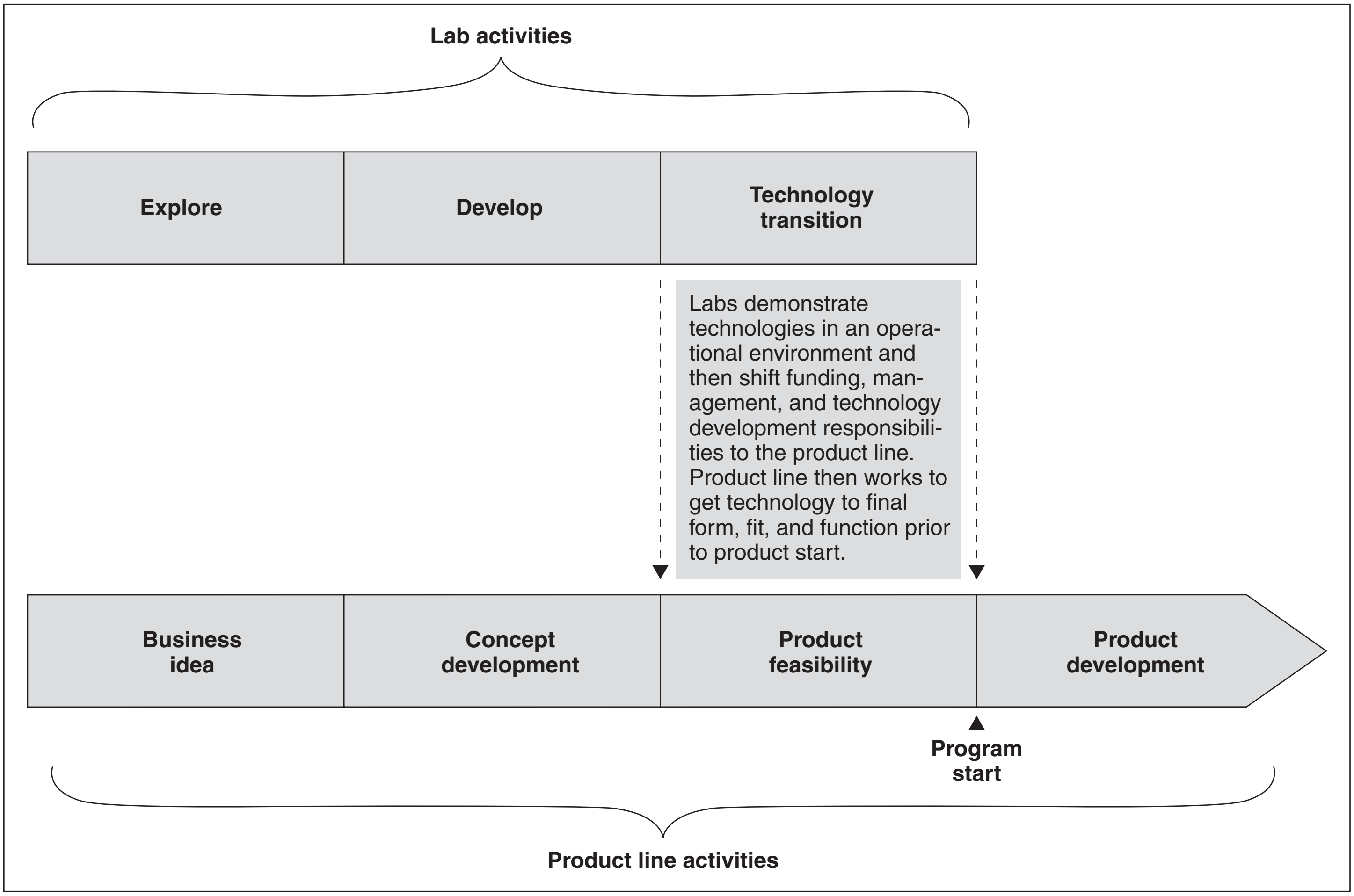
Source: GAO analysis based on Boeing Commercial Airplanes, Motorola, and 3M processes.

Explore gate: Lab technologists turn technology proposals into viable, executable projects that ideally will meet future market needs, while lab managers determine the amount of resources they need to invest in the projects. Funding goes to projects that are deemed relevant. Prior to the gated review, technologists deliver to lab managers a preliminary assessment of the competitiveness of the technology and a road map for completion. Technologists must address key deliverables related to such areas as manufacturing, intellectual property, marketing, life cycle management, and plans for the next gate.

Develop gate: Technologists develop prototypes of the project and measure performance for relevancy and feasibility on an eventual product. Technologists deepen their understanding of the technology, refine the technology solution, identify the most attractive market segments for introducing the technology, and select a product line that will incorporate the technology into a new product. 3M and Motorola require product line commitment to transition a technology before the gated review draws near. This prevents labs from wasting valuable time and resources developing technologies that product lines do not want. Projects that do not gain product line commitment will either be terminated or go through a different process to demonstrate their relevancy and feasibility. Motorola leadership, for example, has a special program called an early stage accelerator under which selected projects can obtain funds to build additional prototypes to demonstrate the value of technology to product line managers or potential customers. Senior lab managers carefully monitor these projects through quarterly reviews to determine how they are progressing. If the project is not making sufficient progress, the project is quickly terminated so resources can be spent on other projects.

Transition gate: Technologists demonstrate a prototype in an operational environment. The product line maintains a “customer” role until managers are confident that the technology will work in the intended product. Then gradually, the responsibility for funding and further developing the technology shifts from the lab to the product line. This shift in responsibility requires up-front and continuous planning by both the lab and product line communities to ensure a smooth transition. As shown in figure 5, companies we visited plan for technology transition to occur prior to program start. This provides product line managers sufficient time to gain additional knowledge about a technology’s attributes as they are maturing it to its final form, fit, and function. Product line managers, who concurrently have been working on the business case for the product, are able to validate that the technology can be integrated into the preliminary product design. In addition, they can develop more reliable product development cost and revenue estimates before they are locked into needing this technology as a product feature.

Figure 5: Linkage between Technology Development and Product Development



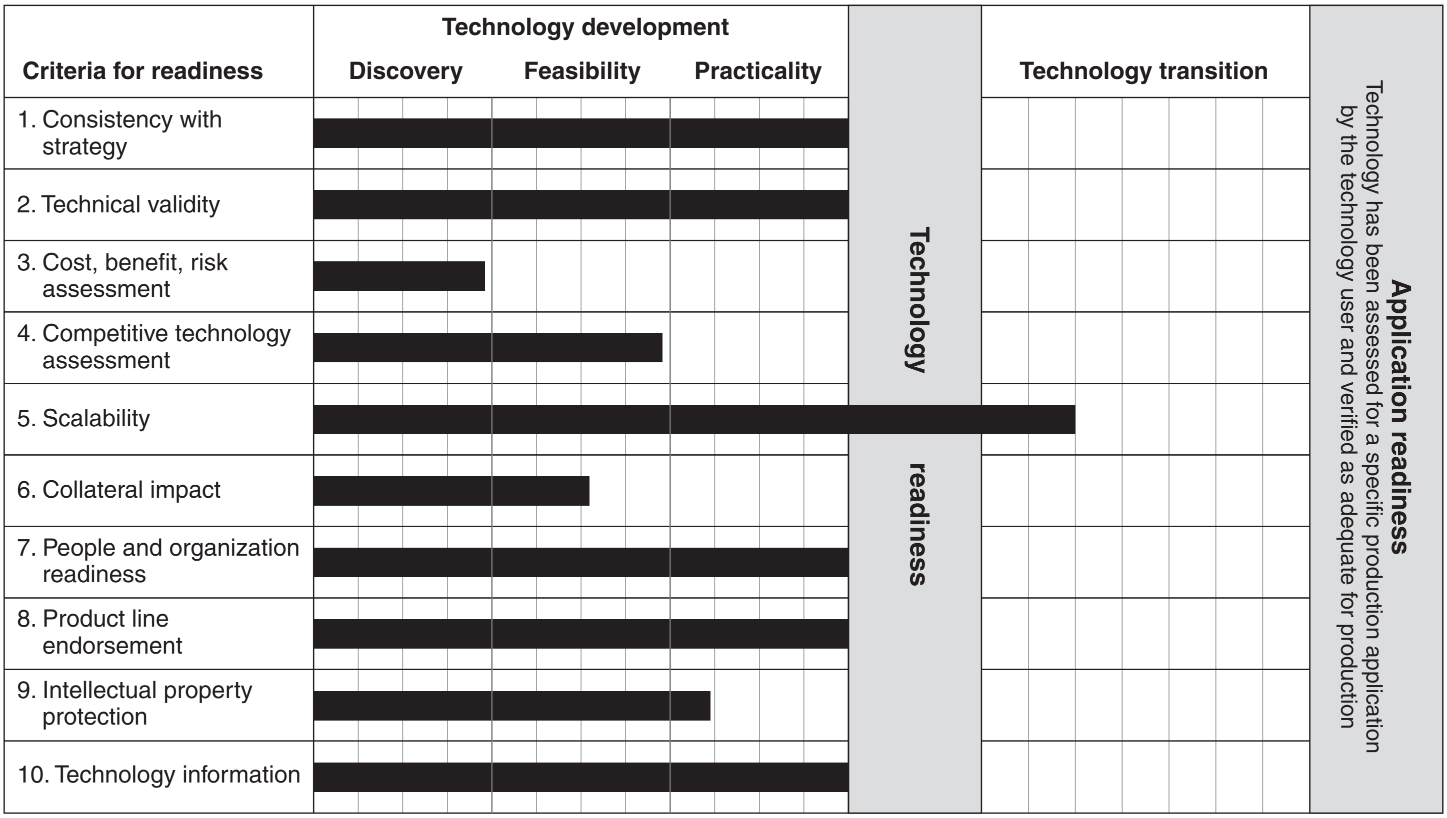
Source: GAO analysis based on leading companies' processes.

During the transition phase, labs and product lines must complete a number of activities for transition to go smoothly. For example, labs must demonstrate that the technology meets product line cost, schedule, and performance requirements. In addition, production costs must be identified and acceptable to the product line. According to 3M officials, past experience has shown that costly manufacturing is a major reason for product line managers deciding not to transition a technology. Labs must also address intellectual property concerns, a step that is crucial to the company's ability to be a market leader. Product lines must address any people or organizational issues, such as the transition of jobs and training requirements that may result from using the new technology. They must also work out any agreements with the labs for on-going support. At the end of the phase, technical documentation related to the technology is transitioned from the labs to the product line.

Boeing Commercial Airplanes[8] assesses the extent to which these activities, as well as others, have been completed to determine whether a particular technology is ready to transition. The information is then summarized on a scorecard that lab and product line managers can use to quickly identify areas that need additional attention. The scorecard is updated continually and measures a technology's readiness from a business and production standpoint as well as its technological readiness. Boeing's labs have three phases for technology development, which they call discovery, feasibility, and practicality, plus a technology transition phase. Each technology is evaluated in 10 readiness categories, and bars are plotted horizontally across the scorecard to indicate how much objective evidence exists for technology readiness. Once a technology has demonstrated full readiness in all 10 categories, it is ready to be transitioned. Figure 6 shows a notional picture of a technology's readiness at one point in time. Because the hypothetical technology has reached full readiness in only five categories and is halfway through transition in one category, the technology is not ready for transition. The lab and product line would have to address issues involving readiness categories 3, 4, 6 and 9 before transition can begin or the technology is in jeopardy of not being applied to a product.

[8]Boeing has two primary businesses: Boeing Commercial Airplanes and Boeing Integrated Defense systems. Both businesses are supported by the same science and technology lab. However, the two businesses have different tools for transitioning technology.

Figure 6: Notional Boeing Technology Maturity Scorecard for a Hypothetical Technology



Source: GAO analysis based on The Boeing Company's scorecard.

Technology Transition Is Bolstered by Formal Agreements, Relationship Managers, and Metrics

Companies we visited use three tools to aid transition, including technology transition agreements, relationship managers, and metrics. Technology transition agreements are formal documents that detail the specific cost, schedule, and performance attributes of the technology that labs must demonstrate before transition can occur. Relationship managers address the details and issues surrounding transition, and metrics allow managers to identify the effectiveness of their technology development and transition processes and make adjustments when necessary. These tools require the active involvement of the labs and product lines to ensure successful transition of technologies to new products.

Technology Transition Agreements

Labs and product lines use technology transition agreements to facilitate each technology's transition to product development. What the agreements specify varies by company but typically consists of specific technology and business readiness metrics, such as cost, schedule, and performance characteristics that labs must demonstrate for product line managers to agree to accept the technology. As figure 7 shows, the agreements should answer some basic questions.

Figure 7: Questions That Should Be Answered in Technology Transition Agreements

- Is it real?
- Is it relevant?
- Is it marketable?
- Where will it transition?
- Do we have product line support?

Source: GAO.

These formal agreements may also include identification of product line resources needed to transition the technology, such as nonrecurring costs to further mature the technology, as well as consideration of recurring manufacturing costs associated with integrating the new technology on the product. Metrics collected in the agreements are used by product line managers to manage technology risk. For example, if the labs cannot develop needed technology within cost and schedule parameters or with specified performance characteristics, the product lines can terminate the agreement and go with an alternative technology.

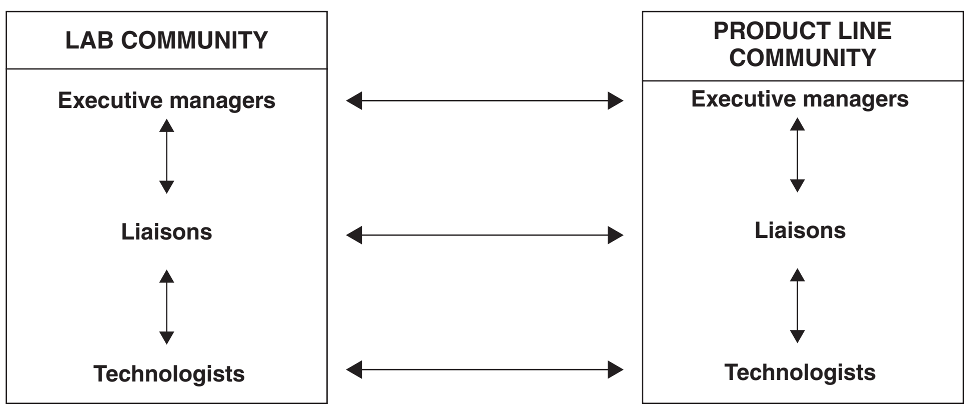
At Motorola, agreements enable technology project leaders to customize their work for a particular product line's needs. Product lines may request that the labs identify alternative technologies for a particular product, produce a detailed report about a specific technology, or conduct various tests to demonstrate the relevancy or feasibility of a technology. Each of these items becomes a "deliverable" in the agreement. 3M uses transition agreements only for technologies that are expected to go into a product. 3M's agreements incorporate many of the same metrics used by Motorola, including feasibility, relevancy, and application of the technology. In addition, agreements include an assessment of the product line's ability and commitment to transition technology. For example, they evaluate a product line's resource constraints that could inhibit a technology from transitioning, such as asking if the technology is too expensive or if manufacturing it would be too costly. 3M officials told us that some agreements include loaning key lab technologists to the product line for a period of time so product line teams can maintain momentum after the lab has signed off and moved on to developing technology for other parts of the company.

Relationship Managers

3M, IBM, and Motorola use lab and product line relationship managers to smooth transition. Relationship managers foster effective transition practices by preventing the labs from pushing technologies that product line managers do not want and by preventing product line managers from pulling immature technologies from the labs. A Motorola official referred to relationship managers as the most important communication tool because communication occurs more frequently, thus allowing problems to be identified and addressed more quickly.

Motorola designates key people at three different levels in both the labs and the product line to serve as relationship managers. As a technology is matured and demonstrated, communication intensifies and additional levels of relationship managers become involved. Figure 8 depicts how Motorola's relationship managers communicate with each other within the lab or product line and with their designated counterparts in the other community.

Figure 8: Communication Flow for Motorola's Three Levels of Relationship Managers



Source: Motorola; GAO (analysis and presentation).

Executive managers in Motorola's labs and product lines are responsible for interfacing with each other on a periodic basis. Altogether, Motorola has eight executive managers—four in the labs and four on the product line side. Motorola officials told us that this number provides a one-to-one match between the labs and the product lines. Lab executive managers are responsible for ensuring product line needs are identified and new technology projects are started or existing projects are reprioritized to meet those needs. Their counterparts have the final word on what priority each technology project has with respect to the needs of the product line. Lab and product line executive managers are required to sign off on key technology projects and milestones for the current year. In addition, they try to remove any roadblocks within their own units and work with their counterparts to address any roadblocks between the two communities.

Motorola considers liaisons the most critical in the process. Again, there are four liaisons in the labs and four on the product line side. They are the primary interface for coordination, collaboration, and communication during technology development and transition. Liaisons in the lab have broad oversight of technologies being developed and share information about technology breakthroughs with their counterparts on the product line side, and remove roadblocks for lab technologists. These lab liaisons work intimately with their product line counterparts to approve technology transition agreements and assess technology readiness. The lab liaisons oversee 40 to 60 technology transition agreements at any one time. Liaisons on the product line side are responsible for providing information about the changing needs of the product lines on a more real-time basis. They determine product line needs and priorities during the annual planning process and remove roadblocks for technologists on the product line side. Lab and product line liaisons are incentivized through their annual performance assessments and pay increases to work together to ensure the successful transition of technologies.

The most direct and constant communication is between the lab's technologist, who developed the technology, and the product line's technologist, who is responsible for maturing the technology for inclusion into the product. These two technologists stay in continuous contact because they are the ones who have the most working knowledge about the technology. The lab technologist is expected to spend as much time as needed to make sure that transition happens as smoothly as possible. While the lab technologist does not become an official asset of a product line, he or she might have to spend a period of time working in the product line's development lab.

Metrics

Leading companies use product metrics—such as weight, power, and reliability measurements—to assess the readiness of transitioning technologies and process metrics—such as profit growth and cycle time—to gauge the impact of their technology development processes and identify areas for improvement. The companies analyze data gained from the use of these metrics to evaluate how well they deliver on what is promised, better understand the value of their respective science and technology activities, and identify cases of inefficient investment in technologies or underutilization of lab technologies. Table 2 provides a composite example of metrics used at the companies we visited and the value of the metrics to management.

Table 2: Metrics Used by Leading Companies to Assess Lab Projects and Processes

Categories of metrics	Examples of metrics	Use of the metrics
Project		
Technology-specific	Nonrecurring development costs Scheduled delivery Recurring manufacturing costs Performance characteristics • Size • Weight • Power • Reliability Head count	Allows lab and product line managers to assess the status of technology development and whether the technology meets the needs of the product. If technologies do not meet agreed-upon goals, the technology project may be terminated or the product line manager may decide to include it on a future product.
Process		
Status	Number of ongoing projects Number of projects with a technology transition agreement Number of projects completed by labs Number of technologies transitioned Number of projects terminated	Provides lab managers information on how many technology projects transitioned, were terminated, and are still ongoing. Companies expect that almost all technologies that make it to the final stages of technology development will transition. If they experience a lower transition rate than expected, officials will examine their processes to determine what changes are necessary to improve transition or determine why the project was not terminated earlier.
Timeliness	Development cycle time Percentage of tasks on time Task slippage Time to market	Measures the amount of time it takes labs to develop technologies. The metrics allow lab managers to identify and focus on projects that are moving slower than expected. A lab project may be terminated or additional resources may be allocated to speed up development. Use of the metrics allows product line managers to decide whether a technology will be ready in time to include on a given product.
Impact	Number of technologies commercialized Number of multiple transitions Return on investment Profit growth Market share growth Orders captured Cost reduction Number of patents/influential papers Customer satisfaction People rotation	Provides lab and corporate managers feedback on the market impact of their technology investments in terms of revenue and market share. The metrics also provide information on product line satisfaction of lab performance. Satisfaction survey results are a useful tool for identifying development and transition problem areas that need management attention.

Source: Interviews with leading companies (data); GAO (presentation and analysis).

Motorola's labs use a suite of metrics, many of which are shown above, to monitor technology projects and lab performance. For example, the company tracks the estimated and actual development time and costs for each project to determine estimation accuracy. In addition, it identifies and tracks the number of lab and product line people (headcount) needed for development and transition. These metrics are not treated with the same rigor as metrics that are used after product development begins. Corporate managers understand that technology development must be managed with more latitude to accommodate calculated risk taking. In addition, Motorola asks each product line to fill out satisfaction surveys twice a year to assess lab performance. Because relationships are at the heart of the process, the product line's perceptions are of paramount importance, making internal customer satisfaction a key metric. A Motorola official indicated that satisfaction surveys are a ubiquitous part of the Motorola culture. Not only do they help the labs improve, but they help the company improve overall, the official said. The surveys also provide compelling anecdotal information about performance problems that need to be addressed by certain labs.

In addition to technology-specific metrics, Boeing tracks the number of technologies that were actually integrated into products. While the intent is that all completed technologies will make it into a product, this does not always happen because of changes in market requirements, timing, or funding constraints. Boeing also has metrics that assess the technology's impact on orders for new airplanes and on its ability to reduce manufacturing costs. The labs, for example, have a responsibility for improving the way Boeing designs and builds its products. As such, they have goals for reducing recurring and nonrecurring costs and cycle time. Finally, Boeing uses a metric that encourages the transfer of people, along with the technologies, to the product line side. The company tracks the rotation of people from its labs to its product lines specifically to improve its transition processes and to refresh staff with "program people." As a result, company officials believe they can better align their labs to their product lines strategies.

Company officials also told us that, similar to DOD, they have struggled to assess return on investment for technologies they develop. This is because technology can undergo a metamorphosis after it leaves the labs and can be applied to multiple products or altered before going into the intended product. Company officials said they are actively trying to track technology utilization and the impact their technology investments have had on company revenues. 3M has a technology database it uses to track each project it funds. The database contains cost, schedule, and performance data and summarizes other information, such as how long a project took to complete and lab and product line funding used to mature the technology. 3M then compares the cost information with worldwide sales, tracked through bar codes, to determine its return on investment for a particular technology. Company officials indicated that there are still problems with this methodology for estimating return on investment and that they are continuing to refine their approach.

DOD Lacks Breadth and Depth of Techniques That Leading Companies Use to Effectively Transition Technologies

DOD has taken some steps over the past few years to improve its technology transition processes, but the practice of accepting high levels of technology risk at the start of major weapon system acquisition programs continues to be the norm. This shortcoming is a major contributor to DOD's poor cost and schedule outcomes. Many of DOD's problems can be attributed to deficiencies in strategic planning for critical technologies, processes for technology development and transition, and tools that support transition. A recent Defense Science Board report states that DOD is not as well positioned as it should be from a strategic standpoint to meet the challenges and exploit the opportunities offered by technology. The report identified several opportunities for improvement at the Director, Defense Research and Engineering level (DDRE)[9] to help the department jointly identify, prioritize, develop, and deliver the technologies most relevant and critical to meeting weapon system requirements in a timely manner. DOD's technology development process is undisciplined and lacks criteria for maintaining a close connection between fledgling technologies and the products that will need them to meet the warfighter's future needs. As a result, technologies are often not ready when they are needed, and acquisition programs pull the technologies into their programs too early, leading to inefficiency during product development and cost and schedule increases. DOD's process for transitioning technologies to product development is funded and managed by its acquisition community, the opposite approach to that taken by the companies we visited.

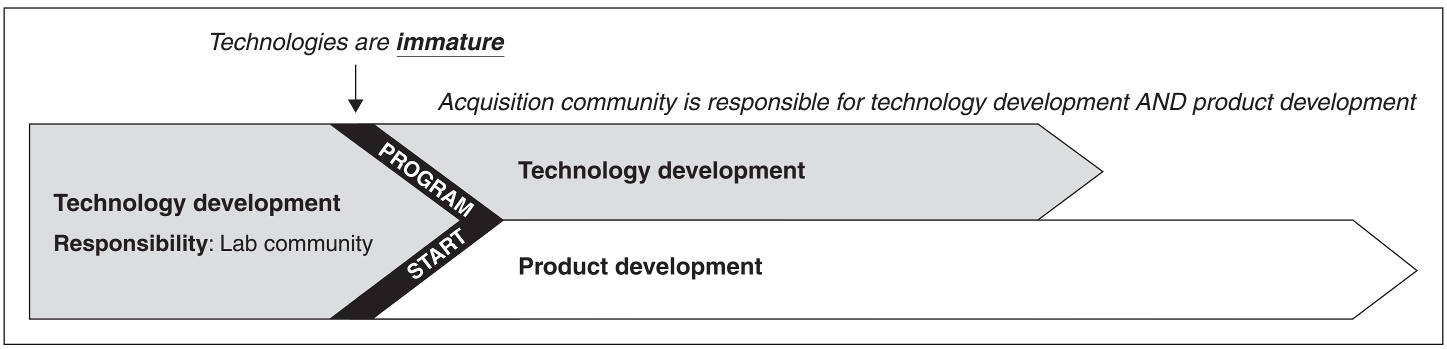
We identified some initiatives within DOD's S&T community that emulate some of the tools we found in the commercial world. They hold promise, but must be accepted, improved, and replicated significantly more than currently to have a positive impact. For example, the military services are using technology transition agreements and have established boards to select and oversee some of its technology portfolio. Also, DARPA uses

[9]DDRE is the principal staff adviser to the Under Secretary of Defense for Acquisition, Technology, and Logistics and the Secretary and Deputy Secretary of Defense for research and engineering matters. DDRE serves as the chief technology officer for the department.

relationship managers to expedite the efficient transition of technologies to products and DOD has established other programs that institutionalize some best practices. The collection and use of meaningful metrics, however, remain a problem.

On the basis of our previous review of 52 major weapons programs, we found that DOD's typical path involves starting programs with immature technologies and concurrently working on technology development and product development. Figure 9 is a depiction of this path.

Figure 9: Path that DOD Routinely Follows for Technology Development and Product Development



Source: DOD (data); GAO (analysis and presentation).

Strategic Planning Affects DOD's Ability to Meet Warfighters' Needs

DOD has an annual strategic planning process that involves the development of several plans at the corporate level and within the services and defense agencies for determining how to invest its S&T funding, which amounted to about $13 billion in fiscal year 2006. Despite these efforts, a recent Defense Science Board report[10] stated that DOD is not as well positioned as it should be at the DDRE level (the corporate level) to meet the challenges and exploit the opportunities offered by technology. The report identified several opportunities for improvement. Until improvements are made, it is likely that the there will be strategic gaps and overlaps in technology coverage as the services and agencies develop their own approaches to meet critical warfighter needs.

[10]DOD. *Defense Science Board Task Force on The Roles and Authorities of the Director of Defense Research and Engineering*, (Washington, D.C.: Oct. 28, 2005).

Similar to private industry, the department goes through an annual strategic planning process led by its corporate level. As part of its responsibilities, DDRE develops the Defense Science and Technology Strategy, which serves as the foundation for DOD's science and technology strategic planning process. The strategy identifies five generic technology thrust areas—information assurance, battlespace awareness, force protection, reduced cost of ownership, and maintaining basic research—that have high priority in the department, and is supported by four other documents, including the

- Basic Research Plan, which presents the DOD objectives and investment strategy for DOD-sponsored basic research performed by universities, industry, and service laboratories;
- Defense Technology Area Plan, which presents the DOD objectives and the strategies for applied research and advanced technology development investments;
- Joint Warfighting Science and Technology Plan, which takes a joint perspective across the applied research and advanced technology development plans to ensure that the science and technology program supports priority future joint warfighting capabilities; and
- Defense Technology Objectives, which identify specific technology advancements that will be developed or demonstrated, the anticipated date of availability, and specific expected benefits.

Together, these documents, as well as the supporting S&T plans of the military services and defense agencies, are supposed to provide the framework for decisionmaking throughout the science and technology community.

However, a recent Defense Science Board report states over time there has been a relative decline in the influence of DDRE at the corporate level on strategic matters. In the 1960s and 1970s, the corporate level was more proactive and provided high-level direction that drove several decisive technological developments, including stealth; standoff precision strike; and tactical intelligence, surveillance, and reconnaissance systems that have transformed U.S. military capabilities. Since the 1980's DDRE has used a decentralized management approach, relying on the services and agencies to determine and prioritize the most needed technology projects. The report states that as a result, the department is not wellpositioned to implement new operational capabilities needed for future warfighters, including

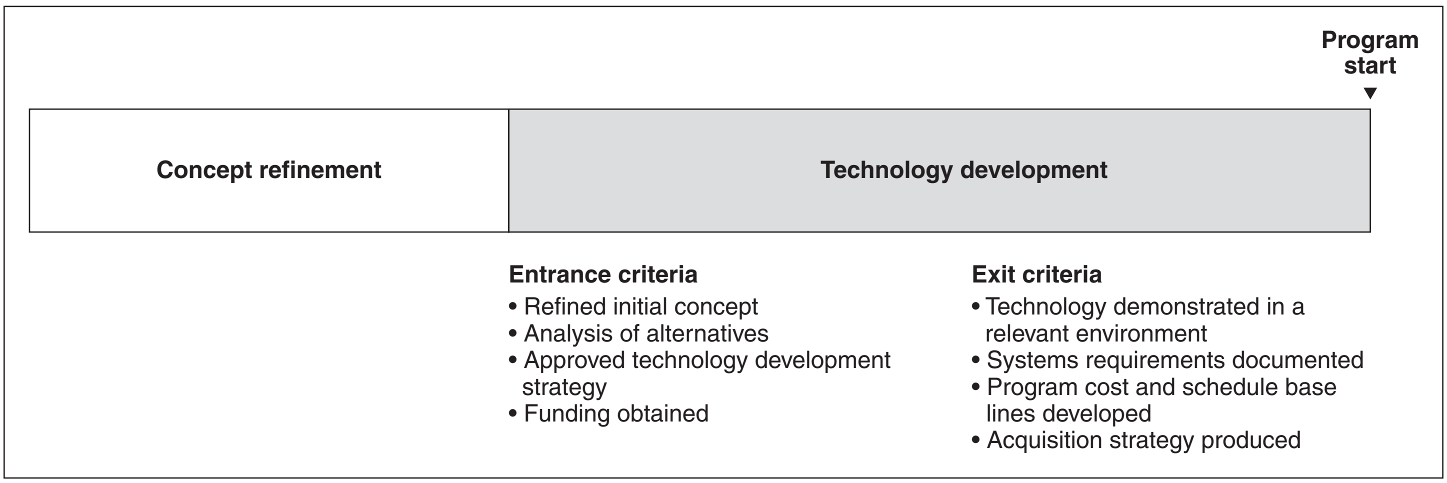
- identifying and tracking terrorists,
- addressing commercialization and globalization issues,
- rapidly evolving technologies such as bio- and nanotechnologies, and
- identifying the proper mix of short- and long-term projects to work on.

One of the recommendations included in the report is for the Undersecretary of Defense (Acquisition, Technology, and Logistics) to develop a strategic technology plan and that DDRE be tasked with assuring that all research and development organizations are implementing DDRE's strategic technology guidance. The board also believes DDRE needs to be more involved in strategic challenges related to (1) gathering and nurturing technology from a variety of sources, (2) developing and exploiting technology to enable new disruptive capabilities; (3) identifying and countering disruptive capabilities developed by adversaries using readily available or advanced technology, and (4) ensuring an adequate level of long-term research for DOD needs. Without effective corporate level leadership, warfighter needs are addressed in a decentralized, uncoordinated manner, thereby increasing the risk that the department will not fulfill these needs.

DOD Does Not Use a Disciplined, Gated Process to Test for Relevancy, Feasibility, and Transition Readiness

DOD's 5000 series acquisition policy specifies that technology development should be separated from product development and that a project shall not exit the technology development phase until the technology has been demonstrated in a relevant environment. This is in line with the practices we found at leading companies, with the exception that the companies require technologies to be demonstrated in an operational environment before program start, which is a higher degree of readiness. However, the department lacks a structured, gated process for managing technology development and transition, as well as criteria that would allow decision makers to know when technology is ready to progress from the technology development environment into an acquisition program to begin product development. As a result, the services continue to launch new programs with immature technologies, and acquisition programs take on technology development responsibilities, an activity that is considered too risky for commercial companies we visited. The following figure shows where the technology development phase occurs in DOD's acquisition process and the entrance and exit criteria for that phase.

Figure 10: Criteria for DOD Technology Development Phase



Source: GAO analysis and presentation of DOD processes and practices.

As shown in the figure above, DOD has two phases prior to program start (also referred to in DOD nomenclature as milestone B). The first is the concept refinement phase, when acquisition programs refine the initial concept and develop a technology development strategy that is supposed to guide activities during the technology development phase. According to the acquisition policy, the strategy should include

- a discussion of the planned acquisition approach, including a summary of the considerations and rationale concerning the approach;
- a discussion of the planned strategy to manage research and development;
- a complete description of the first technology demonstration; and
- a test plan.

The policy, however, does not address the role of the S&T community in designing or supporting a technology development strategy. And according to S&T officials, their role in this phase is minimal. We recently reported that DOD skipped a formal milestone meeting that should take place at the end of the concept refinement phase, referred to as milestone A, for 80 percent of the programs we reviewed.[11] This inhibits the S&T and acquisition communities' ability to create a realistic plan for developing and maturing needed technologies prior to program start and executing a plan once the program begins.

During the technology development phase, the acquisition policy calls for DOD to focus on the development, maturation, and demonstration of the technologies needed for the capability under consideration. To exit this phase, technologies should be demonstrated to be sufficiently mature. DOD defines this as demonstrating technologies in a relevant environment. (See app. IV for definitions of technology readiness.)

When comparing the DOD process with that used by commercial companies we visited, we identified two major differences. First, although DOD policy states that the S&T community "shall enable rapid, successful transition … to useful military products," there is no defined transition phase with criteria to facilitate assessment of a technology's readiness to transition. Instead, the services have senior-level boards that review projects on an annual basis to determine if they are on track relative to cost, schedule, and performance goals set out for the program and rely on a technology readiness tool to gauge development progress. The reviews do not include a formal assessment of many of the technical and business criteria contained in the Boeing scorecard, such as determining if the costs, benefits, and risk are well understood and technology is affordable. As a result, program managers often pull a technology from technology developers before the program manager has the opportunity to validate that the technology can be integrated into the preliminary product design and to develop good product development estimates prior to the start of system development. As stated earlier, commercial companies we visited had a dedicated phase at the end of the technology development process for shifting technology responsibilities to their product lines. We recently reported that almost three-fourths of the programs started since the acquisition policy was revised in 2000 began with critical technologies that were not ready for product development.[12] Seven of the nine programs we reviewed more indepth, about 80 percent, were approved to begin

[11] GAO, *Defense Acquisitions: Major Weapon Systems Continue to Experience Cost and Schedule Problems under DOD's Revised Policy.* GAO-06-368 (Washington, D.C.: April 13, 2006).

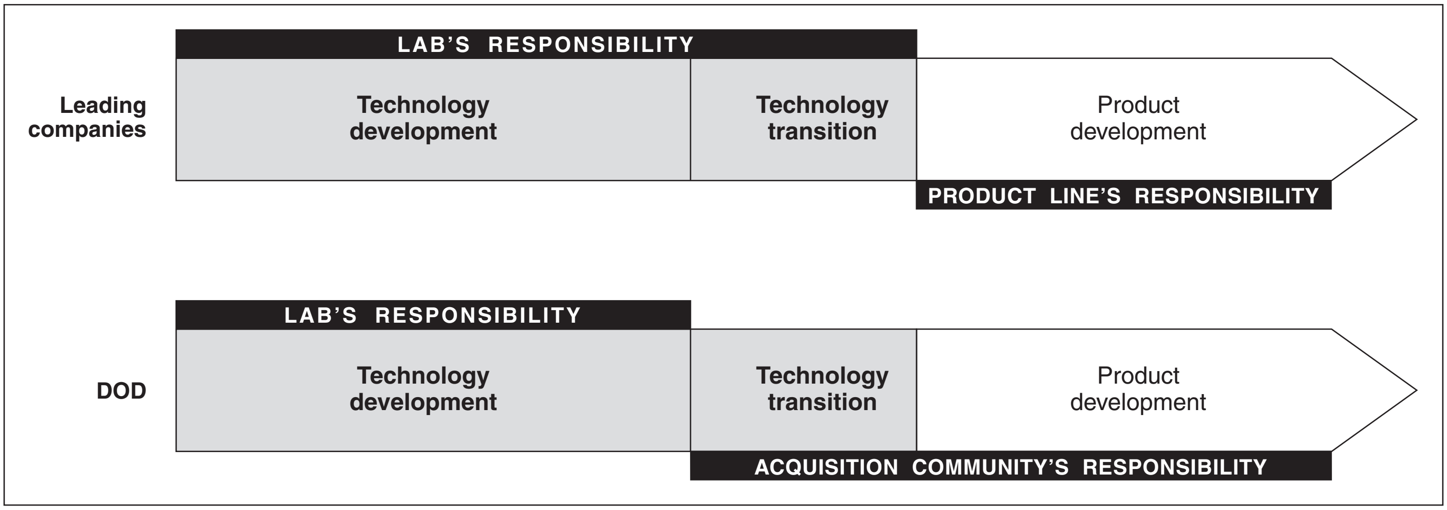
[12] GAO-06-368.

development even though program officials reported that technologies were below readiness levels required for entering product development. This included programs like the Future Combat System and the Joint Strike Fighter.

We found DOD generally views immature critical technologies at the beginning of development as an acceptable risk as long as there is a plan to mature the technologies by the time the program reaches its design readiness review. In effect, the department views risk management plans as an acceptable substitute for demonstrated knowledge. For example, the Navy's Multi-Mission Maritime Aircraft program had none of its critical technologies mature at program initiation. Instead of holding the program to the acquisition policy criteria for entering development, the decision maker simply directed the Navy to work with the Office of the Secretary of Defense to implement risk mitigation and technology maturation plans during the integration phase of system development.

Second, under DOD's current funding structure, the transition of technology—which should occur prior to the beginning of product development and milestone B—is funded and managed by acquisition programs. This contrasts with the approach used by commercial companies, where the lab manages and funds these activities. Commercial firms find that holding their labs accountable for the management and funding of technology as it transitions to a new product forces them to deliver more quickly and efficiently and allows the product lines to focus on product development and the risks associated with it. Figure 11 illustrates the difference in responsibility.

Figure 11: Accountability for Management and Funding of Technology



Source: GAO analysis and presentation of leading companies' and DOD practices.

As shown above, in the commercial companies we visited, product developers are allowed to act like customers for emerging technologies; they are not required to accept, manage, and fund technology risk. This significantly improves the chances of their products reaching the market quickly, at predictable cost, and with high quality. In DOD, major weapon system acquisition programs pull technologies that are not yet ready for a product in order to meet that product's requirements. The S&T community, although still called upon to review technology readiness, has no funds at stake and is no longer responsible for the risk from technology at that point. This is a major contributor to the significant cost overruns and late deliveries of major weapon systems to the warfighter in recent years.

DOD Is Adopting Transition Tools, but Use Is Not Widespread

DOD is using several tools we found were also being used by commercial companies to facilitate the transition of technology to weapons programs. For example, the services are using technology transition agreements for some of their technology projects, DARPA is using relationship managers to address transition issues, the services have established boards to oversee and manage a portion of their technology portfolios, and DOD has several new programs, including the Joint Capability Technology Demonstration program to speed a technology's transition to a weapon system. However, because of the newness or small amount of funding associated with these tools, widespread use has yet to occur. We also found that DOD is using technology-specific and status metrics, but does not have sufficient measures in place to assess the impact of their technology investments or technology transition processes.

Technology Transition Agreements

The services have recently begun using technology transition agreements to formalize technical expectations labs must demonstrate in order for acquisition programs to transition technologies into their programs. DOD science and technology officials believe the agreements are a useful way to hold the technology developers accountable and gauge lab progress toward meeting technology specifications. We are encouraged by their use of agreements, particularly in the Navy. Agreements we reviewed, however, did not contain some of the information or metrics commercial companies believe is valuable to track, and use thus far has been limited.

The agreements we reviewed contained some of the same elements included in agreements used by leading companies we visited, such as a description of the technology project, key technology developer and weapon system personnel associated with the project, and specific performance characteristics that the lab must meet for transition to occur. In addition, they identify the amount of funding acquisition programs will have for transition and when that funding will be available. Unlike the leading companies we visited, however, these agreements did not typically require the technology developer to demonstrate cost metrics for the technology to be included in a weapons program. Commercial companies, for example, include an assessment of manufacturing costs that could be expected if a technology were to be included on a new product and they usually demand prototypes of the technology as demonstration of readiness to transition. A recent Defense Science Board Report highlighted the importance of addressing manufacturing concerns during technology development. Excerpts are shown in figure 12.

Figure 12: Excerpts from a Defense Science Board Task Force Report on the Manufacturing Technology Program

“Immature technologies and manufacturing challenges have a significant impact on DOD’s ability to rapidly and affordably transition technology to the war fighter.”

“S&T program managers often believe that affordability and manufacturing issues are not relevant concerns in 6.3 programs, focusing instead on fabrication of test and evaluation and prototype articles. But this line of thinking leads to higher costs later in a program, when manufacturing concerns are addressed after technical designs are considered ‘ready.’ “

“In order to achieve the objective of lower cost equipment, manufacturing concerns must be addressed earlier in the program life cycle. Production and support costs need to become a component of key technical design requirements, before the final stages of development when technologies are released for prototyping.”

Source: Defense Science Board study (data); GAO (presentation and analysis).

We also found that the services’ use of technology transition agreements has been very limited. For example, we found that the services have a combined total of 224 applied and advanced technology projects that they have identified as candidates for transition, of which 146—or about 65 percent—have technology transition agreements. The Navy accounted for the greatest percentage, with 90 of its 115 projects having an agreement, almost 80 percent. However, there are hundreds of other military services applied and advanced technology research projects that were not selected as candidates where agreements may also be useful. As stated earlier, commercial companies we visited had agreements for nearly all technology projects. The agreements were updated at least annually or sooner if particular tasks were completed. Lab officials use metrics included in the agreements, as well as other criteria, to determine if the project should be continued.

It should also be pointed out that while technology transition agreements are useful tools for firming weapons program commitment to transition, they do not guarantee transition success. For example, a Navy official told us that about one-third of the projects that had been expected to transition in fiscal year 2005 did not transition for the following reasons:

- The technology did not meet the cost parameters required for transition to occur.
- Weapon system requirements changed, forcing changes to the original agreement.
- Program offices did not identify dollars in its budget to transition the technology.

- A program office decided the technology was too risky compared with current hardware in production.

Air Force and Army officials told us they do not track information on why their technologies do not transition. However, they have experienced similar problems as the Navy. They also stated that some lab technologies do not transition because prime contractors decide to use technologies developed in-house, even though DOD technology developers met the metrics included in the transition agreements. Because agreements are usually established between the technology developers and program offices prior to the selection of prime contractors, there is no assurance that the technologies will transition. Even in cases where a prime contractor is known, such as for ongoing development programs, the prime contractor is not a party in the agreement.

Relationship Managers

With the exception of DARPA, DOD does not use relationship managers in the same manner as leading private companies. According to an Air Force lab official, relationship managers market technologies being developed by the labs or gather data about ongoing projects for senior lab management. Most communication about technology transition in DOD takes place through integrated product teams or during annual reviews of technology projects by the senior-level oversight boards for each of the services. Use of relationship managers for these purposes are helpful, but the managers do not necessarily serve as points of contact within the labs and acquisition communities, do not devote time toward efficiently transitioning technologies to multiple weapon system programs, and do not help identify and address systemic transition problems.

Within DARPA, senior officers, called operational liaisons, focus on marketing and transitioning DARPA-sponsored technologies. According to the DARPA director, the liaisons have been very helpful with transitioning technologies because they are well practiced at using the command chain of their respective services and finding the right service contact at the right time. The liaisons

- provide operational advice for planning and strategy development;
- provide an understanding of service perspectives, issues and needs so that potential customers can be identified and effective agreements can be written;
- draft and coordinate agreements between DARPA and the services; and

- direct technology insertion in the services.

Figure 13 describes the impact that operational liaisons have had on transitioning a DARPA-sponsored program called Boomerang. We believe that DARPA's approach could serve as a model for how the military services might establish more formal roles for communication between the S&T and acquisition communities.

Figure 13: DARPA, a Success Story

The DARPA director credits operational liaisons for the quick transition of the Boomerang, an acoustic shot-detection system, from the lab to troops in Iraq. DARPA developed the system in response to feedback from Iraq that convoys were being engaged by snipers yet remained unaware of sniper attacks until a windshield was broken, a soldier was hit, or a vehicle was visibly damaged upon inspection at the end of the convoy mission.

Within 60 days of an urgent Army request, DARPA fielded the first Boomerang system. But DARPA's director said the system did not hold up well in the extreme weather conditions and under wartime conditions. As Boomerang II was being prepared for fielding, the director said the operational liaisons helped craft a more realistic concept of operations, training package, and logistical support package to ensure that Boomerang II not only was technologically ready for combat but was properly supported with spare parts, maintenance facilities, maintenance personnel, training, and lessons-learned feedback to DARPA and the Army. The liaisons also ensured that the Army acquisition community was alerted to Boomerang II's deployment so product developers would be ready to evaluate the final product for movement into the more traditional acquisition process.

Source: DARPA (data); GAO (presentation and analysis).

DOD Programs to Aid Transition

The military services and the Office of the Secretary of Defense have a variety of programs to help transition technologies to weapons systems or directly to the warfighter. These programs, some of which are relatively new and others that have been around for several years, have met with some success. However, these programs represent a small portion of $13 billion DOD spends on science and technology development. As such, they cannot single-handedly overcome transition problems, but rather demonstrate various ways to ease transition.

In recent years, each of the military services has established senior-level boards to oversee technology programs that include advanced and in some cases applied research projects. This includes the Air Force's Advanced Technology Demonstration program, the Army Technology Objectives program, and the Navy's Future Naval Capabilities program. The boards, which are comprised of representatives from the lab, acquisition, and warfighter communities, are responsible for selecting projects to be developed, allocating funding to those projects, and reviewing the projects' progress on an annual basis. The boards emphasize transition planning and can address obstacles to successful transition. According to officials, these programs represent about $1.3 billion of DOD's S&T budget.

The Advanced Concept Technology Demonstration program and the newly established Joint Capability Technology Demonstration program were initiated by DOD as a way to get technologies that meet critical military needs into the hands of users faster and at less cost than by the traditional acquisition process. Under these programs, military operators test prototypes that have already been developed and matured in realistic settings. If they find the items to have military utility, DOD may choose to buy additional quantities or just use the items remaining after the demonstration. Fiscal year 2006 was the first year of a 3- to 5-year period where the current Advanced Concept Technology Demonstration program will be phased out in favor of the new Joint Capability Technology Demonstration program. Department officials believe the new joint program offers improvements over the earlier program in that capabilities will be demonstrated 1-2 years earlier, there is a greater focus on combatant command needs during the selection process, and the Office of the Secretary of Defense provides significantly more funding during the first 2 years of the demonstration project.

A big difference between the two programs is that the new joint program is expected to provide a better path for the transition of technologies because it includes funding for both advanced technology development and advanced component development and prototypes. The Advanced Concept Technology Demonstration program only includes funding for advanced technology development. It must rely on the acquisition community to identify advanced component development and prototype funding for transitioning the technologies. An additional benefit is that the Office of the Secretary of Defense is partnering with the Naval Postgraduate School to conduct business case analysis for completed demonstration projects. This type of analysis is expected to aid decision makers in evaluating alternative approaches to the allocation of scarce resources competing for transition funds.

The Manufacturing Technology Program is aimed at quickly identifying and solving production problems associated with technology transition. It focuses on the needs of weapon system programs for affordable, low-risk development and production. For example, one project, which was given $730,000, was geared toward improving the reliability and strength of large-diameter fasteners used to attach various components on the Seawolf and Virginia Class submarines. Corrosion concerns required that the existing fasteners be replaced at periodic intervals to preclude catastrophic failure. Navy and commercial companies evaluated a wide variety of materials for strength and corrosion resistance to determine the best candidate material and then adjusted the material manufacturing process to obtain the required strength and toughness levels to ensure the fasteners could be produced without extraordinary measures or a deterioration of the material properties. Among other things, program officials expect the project to result in cost avoidance of $1.1 million per fielded submarine per year and improved reliability.

There are other, smaller programs that also focus on transition. Two of these are the Foreign Comparative Testing Program, which focuses on identifying, evaluating, and procuring technologies that have already been developed and tested in other countries, and the Technology Transition Initiative, which focuses on speeding the transition of technologies developed by DOD's S&T programs into acquisition programs. These programs received about $37 million and $29 million in fiscal 2006, respectively. The Foreign Comparative Testing Program, for example, successfully evaluated a South African mine-protected clearance vehicle that will protect soldiers from the effects of landmine explosions during route clearance operations. As of June 2006, 61 of these vehicles have been delivered to the Army, Navy, and Marine Corps.

Metrics

For the most part, the military services track and use only a few of the metrics we found at commercial companies. As stated earlier, they have some technology-specific metrics in their technology transition agreements. In addition, they have status metrics to track some of the on-going, completed, and transitioned projects that are funded by the Air Force, Army, and Navy S&T communities as well as the number of projects with technology transition agreements. However, the services have few metrics that would enable them to gauge the impact of their investments and the effectiveness of their processes for developing and transitioning technology.

DOD officials told us that establishing good, quantifiable metrics to measure transition success is difficult to do. Some of the challenges they face include determining

- how long to track a technology after it has transitioned,
- how to track and distinguish transition success when the same technology is used on multiple weapons programs, and

- how much credit to take when only portions of a technology transition to a weapon program.

Further, DOD S&T officials do not believe that they have enough resources to track technology once technology developers finish working on a project. They say that it would be very labor-intensive to track long-term measures, such as the impact of transitioned technology in terms of cost savings and improved performance. Instead, the services rely heavily on projected cost, schedule, and performance improvements that are required by S&T program management as part of the project selection process. Although progress in meeting technology expectations is monitored throughout technology development, once technology developers are finished working on a technology, little is done to determine if it actually went onto a weapon system and if it is being used in the field.

Last year, we reported that the Office of the Secretary of Defense had difficulty tracking the impact of three small technology transition programs it oversees—the Technology Transition Initiative, the Defense Acquisition Challenge Program, and the Quick Reaction Fund.[13] Nevertheless, we pointed out that there may already be readily available starting points within the department to capture more information regarding return on investments. For example, we pointed out that the DOD Foreign Comparative Testing Program has established metrics to measure the health, success, and cost-effectiveness of the program and has a database to facilitate return on investment analyses. Further, a study by the Naval Postgraduate School to identify metrics for the Advanced Concept Technology Demonstration program may also be useful to the military services for assessing transition success and impact.

Differences in Environment and Incentives Contribute to Different Practices and Outcomes

There are critical differences between the environments and cultures of private world-class companies and DOD that must be recognized before tangible progress can be made in establishing more efficient practices for transitioning technologies to major weapon system acquisition programs. Examples from past initiatives serve as reminders that just changing the mechanics of technology transition processes, without changing the environment that determines incentives, may not produce better outcomes. Private companies operate in a competitive environment that

[13] GAO, *Defense Technology Development: Management Process Can Be Strengthened for New Technology Transition Programs.* GAO-05-480 (Washington, D.C.: June 17, 2005).

demands speedy delivery of innovative, high-quality technologies and products to satisfy market needs. If the company cannot meet those criteria, it will cease to exist in that environment. On the other hand, DOD operates in an environment with a complex variety of “customers.” These complex relationships often hinder the ability of DDRE, its “corporate” component, to provide strategic leadership similar to that of the private company. Success in this environment is often based on a single service’s ability to launch a program to address critical needs and to secure annual funding for the program. The challenge for DOD and congressional decision makers may not lie so much in the “how to” aspects of technology transition as in creating stronger and more uniform incentives that encourage the S&T and acquisition communities to work together to deliver mature technologies to programs.

Private firms must continually deliver innovative, reliable products to market very quickly to prosper. The delivery-oriented environment that private firms live in creates a need for strategic simplicity and directness from leadership and forces product lines and labs to measure success in terms of lower costs and increased revenue and market share. The ability to deliver new, innovative, reliable products of high quality to market as soon as possible drives revenue and market share. This environment creates incentives to maintain an efficient technology base that is focused on market needs and can efficiently transition feasible technologies into new products, keeping costs down while achieving greater revenues. Because commercial firms understand that they do not succeed until a new, innovative product is delivered to the customer, they view successful transition of technologies to products as a critical part of their value chain. The corporation, therefore, insists on accountability from and supports its technology developers with a strong strategic process for ensuring that its product portfolio is balanced. It does not want too many programs vying for scarce investment dollars.

For example, IBM officials stated that poor strategic planning was one of the problems the company had to address after it incurred an $8 billion loss in 1992-1993. According to company officials, technologies no longer could be developed for the sake of development; they had to be aligned with a product line and have market potential to be funded. IBM labs now conduct a situation analysis that takes an internal and external look at technologies being developed and a gap analysis to determine where IBM might be behind in technology development.

At 3M, meeting market imperatives is critical and senior leadership has set a goal to increase sales 5 to 8 percent annually through new products. In this environment, the company has established a companywide initiative referred to as 2X/3X. Generally, the goal is to double the number of new ideas going into the product development pipeline and to triple the market success of the products coming out of the pipeline. Lab and product line managers are evaluated and held accountable for the success of the initiative based upon their ability to meet sales goals and properly resource their projects. According to 3M's 2004 annual report, the initiative is producing strong results. 3M officials believe their culture is well aligned with this competitive environment. For example, technologists participate in companywide technology forums to discuss problems and share information. A technology council, comprised of about 80 lab and technical directors, meets monthly to share ideas, experiences, and best practices among the labs.

At Motorola, the corporate vision is known as "seamless mobility." Senior leaders have aligned the company's global resources—including its $3.1 billion annual research and development budget and a worldwide research network—to help achieve this goal. According to Motorola officials, the seamless mobility vision has been instrumental in uniting Motorola labs and product lines over the past 3 years toward a common goal.

On the other hand, DOD operates in an environment that often hinders the ability of its corporate component—DDRE—to provide strategic leadership similar to the private company. Not only must the department worry about national security imperatives, it must also answer to Congress and its oversight agencies; manage a stove-piped, parochial culture; ensure the public's trust that tax dollars are wisely and fairly spent; and incentivize an industrial base to deliver cutting-edge, often very risky technologies and products. This is a complex set of deliverables by any measure. It creates an environment that makes it difficult for DDRE to lead and has contributed to an undisciplined strategic planning process. Success in this environment is often based on a service's ability to launch a program to address critical needs and to secure annual funding for the program. It is characterized by fierce competition among the services to win scarce funding to begin major weapon system acquisition programs, regardless of the readiness of technologies to meet far-reaching requirements. As a result, programs are pressured to distinguish themselves from other programs previously developed by promising new, enhanced features such as being faster and/or more lethal than anything else. It is very common for these new programs to include requirements for new technologies with overly optimistic assessments of technological feasibility, risk, and delivery schedules. This environment and these incentives breed uncertainty and risk and, as a result, cost overruns and delivery delays.

Conclusions

In DOD, delivering mature technologies to weapon system acquisition programs at the right time continues to be a challenge. Rather than addressing technology issues in a science and technology environment before product development starts, acquisition programs carry significant technology risk into product development. This brings with it a high risk that costs will rise and deliveries to the warfighter will be delayed. In fact, there is strong evidence that acquisition programs that start with immature technologies encounter significantly poorer acquisition outcomes than others. This approach is in sharp contrast to the approach taken in the commercial world. High-performing companies solve technology challenges in the S&T environment. To do this, they have put in place processes and adopted techniques that are pertinent to DOD. Strong strategic planning defines critical investment priorities, and a structured process defines the path towards a technology's transition to product development. This transition is supported by technology transition agreements that hold the research labs accountable for what they must deliver. They also include clarification of the responsibilities the product developer has in accepting new technologies. Metrics are used to force demonstration of relevancy and feasibility at key points in the process and gauge the success of individual projects and the process itself. Funding for technology development largely comes from the corporate level, with the research labs having responsibility for technology development until technology is matured and transitioned to the product line. This is critical to success, because it allows product developers to play a customer role. They are allowed to say no to technologies that are not ready for their programs and can focus on their job at hand—product integration, supplier management, and quality.

DOD has adopted some of these practices. The department has begun using technology transition agreements and relationship managers and has initiated programs that place greater emphasis on technology transition planning. However, the reach of these initiatives is limited, and there is no unified, corporate approach to using them at this point. We recognize that the environment and incentives for DOD are very different than those of commercial firms we visited. For commercial practices to work on a broad scale, the DOD environment must be conducive for applying such practices. DOD senior leadership is a critical factor in providing this direction and vision as well as in maintaining the culture of the organization. The department must devote greater attention to strategic planning and technology development processes so that resources are spent on technologies that can and will be transformed into capabilities for the warfighter. In addition, the S&T and acquisition communities must work together to expand the use of technology transition agreements and relationship managers. Finally, the department should examine the way it currently funds technology transition. It may benefit from an examination of commercial companies' methods in this regard. They hold their technology developers accountable for delivering relevant technologies that are ready to be integrated into new products, but they empower them to succeed by providing adequate funding to get the job done.

Recommendations for Executive Action

DOD should take steps to improve its transition of technologies to more efficiently deliver capabilities to its warfighters. The Defense Science Board has recommended strengthening of DOD's strategic planning function, and we believe this would move the department in the right direction. We believe a disciplined, gated approach for technology development, supported by technical and business criteria, would provide adequate knowledge to acquisition program managers about the risk of including particular technologies on specific weapons programs. It would also provide a more systematic way for the S&T community to continually assess the relevancy, feasibility, and potential transition commitment of its technologies and make decisions about future investments. DOD's current process lacks specific decision points with "go/no go" decisions. As such, we recommend that the Secretary of Defense take the following actions:

- develop a gated process for developing and transitioning technologies that establishes a transition phase and defines activities that should occur during this phase, and
- include specific criteria to support continued funding of specific projects in that process.

We also believe greater use of tools, such as technology transition agreements, relationship managers, and metrics, could help the department improve its ability to deliver mature technologies when needed, address transition issues more quickly, and gauge the impact of their science and technology investments and lab processes. Therefore, we recommend that the Secretary of Defense:

- expand the use of technology transition agreements to applied and advanced development projects;

- include additional metrics in technology transition agreements to provide S&T and acquisition program managers demonstrated knowledge about the manufacturing readiness, producibility, other benefits, and risks of including the technology on a weapons program;

- expand the use of relationship managers by designating people at various levels in both the S&T and acquisition communities to address systemic transition issues and those related to specific weapon system programs. Also, define responsibilities for each level of relationship manager;

- adopt additional process-oriented metrics, such as the percentage of advanced technologies that—once past milestone A of the acquisition process—transitioned into a weapons program or were fielded and the cycle time from milestone A to milestone B as a way to measure the effectiveness of S&T processes and the impact of science and technology investments;

Commercial companies fund technology development and transition activities in their labs and hold the labs accountable for delivering mature technology to their product lines. As such, we are recommending that the Secretary of Defense

- Set aside a portion of advanced component development and prototype funds for the S&T community to manage the transition of technologies to acquisition programs. For this funding to be used effectively, it will require the discipline provided by corporate leadership in defining priorities, processes, and metrics.

Agency Comments and Our Evaluation

DOD provided us with written comments on a draft of this report. DOD generally concurred with the recommendations in our report to improve its ability to transition technology to our warfighters. In doing so, it emphasized that that commercial industry program managers operate in an environment driven by profit and market opportunities, while DOD is organized to support our warfighters. We understand the basic differences in the environments, but believe there are many lessons that can be gleaned from our commercial visits. While it is true that private companies are motivated by profit, they can not achieve a profit without being focused on the timely delivery of products to the market. We note in this and other best practices reports that commercial firms have significant pressures on them to deliver cutting edge technologies quickly. They often bet their very existence on delivering new products and technologies before anyone else does so. In some cases, such as medical systems, their customers have urgent, life-or-death needs, similar to those of the warfighters, that demand very complex technological solutions. The real difference between these companies and the department is that they understand the futility of promising more than can be delivered to the market at any given point. They understand that, in the final analysis, they only succeed—or survive—only by delivering needed capability. On the other hand, the department's acquisition programs consistently accept immature technologies into product development that become a major cause of cost increases, schedule delays, and ultimately very late delivery to the warfighter who needs the equipment. The list of programs that have delivered late is extensive.

Rather than focus on the different environment in the commercial world, DOD should focus on the practices used in the commercial world that allow it to deliver mature technology to product development (then, to the user) quickly and efficiently, an outcome woefully lacking in the department.

Specially, of the six recommendations we made, DOD concurred with two recommendations, partially concurred with two others, and did not concur with the final two. DOD's comments appear in appendix II.

DOD concurred with the recommendation that called for establishing a gated process for developing and transitioning technologies. In its response, the department stated that it has a gated process for programs that have a formal milestone A decision point and that technology maturity and technology readiness assessments are used in this process. DOD explained that the technology maturity assessments, in particular, often lead to risk mitigation plans, which include explicit gates that immature technologies must pass through to become qualified for adoption.

We are not confident that DOD's implementation plans are fully responsive to this recommendation. First, the department does not have a process similar to those that we found at commercial companies to actively manage and make investment decisions across all technologies and determine if an individual technology is ready to transition. In its comments, DOD refers to a process for programs beginning at milestone A. However, we have reported that 80 percent of the programs we reviewed that passed milestone B since 2000 did not have a milestone A.

Second, we found that even when technology readiness assessments indicated that technologies were not ready to be included in an acquisition program, DOD often decided to use them anyway. Third, risk mitigation plans used by DOD are subjective engineering judgments and are of limited value when evaluating the transition readiness of technologies.

The department also concurred with our recommendation that it expand the use of technology transition agreements to applied and advanced development projects. However, in its response, DOD did not identify specific actions it plans to take to implement this recommendation.

DOD partially concurred with the recommendation that it include additional metrics in technology transition agreements. In its response, the department indicated that it has taken steps to incorporate manufacturing readiness assessments as a means to improve technology readiness and that any additional metrics should be project-specific and included as exit criteria as part of the technology transition agreement. We are encouraged by DOD's recent development of manufacturing readiness levels and believe they should be a mandatory tool for the S&T and acquisition program managers to use to assess the manufacturability of a new technology. While we agree that the department should develop additional metrics on a project-by-project basis, we also believe that a more holistic approach, as depicted earlier in the report, is needed to determine the transition readiness of a particular technology. Transition readiness is not solely dependent upon the technical maturity achieved by S&T, but is also dependent upon the readiness of an acquisition program to accept the new technology and therefore should include an assessment of other factors such as cost, benefit, risk, scalability, and acquisition program endorsement.

DOD also partially concurred with the recommendation to expand the use of relationship managers to address systemic transition issues and those related to specific weapon system programs. In its response, DOD indicated that it relies on written documents—the technology maturity assessments and technology transition agreements—to facilitate communication between the S&T and acquisition communities, particularly at the executive level. As stated earlier, these documents do not address many of the factors that could hinder transition. As DOD states in its comments, technology transition is referred to as a "body-contact sport." We agree, and this is why our recommendation is aimed at more direct person-to-person communication. Leading companies believe relationship managers play a key role in their ability to successfully transition technology. While DOD did acknowledge that its S&T investment would benefit from expanded emphasis by staff at the execution levels on technology transition issues, it did not directly address the need for midlevel relationship managers. We continue to believe DOD would benefit from the use of midlevel relationship managers. These managers provide the back and forth communications between the S&T and acquisition communities that help ensure that the right technology is being developed in the time frame needed. These managers are also uniquely positioned to ensure that technology is applied to multiple platforms when applicable and can identify systemic transition problems that should be addressed.

DOD did not concur with the recommendation that it should develop additional process-oriented metrics, even though it stated that it is installing a process to do this through the use of technology maturity and technology readiness assessments. DOD stated that it does not want to commit to overly burdensome metrics that may be more oriented to measuring the process for the sake of measurement. Like DOD, we do not believe the department should develop metrics just for the sake of measurement. Rather, we believe DOD should develop and use metrics that allow DOD, Congress, and taxpayers to gauge the effectiveness of DOD S&T investments, which are expected to reach about $13 billion this year. The metrics that DOD references—those derived from technology maturity and technology readiness assessments—are project-level metrics rather than portfolio and process metrics that would allow the department to analyze its investment and make adjustments appropriately.

DOD also did not concur with the recommendation to set aside a portion of advanced component development and prototype funds for the S&T community to manage the transition of technologies to acquisition programs. In its response, DOD stated that acquisition programs are best suited for transitioning technology because they have the training and discipline to field systems and have the responsibility to ensure a stable design, identify a responsive and responsible contractor, manage execution, and plan for life cycle support of the system. While DOD discusses transition to the warfighter, our recommendation is aimed at transitioning technology from S&T to acquisition programs. We found that in the commercial world, the training and discipline for transitioning technologies to product development is managed by the technology development community and is adequately funded. DOD believes its current approach of setting aside a small portion of S&T funds for transition through programs such as the Advanced Concept Technology Demonstration program, Joint Capability Technology Demonstration program, the Technology Transition Initiative, Manufacturing Technology program, and the Foreign Comparative Testing program is appropriate. We continue to believe DOD's approach to funding transition is flawed and that small pots of money for specific transition activities offer a piecemeal solution to a more systemic problem. DOD currently uses some of its advanced component development and prototype funds for S&T activities, including transition. However, acquisition programs typically carry out and fund these activities. We believe the S&T community should be responsible for these activities and as such, should be given the appropriate level of funding to carry them out. We believe DOD would be better positioned to develop and deliver weapon systems more quickly to its warfighters if the S&T community was responsible for developing, maturing, and transitioning mature technologies to the acquisition community and if the acquisition community focused solely on product development activities and delivering weapon systems to the warfighter That being said, we recognize that the acquisition and warfighting communities play critical roles in this process and therefore must continue to work toward setting realistic program requirements and establishing an evolutionary approach for developing new weapon programs.

We are sending copies of this report to the Secretary of Defense, the Director of the Office of Management and Budget, and interested congressional committees. We will also make copies available at no charge on the GAO Web site at http://www.gao.gov.

If you have any questions about this report or need additional information, please contact me at (202) 512-4841 or sullivanm@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report were Karen Zuckerstein, Assistant Director; Cheryl Andrew; Lily Chin; Sameena Ismailjee; and Sean Merrill.

Michael Sullivan
Director
Acquisition and Sourcing Management

Appendix I: Objectives, Scope, and Methodology

This report examines the Department of Defense's (DOD) efforts to improve its technology transition processes, with a focus on identifying specific management, funding, and organizational practices that could improve technology transition and weapon system outcomes. Specifically, our objectives were to (1) identify techniques that commercial companies use to transition mature technologies before the start of product development and (2) assess the extent to which DOD is using these techniques.

We used a case study approach to compare and contrast DOD and leading commercial companies' practices. Companies were selected on the basis of such factors as the amount of money spent on research and development activities over the past several years and the percentage of change in research and development spending. For the most part, we selected Fortune 500 companies that were in the top 100 for research and development spending and had not experienced major cutbacks in this funding. We also took into account the type of products each company develops and selected companies representing several different business sectors. Below are descriptions of the four companies featured in this report.

Boeing

Boeing is a leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft combined, with capabilities in rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles, and advanced information and communication systems. Boeing Phantom Works develops advanced systems solutions, such as advanced homeland security and air traffic management, as well as breakthrough technologies, such as advanced avionics and composite materials that are intended to significantly improve the performance, quality, and affordability of aerospace products and services. We met with research officials, as well as product line officials representing both its commercial and defense sectors in Seattle, Washington.

3M

3M is a diversified technology company with a worldwide presence in various markets, including consumer and office; display and graphics; electronics and communications; health care; industrial; safety, security, and protection services; and transportation. With more than 55,000 products, 3M invests more than $1 billion annually in research and development and related activities associated with 30-plus core technologies. The company was awarded nearly 500 U.S. patents in 2005.

We met with research, business unit, and government programs officials at 3M headquarters in St. Paul, Minnesota.

IBM

IBM is one of the world's largest technological companies, spending about $3 billion annually on research and development activities. It is the largest supplier of hardware, software, and information technology services and pioneered the development and implementation of on-demand business. With 3,248 U.S. patents, IBM earned more patents than any other company for the 12th consecutive year in 2004. In the past 4 years, IBM inventors received more than 13,000 patents—approximately 5,400 more than any other patent recipient. We met with research and product development officials at the Watson Research Center in Hawthorne, New York.

Motorola

Motorola is a Fortune 500 global communications leader that provides seamless mobility products and solutions across broadband, embedded systems and wireless networks for products in homes, automobiles, and workplaces. Motorola spent about $3.5 billion in 2005 on research and development activities. Approximately 22,000 professional employees were engaged in research activities during 2005. We met with research officials and product development officials, as well as partnership development managers at its offices in Schaumburg, Illinois.

For each of the companies, we interviewed senior management officials knowledgeable about research and development activities to gather consistent information about processes, practices, and metrics the companies use to transition technology smoothly. In particular, we discussed their (1) strategic planning process for identifying and prioritizing customer needs, (2) technology development process used to fund and mature technologies required to meet customer needs, (3) tools used to facilitate communication between labs and product lines to transition technology, and (4) technology transition process, including when transition occurs, the organizations involved, and how technology is funded throughout the transition phase. We synthesized information from GAO's past best practices work about technology and product development.

To determine DOD's practices for transitioning technology, we met with science and technology (S&T) and acquisition officials to discuss the same categories of questions listed above that we asked leading commercial companies. The following is a list of the organizations we met with:

- Director, Defense Research and Engineering, Alexandria, Virginia
  - Director, Plans and Programs
  - Deputy Under Secretary of Defense, Advanced Systems and Concepts
  - Director, Defense Advanced Research Projects Agency
- Air Force
  - Office of the Assistant Secretary of the Air Force for Acquisition (Science, Technology, and Engineering), Alexandria, Virginia
  - Air Force Material Command, Wright Patterson Air Force Base, Ohio
  - Air Force Research Labs, Wright Patterson Air Force Base, Ohio
  - Joint Unmanned Combat Air Systems Program Office, Wright Patterson Air Force Base, Ohio
- Army
  - Assistant Secretary of the Army Acquisition, Logistics and Technology, Alexandria, Virginia
  - Deputy Assistant Secretary for Research and Technology Chief Scientist, Alexandria, Virginia
  - Joint Tactical Radio System Cluster 5 Program Office, Alexandria, Virginia
- Navy
  - Deputy Assistant Secretary of Navy for Research, Development, Test and Evaluation, Alexandria, Virginia
  - Office of Naval Research, Alexandria, Virginia
  - Naval Air Systems Command, Patuxent River Naval Air Station, Maryland
  - Naval Sea Systems Command, Washington Navy Yard, D.C.
  - CVN-21 Program Office, Washington Navy Yard, D.C.
  - Multi-mission Maritime Aircraft Program Office, Patuxent River Naval Air Station, Maryland
  - Aircraft Launch and Recovery Equipment Program Office, Patuxent River Naval Air Station, Maryland

At each of these locations, we collected appropriate documents that describe the various programs, organizations, responsibilities, and funding. We obtained examples of key documents, such as technology transition agreements or memorandums of agreement that are used to solidify agreements made between labs and weapon programs. We reviewed DOD and military service strategic plans and research, development, test, and evaluation funding documents. In addition, we reviewed documents required as part of the selection and oversight process for the Air Force Advanced Technology Development program, the Army Technology Objectives program, and the Future Naval Capabilities program. We relied on previous GAO best practices and weapon system reports that highlight cost and schedule impacts of launching new weapon programs with immature technology. A list of these reports can be found at the end of this report.

Appendix II: Comments from the Department of Defense

OFFICE OF THE DIRECTOR OF
DEFENSE RESEARCH AND ENGINEERING
3040 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3040

SEP 5 2006

Mr. Michael J. Sullivan
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Sullivan:

This is the Department of Defense (DoD) response to the General Accountability Office (GAO) draft report, "BEST PRACTICES: Stronger Practices Needed to Improve DOD Technology Transition Processes," dated August 2006 (GAO Code 120454/ GAO-06-883).

While we generally concur with recommendations in the report that would encourage DoD to improve its ability to transition technology to our warfighters, we believe it is important to recognize there are differences between the Government and industry. Industry program managers operate in an environment driven by profit and market opportunities while DoD is organized to support our warfighters. Some of the ways DoD provides warfighter capabilities is through technology upgrades, leap-aheads, and transformation driven by the near and mid-term operational priorities. The essential governance process of annual appropriations and authorizations is also a factor that private sector technology investment does not experience. We adopt industry best practices where practical and in a manner consistent with both our legislative mandates and the DoD mission. Comments are provided at the enclosure.

The staff has worked closely with the GAO team and appreciates their inputs for transitioning technology to the warfighter. Thank you for the opportunity to comment on the draft report.

Sincerely,

Alan R. Shaffer
Director, Plans and Program

GAO DRAFT REPORT DATED AUGUST 2006
GAO CODE 120454/GAO-06-883

"BEST PRACTICES: Stronger Practices Needed to Improve DOD Technology Transition Processes"

DEPARTMENT OF DEFENSE COMMENTS TO THE RECOMMENDATIONS

The Department has reviewed the GAO's report concerning implementation of industry best practices for technology transition and partially agrees with the findings. However, as discussed during the exit briefing, private sector industry program managers operate in a significantly different environment than DoD managers, with profit objectives driving commercial investments, vice our DoD-mission focus on meeting warfighter objectives for technology upgrades, leap-aheads, and transformation. These objectives drive many of the inherent cultural changes which we are continuing to address with periodic process changes across multiple programs and organizations in the Department.

RECOMMENDATION 1: The GAO recommended that the Secretary of Defense develop a gated process for developing and transitioning technologies that establishes a transition phase and defines activities that should occur during this phase, and include specific criteria to support continued funding of specific projects in that process. (p. 32/GAO Draft Report)

DOD RESPONSE: Concur.
The Department has, and recognizes the value of, a gated process for programs that have a formal Milestone A. That process involves the use of Technology Maturity Assessments (TMA's) and Technology Readiness Assessments (TRA's). This formal process is under the responsibility of the Science and Technology community and helps ensure that critical technologies are proven prior to delivery to the Acquisition community. The use of TMAs and TRAs has been in use for about two years, and we would expect that another 4-5 years of assessments will be needed in order to realize the desired results. TMA's often lead to technology risk mitigation plans, which include explicit "gates" that immature technologies must pass through to become qualified for adoption. The Department also supports technology transition agreements, signed by the developer and acquisition managers, with specific, mutually agreed upon exit criteria, as a viable alternative for those programs that have transition as a specific objective.

RECOMMENDATION 2: The GAO recommended that the Secretary of Defense expand the use of technology transition agreements to applied and advanced development projects. (p. 32/GAO Draft Report)

DOD RESPONSE: Concur.
Technology transition agreements have been used successfully by the Services and OSD to document and facilitate technology transition between the Science & Technology (S&T) and acquisition communities.

RECOMMENDATION 3: The GAO recommended that the Secretary of Defense include additional metrics in technology transition agreements to provide S&T and acquisition program managers demonstrated knowledge of manufacturing readiness, producibility, other benefits, and risks of including the technology on a weapons program. (p. 32/GAO Draft Report)

DOD RESPONSE: Partially Concur.
The Department has taken steps to incorporate manufacturing readiness assessments as a means to improve technology transition. Recently the Joint Defense Manufacturing Technology Panel, with the support of industry and the defense acquisition community, developed a set of Manufacturing Readiness Level (MRL) definitions and supporting tools. MRLs are designed to serve the same purpose for manufacturing risk/maturity as the Technology Readiness Levels (TRLs) serve for technology readiness, and incorporate a similar numbering system. They are described in the DoD Technology Readiness Assessment Deskbook, at http://www.dod.mil/ddre/doc/tra_deskbook.pdf. Any additional metrics should be project specific and determined by the S&T and acquisition managers, and be documented as mutually agreed upon exit criteria as part of the technology transition agreement.

RECOMMENDATION 4: The GAO recommended that the Secretary of Defense expand the use of relationship managers by designating people at various levels in both the S&T and acquisition communities to address systemic transition issues and those related to specific weapon system programs. Also, define responsibilities for each level of relationship manager. (p. 32/GAO Draft Report)

DOD RESPONSE: Partially Concur.
The DoD already has a process in place with defined responsibilities for both the S&T and acquisition communities. TMAs are provided to the Program Executive Officers, the Defense Acquisition Board (DAB), and the Overarching Integrated Process Teams for Acquisition Category 1 (ACAT 1) programs. The TMAs are part of the DAB reviews to ensure a transition path is established. For technology not part of an ACAT 1 program, the Department uses Technology Transition Agreements to accomplish this purpose thereby causing the S&T and Acquisition managers to negotiate exit criteria that must be met before the technology transitions. Technology transition is frequently referred to as a "body-contact sport," in recognition of the important role that personal communication and relationships usually play in successful efforts. Throughout DoD's S&T enterprise, there are many staff who focus on fostering transitions by establishing relationships between technology developers and potential technology users, and by breaking down barriers to technology transition. Many of these efforts are successful and move certain technologies forward from research to adoption reasonably quickly. However, it's probably a fair observation that a substantial fraction of DoD's S&T investment would benefit from expanded emphasis by staff at the execution level in the labs, Agencies, and Program Managers, etc. in terms of technology transition versus technology development.

RECOMMENDATION 5: The GAO recommended that the Secretary of Defense adopt additional process-oriented metrics, such as the percentage of advanced technologies that—once past Milestone A of the acquisition process—transitioned onto a weapons program or were fielded and the cycle time from Milestone A to Milestone B as a way to measure the effectiveness of S&T processes and the impact of science and technology investments. (p. 32/GAO Draft Report)

DOD RESPONSE: Nonconcur.
We are installing a process to do this through the use of TMAs and TRAs. As we mature this process over the next 4-5 years, we would not want to commit to overly burdensome metrics that may be more oriented to measuring the process for the sake of measurement rather than using this process to improve transition. Technology has transitioned when: it has moved into an acquisition program of record; it can be acquired/procured through normal DoD procurement programs; it has addressed or met the requirements of DoD doctrine, operations, training, maintenance, procurement, logistics, and facilities and; it provides sustainable capability. With this transition we also transition from S&T funding to Acquisition funding to reflect the proper alignment of programs and funding. Technology transition is the result of a collaboration between the requirements, technology, and acquisition communities. Each of the Military Services have a process in place to bring these collaborative elements together. The technology is already certified at Acquisition Milestone A with a technology pathway for achieving Technology Readiness Level (TRL) 6 at Acquisition Milestone B.

RECOMMENDATION 6: The GAO recommended that the Secretary of Defense set aside a portion of advanced component development and prototype funds for the S&T community to manage the transition of technologies to acquisition programs. (p. 32/GAO Draft Report)

DOD RESPONSE: Nonconcur.
GAO recognizes the transition programs established by the Department to make technologies ready for transition, including the Advanced Concept/Joint Concept Technology Demonstrations (AC/JCTDs), Technology Transition Initiative (TTI), Manufacturing Technology (ManTech) and Foreign Comparative Testing (FCT). But these, in practice, reflect a collaborative contract between the S&T community, the acquisition community procurement program of record, and the warfighter to deploy the technology when it is ready to be fielded. In addition, the training and discipline to field systems resides in the acquisition community, as they have the responsibility to ensure a stable design, identify a responsive and responsible contractor, manage execution, and plan for life cycle support of the system. While there may be examples of stand-alone systems where the S&T community could manage the transition to a fielded system, this is not a desirable or feasible approach for larger system-of-system development programs with broad involvement from many stakeholders and longer system life cycles. However, to assist the transition of those technologies not specifically tied to a program of record, the DDR&E invests approximately $500 million annually in programs like but not limited to ACTDs/JCTDs, TTI, ManTech, and FCT as mentioned above. Accordingly, DoD is setting aside a portion of S&T funds for transition. We believe the current balance is correct, but we will continue to assess to assure ready technologies are offered to our warfighters rapidly, efficiently, and affordably.

Appendix III: DOD Research, Development, Technology, and Engineering Budget

Dollars in billions

Name	Budget activity	Description	Which DOD community controls spending	Budget (fiscal year 2006)
Basic research	1	Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed towards increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high-payoff research that provides the basis for technological progress.	S&T	$1.5
Applied research	2	Applied research is systemic study to understand the means to meet a recognized and specific need. It is a systematic expression and application of knowledge to develop useful materials, devices, and systems or methods. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. Applied research precedes system-specific technology investigations or development.	S&T	$5.2
Advanced technology development	3	Advanced technology development includes development of subsystems and components and efforts to integrate them into system prototypes for field experiments and/or tests in a simulated environment. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use. Projects in this category have a direct relevance to identified military needs. Program elements in this category involve pre-acquisition efforts, such as system concept demonstration, joint and service-specific experiments, or technology demonstrations, and generally have technology readiness levels (TRLs) of 4, 5, or 6. Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of science and technology and into the acquisition process within years defense program. Upon successful completion of projects that have military utility, the technology should be available for transition.	S&T	$6.6
Advanced component development and prototypes	4	Advanced component development and prototypes consists of efforts necessary to evaluate integrated technologies or prototype systems in a high fidelity and realistic operating environment. These activities include system-specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex system sand may involve risk reduction initiatives. Advanced component development and prototypes efforts are to occur before an acquisition program starts product	Acquisition	$13.9

System development and demonstration	5	System development and demonstration consists of newly initiated acquisition programs and includes engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. Characteristics of this activity involve mature system development, integration, and demonstration to support a production decision.	Acquisition	$19.3
Research, development, test and evaluation management support	6	RDT&E management support includes efforts to sustain and/or modernize the installations or operations required for general RDT&E. Such efforts may related to test ranges, military construction, maintenance support of laboratories, operation and maintenance of test aircraft and ships, and studies and analyses I support of the RDT&E program.	Acquisition	$4.0
Operational system development	7	Operational system development includes development efforts to upgrade systems that have been fielded or have received approval for full-rate production and anticipate production funding in the current or subsequent fiscal year.	Acquisition	$20.6

Source: DOD (data); GAO (presentation and analysis).

Appendix IV: DOD Technology Readiness Levels

Technology readiness level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumption. Examples are still limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard. Validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5. Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: DOD (data); GAO (presentation and analysis).

Related GAO Products

Defense Acquisitions: Assessments of Selected Major Weapon Programs. GAO-06-391. Washington, D.C.: March 31, 2006.

Best Practices: Better Support of Weapon System Program Managers Needed to Improve Outcomes. GAO-06-110. Washington, D.C.: November 1, 2005.

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