Assessing the Potential for Civil-Military Integration: Selected Case Studies

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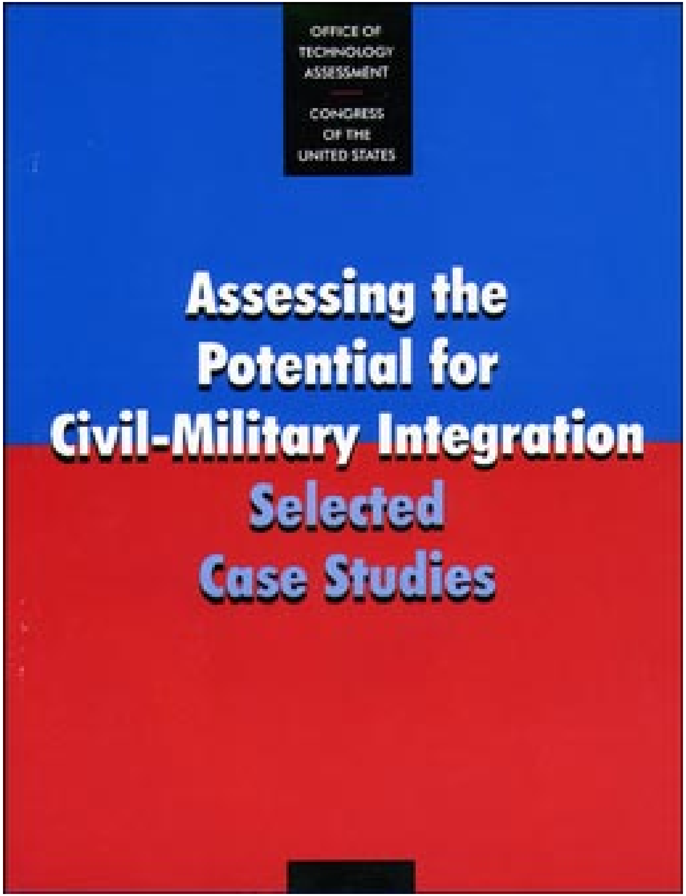

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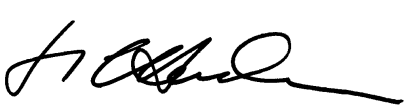
Foreword

The Office of Technology Assessment, at the request of the Congress, has conducted a series of assessments of the Nation's ability to provide for its future national security technology and industrial needs. In the most recent report, *Assessing the Potential for Civil–Military Integration*, OTA examined the potential for making greater use of common technologies, processes, labor, equipment, material, and/or facilities to meet both defense and commercial needs. This effort, often termed civil–military integration or CMI, is believed by many observers to be an essential element of a successful U.S. national security strategy. OTA's assessment found that greater CMI is possible, and confirmed the potential for cost savings and increased technology transfer as the result of increased integration. The assessment noted that CMI appears essential if defense is to take advantage of many rapidly developing commercial technologies.

This background paper presents material from three of the case studies undertaken during the assessment: flat panel displays, polymeric composites, and shipbuilding. The three cases illustrate both the opportunities and the challenges facing those designing policies to increase the level of CMI. While some military performance requirements create special technical demands, the cases reveal that both commercial and defense needs can often be met with common technologies. Better planning during system design can further reduce the need for different technical solutions to defense problems and reduce market differences between the commercial and defense markets. Acquisition laws and regulations often remain the major inhibitor to increased integration. Some of these laws and regulations have recently been changed; however, as the main report points out, and as these cases illustrate, more changes are needed.

In undertaking the assessment and these case studies, OTA sought information from a broad spectrum of knowledgeable individuals and organizations whose contributions are gratefully acknowledged. As with all OTA studies, the content of this report is the sole responsibility of the Office of Technology Assessment and does not necessarily represent the views of our advisors and reviewers.



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Note: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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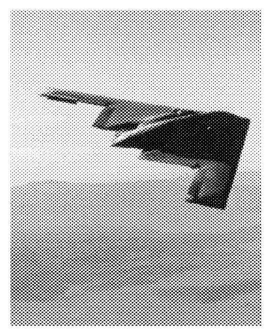
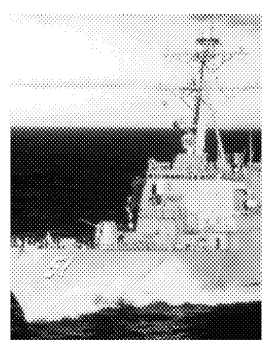




Overview

In response to the changing global military situation, Congress requested the Office of Technology Assessment (OTA) to conduct a number of assessments examining the health and viability of the technology and industrial capabilities that provide the United States with the goods and services necessary to meet its national security needs. OTA was asked to assess trends in the technology and industrial base, future technology and industrial base needs, and options for preserving a viable defense technology and industrial base (DTIB). OTA has produced a series of reports on these issues.[1] The latest report, *Assessing the Potential for Civil-Military Integration*, examined the potential for making greater use of commercial goods and services to meet defense needs.

BACKGROUND

Assessing the Potential for Civil-Military Integration found that a strategy aimed at making greater use of the commercial technology and industrial base to help meet national security needs—often termed civil-military integration (CMI is defined in some detail in box 1.)—had the potential to produce substantial future government savings and provide access to critical technology. OTA's analysis, however, indicated that savings may be lower and take longer to be achieved than some advocates have

[1] U.S. Congress, Office of Technology Assessment, *Adjusting to a New Security Environment: The Defense Technology and Industrial Base Challenge*, OTA-BP-ISC-79 (Washington, DC: U.S. Government Printing Office, February 1991); *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base*, OTA-ISC-500 (Washington, DC: U.S. Government Printing Office, July 1991); *American Military Power: Future Needs, Future Choices*, OTA-BP-ISC-80 (Washington, DC: U.S. Government Printing Office, October 1991); *Lessons in Restructuring Defense Industry: The French Experience*, OTA-BP-ISC-96 (Washington, DC: U.S. Government Printing Office, June 1992); *Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base*, OTA-ISC-530 (Washington, DC: U.S. Government Printing Office, June 1992); *Assessing the Potential for Civil-Military Integration: Technologies, Processes, and Practices*, OTA-ISS-611 (Washington, DC: U.S. Government Printing Office, September 1994); and *Other Approaches to Civil-Military Integration: The Chinese and Japanese Arms Industries*, BP-ISS-143 (Washington, DC: U.S. Government Printing Office, March 1995).

BOX 1: Definition of Civil-Military Integration

OTA found no single definition of CMI. The term encompasses a number of different activities, each of which is viewed as an element of integration. For example, those advocating the increased use of nondevelopmental items, including commercial off-the-shelf items, consider such use to be CMI. Analysts recommending changes in government acquisition laws to promote combined R&D, or production of civilian and defense products on a single assembly line, consider such changes to be CMI. Others maintain that CMI involves increased cooperation between government research facilities and the private sector in both R&D and manufacturing technologies. Still others claim that the rationalization of private and public depot-level maintenance facilities (e. g., transferring jet aircraft engine maintenance and overhaul from military facilities to existing private sector facilities) is a component of CMI.

These definitions are not mutually exclusive. Accordingly, OTA has incorporated all these elements in its definition of CMI as:

> The process of merging the Defense Technology and Industrial Base (DTIB) and the larger Commercial Technology and Industrial Base (CTIB) into a unified National Technology and Industrial Base (NTIB)[1].

More specifically, in an integrated base, common technologies, processes, labor, equipment, material, and/or facilities would be used to meet both defense and commercial needs. Decisions on how to use Integrated resources would be based on the same technical, legal, and economic reasoning that commercial firms use when servicing global markets.

[1] The NTIB includes other noncommercial elements, such as public utilities and other non-DOD government procurements The national base is also embedded in the larger Global Technology and Industrial Base

SOURCE Off Ice of Technology Assessment, 1995.

claimed. The findings of OTA's CMI assessment are summarized in box 2.

Integration is usually discussed as a function of activities occurring at a firm or a specific facility. However, OTA's assessment revealed that integration actually occurs at various levels within the base and should be analyzed at three separate levels—the technology or industrial sector level, the firm level, and the facility level. Each level presents its own unique set of policy challenges.

Integration at the technology or industrial sector level is characterized by the DTIB and the Commercial Technology and Industrial Base (CTIB) sharing common technologies, processes, and specialized assets (e.g., unique test stands, wind tunnels, and industrial research centers). An industrial sector can be said to be integrated if its defense goods or services are drawn from the same pool of technologies, specialized assets, and processes (and, by extension, standards) as are commercial goods or services. However, while integration at the sector level aids the development of common products, it does not assure that defense and commercial products will be the same, that they will be produced in the same facilities, or that they will be less expensive than if they were produced without such integration.

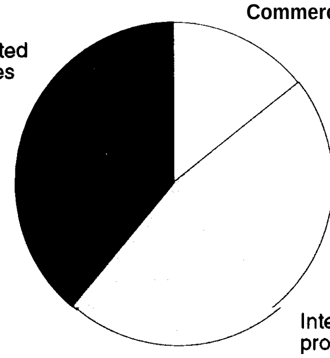
Integration at the firm level is characterized by the sharing of corporate resources to meet both defense and commercial needs. These resources include management, workers, research centers, equipment, stocks, and common facilities. A corporation that readily moves staff between defense and commercial work and transfers manufacturing and product technologies back and forth can be considered integrated at the firm level, even though it may separate its operating divisions along commercial and defense lines.

The third and deepest level of integration is at *the facility level.* Integration at this level is characterized by the sharing of personnel, equipment, and stocks within a single facility. In an integrated facility, defense and commercial goods would be manufactured side by side, with any differences in

BOX 2: Assessment Findings

Despite several previous initiatives to promote integration, much of the DTIB remains isolated. Still, significant CMI currently exists. OTA's estimate of current integration is shown in figure 1.[1] Increased CMI is possible, but requires changes in government acquisition policy, taking advantage of technological developments, adapting technologies for both defense and commercial use, and restructuring the DTIB. The growth of CMI depends on the extent of policy change. OTA's estimates of the potential for increased CMI, based on significant acquisition reform and restructuring, are shown in figure 2.

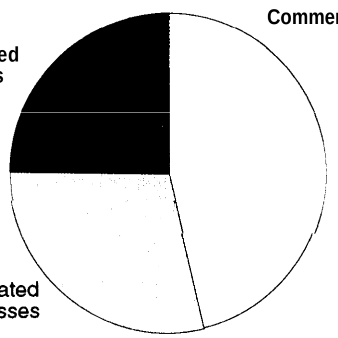
FIGURE 1: Current Facility-Level CMI Division of the Private DTIB at All Tiers



SOURCE: Industrial survey conducted by Office of Technology Assessment, 1994.

Some technologies, industrial sectors, and product tiers are **more amenable to integration** than others. Prime contractors performing systems integration on complex defense systems may have a limited ability to integrate production. Lower tier tier activities, such as production of components and subcomponents, appear far more amenable to integration. Services appear particularly amenable to commercial purchases

FIGURE 2: Potential Facility-Level CMI Division of the Private DTIB at All Tiers



SOURCE: Industrial survey conducted by Office of Technology Assessment, 1994.

Cost savings and increased technology transfer are difficult to quantify. OTA's analysis, however, indicates that savings may be lower than some advocates have claimed. Implementation may be more difficult, and take longer to achieve, than many anticipate because: 1) integration is already occurring in many of the tiers and technologies most amenable to CMI, 2) change is more difficult to implement than many have anticipated, and 3) important portions of the base may not be amenable to integration.

Still, after several years overall savings could amount to several billion dollars per year. Possibly more important than direct savings, however, is that increased CMI can provide access to those rapidly developing commercial technologies in critical areas (e.g., electronics) that will be essential to defense in a more fiscally constrained environment.

[1] Estimates for figures 1 and 2 are for the private sector DTIB only. They are based on a macroeconomic examination of the DTIB and an industry survey of 16 randomly selected industrial sectors providing goods and services to national defense. Since the estimates are based on a limited industrial sector survey, they should be considered suggestive rather than definitive. OTA also used interviews, case studies, and analyses of selected industrial sectors to validate its estimates

(continued)

BOX 2: C

The assessment identified no "silver bullet" policies that might easily achieve CMI goals. The complexity of the DTIB demands a diverse set of CMI policies. Some policies can have broad effects, but in most instances the barriers to CM I are sufficiently intertwined to demand a comprehensive (and complex) set of policies if projected benefits are to be achieved. Operations and Maintenance spending, for example, may be influenced by policies directed at increased use of commercial items and greater use of commercial practices. R&D, on the other hand, would be influenced by research goals that encompass both civilian and defense uses, and by modifying government requirements for rights in technical data.

The assessment outlined three strategies for consideration: Readjustment, Reform, and Restructuring. Together they form a phased implementation of CMI. A Readjustment Strategy modestly increases CMI, but retains many of the current procedures for oversight of defense expenditures; thus both the risks and the benefits are likely to be relatively small. A Reform Strategy builds on the foundation of a Readjustment Strategy and takes a more expansive approach to fostering CMI. It promises more benefits, but with a corresponding increase in potential risks. Finally, a Restructuring Strategy might gain the maximum potential CM I benefits, but would demand major changes in future military acquisition policy, system design, and force structure, and could present greater risks.

SOURCE. Office of Technology Assessment, 1995

production processes and parts dictated solely by product function. Table 1 illustrates some of the activities that comprise integration at the various levels, the barriers to such integration, and the rationale for increased integration.

Early in the assessment, OTA found that almost all of the previous studies of civil-military integration were based on case studies of specific products or firms.[2] Although many of these studies produced useful findings, there were concerns about the ability to generalize the findings of individual case studies.

The previous case studies were, for example, largely concentrated in areas of electronics and aviation. While these are important defense sectors, OTA estimated that they account for less than 30 percent of the value added to total defense goods and services purchased from the private sector.[3] Further, these particular sectors appeared to be somewhat more amenable to commercial use than many other industrial sectors. The cases selected also largely excluded many other important defense product sectors (e.g., conventional ammunition, ground vehicles, and shipbuilding). Finally, the previous case studies largely ignored services—a category that accounts for roughly 20 percent of the spending for direct final purchases, and about 40 percent of the spending for indirect and lower tier defense purchases.[4]

[2] A listing of many of these case studies is found in ibid., *Assessing the Potential for Civil-Military Integration,* Table 3-5, Selected Previous Civil-Military Case Studies, pp. 53-54. An exception to the concentration on the case-study approach was one study then ongoing by The Analytic Sciences Corp. (TASC), *The DoD Regulatory Cost Premium: A Quantitative Assessment, The* Analytic Sciences Corp., Arlington, VA, December 1994. This study considered macro level data collected from the Census Bureau in an attempt to validate the findings of earlier case studies.

[3] Electronics and aviation may represent a greater percentage of direct sales, but OTA's estimates were directed at value-added by particular sectors---and thus attempted to disaggregate such things as distribution, transportation, and other embedded activities from the sales figures for major categories of equipment.

[4] Department of Defense, *Projected Defense Purchases Detailed by Industry and State: Calendar years 1991-1997,* p. 4.

TABLE 1: CMI at Three Levels

Level of integration	What might be integrated	Examples of integration at this level	Examples of barriers to further CMI	Rationale for further CMI
Industrial sector	All activities in an industrial sector, including companies, industry groups, standards bodies, government labs, defense acquisition officials, and academia.	Use of common technologies, processes, and specialized assets (e.g., unique test stands, wind tunnels, and industrial research centers) within an industrial sector,	Differing commercial and military product and process requirements; separate specification and standard systems; go-it-alone attitude in businesses or the DOD; classification.	Product and process technology transfer; reduced costs by avoiding duplication; increased competitiveness; leverage limited R&D funds
Firm	Corporate management, divisions, branches, and assets of an individual company or corporation,	Sharing of corporate vision and resources, including management, workers, research centers, accounting and data systems, equipment, stocks, and facilities,	Need to shield commercial work from DOD oversight and added overhead costs; different accounting/data systems; different management and marketing environments; classification.	Internal technology transfer; preservation of capabilities in commercial or defense downturns; economies of scale, Increased long-term stability due to diversification; capital availability
Facility	R&D, production, maintenance and/or administrative processes within a single facility.	Sharing of personnel, equipment, material, and administration within a single facility; joint defense and commercial activity on a production line, in a work group cell, or at an R&D lab bench,	Need to shield commercial work from DOD oversight and added overhead costs; different accounting, data and supply systems; military uniqueness; use of military specifications and standards; limits on uses of government equipment; classification.	Source of cost savings; economies of scale, reduction of redundancies; lower capital investments and over-head costs; less worker retraining, direct process technology transfer; job retention

SOURCE: Office of Technology Assessment, 1995.

As a result of these early findings, OTA decided to base its assessment on a combined analysis of macro level industrial base data with examinations of the findings of previous case studies and some additional case studies undertaken specifically for the assessment. It was thought that the combination of macro level data and individual cases would provide better insights into trends in the base and the implications of change than would either case studies alone or simply examining macro level data.

Indeed, despite their short-comings, case studies have been, and continue to be, essential to the study of CMI. Case studies can serve one or more of three purposes:

1. cases are useful as anecdotes, to illustrate degrees of varieties of CMI or barriers to CMI,
2. cases can provide essential information and insights on critical firms or sectors, and
3. randomly selected cases---combined with proper statistical considerations--can be used to represent the larger population of companies, contracts, or programs from which they were drawn.

Previous case studies on CMI have served the first two purposes noted above. Case studies, however, are very time consuming, and many must be done to provide good insight.

Examination of available macroeconomic data or larger surveys, on the other hand, can provide additional useful CMI information. Such surveys could address the critical barriers to integration and assess why some commercial businesses avoid defense work. While surveys have the benefit of reaching an under-studied population, they: 1) demand extensive private sector time, 2) provide far less detailed information than that obtained from case studies, and 3) are expensive to conduct.

This background paper reports on three of the case studies that were conducted during the assessment: flat panel displays (FPD), polymeric composite materials, and shipbuilding. They illustrate varieties of CMI, barriers to CMI, and provide insights useful for developing CMI policy. Some of the general observations are briefly outlined below.

OBSERVATIONS

Many of the CMI issues discussed in *Assessing the Potential for Civil-Military Integration* are illustrated in these three cases. These cases represent important industries and technologies with both commercial and national security application. FPDs, for example, are being increasingly used in a wide variety of commercial products. Their size, weight, and ability to convey data make them useful in many military applications. But the future commercial market is expected to far exceed the defense market. Integration in the FPD sector is seen as a means to provide the DOD with access to rapid technological developments and lower DOD costs in meeting its needs.

The polymeric composites industry also provides important national security capabilities. Like the FPD industry, these capabilities generally involve critical performance-enhancing components of military systems rather than end products. There are important commercial as well as defense uses for these materials. Aerospace applications are of particular interest. Like FPD, integration is seen as important for both providing access to new technological developments, and for lowering DOD's product costs.

The shipbuilding industry differs from the other two industries in that the industry provides critical end products (aircraft carriers, submarines, and frigates to name a few) directly to the military, as well as providing components and subcomponents for these systems. Further, in contrast to the other two cases, shipbuilding is a relatively mature industry with an extensive history in the United States. But the commercial shipbuilding business has been in long-term decline; during much of the 1980s, few (in some years, zero) large commercial ships were built in U.S. shipyards and the industry became highly dependent on U.S. Navy work for survival. Thus, the greatest challenge for creating the integrated shipbuilding base, viewed as essential to preserve the nation's ability to provide affordable naval craft for national defense needs, is creating a viable, domestic large-ship commercial shipbuilding base.

Current Level of Civil-Military Integration

As with the base as a whole, all three of these sectors already have some degree of integration. As noted above, there is currently little integration at U.S. shipyards, but some CMI exists in the development and production of components.

Polymeric composites have considerable integration at lower tiers and face their greatest CMI challenge at the first tier where the specific military application (e.g., surface manufacturing to obtain stealth characteristics) may have little or no commercial counterpart.

A good deal of integration exists at the sector level in the FPD industry, for example, where many common technologies are pursued for both commercial and defense application. At the firm and facility levels, however, there is relatively little integration in the United States, where only a small domestic industry currently exists. If successful, the National Flat Panel Display Initiative, combined with recent DOD changes in the use of military specifications and standards, and continued acquisition reform, may increase both firm- and facility-level integration in the United States.

Potential for Civil-Military Integration

OTA's assessment of CMI indicated that integration is more likely at the lower industrial tiers than at the level of the prime assembler where many components are combined to fashion unique military products.[5] These cases generally support those findings. Both FPD and polymeric composites appear to be more amenable to integration than does shipbuilding; however, component producers in the shipbuilding sector report an ability to integrate, and where a commercial market exists, they are already producing in integrated facilities. The shipyards and design firms also report that much greater integration is possible.

The polymeric composites industry reports the potential for greater integration. Government procurement practices were identified during interviews for this assessment as a major inhibitor. Composites firms were reportedly hopeful that government changes in these practices would improve prospects for integration.

The potential for integration could probably be enhanced in all three industries by concerted efforts during the design phase of military equipment to make greater use of commercially available (or useful) technologies, and by making greater use of common process technologies (design and manufacturing). In the past, however, the introduction of more efficient commercial manufacturing technologies into defense application has been inhibited by the inability to adequately recoup investment costs. This problem must be addressed if greater use of common process technology is to become acceptable to industry.

Factors that Inhibit CMI

The case studies revealed a number of factors that inhibit CMI. There are sometimes technological inhibitors to CMI. For example, the relatively greater use of complex electronics and the need for integrated weapons systems on warships make it more difficult to use a common workforce to perform many production functions in shipyards building or service both civilian and military ships. Similarly, the need for great precision in the fabrication of the surface shape of composites used on stealthy aircraft does not exist in commercial aircraft and thus calls for different skills. This increases the difficulty of integration. The need for good, all-aspect viewing of cockpit displays in bright sunlight places somewhat different technical demands on those displays used in defense from those used in the commercial sector. Yet none of these examples make increased integration impossible; rather, they challenge those who wish to exploit the synergies of CMI to greater thought in designing both the process and product technologies involved.

Despite the recent changes in acquisition laws, new implementing regulations, and the changes in the use of military specifications and standards, integration continues to be inhibited in the three industries by current acquisition procedures. In part, this is a function of the inherent time lag between change at the top of a large organization and change at the bottom. *Assessing the Potential for Civil-Military Integration* outlines some of the reasons for this lag.[6] But, recent DOD and congressional actions making changes in the use of military specifications and standards and in acquisition reform (e.g., the Federal Acquisition Reform Act of 1994—FASA) appear likely to positively affect the potential for successful CMI. Still, further acquisition changes are essential if firms that produce both militarily unique items as well as commercial items are going to effectively integrate at the facility level.

Finally, some market factors inhibit integration. For example, the high cost of some FPDs needed for fighter aircraft cockpit applications limit their use in commercial aircraft. Similar limitations exist in the application of composites.

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[5] OTA, *Assessing the Potential for Civil-Military Integration*, op. cit., footnote 1, pp. 9-10.

[6] Ibid., pp. 29-42.

Yet even where market factors inhibit some integration, there is potential for greater integration in the design and production processes of many of these products.

Factors that Favor CMI

A number of factors, if exploited, appear to favor increased CMI in these three cases. There are, for example, clear indications in these three cases that trends in technologies are blurring the differences between commercial and defense technology. One good example is that process technologies are converging to make it easier to design and build defense and commercial products in a more integrated fashion. Many design software packages are applicable to both needs.

Product technologies—particularly at the lower tiers—also often overlap. The same composite materials may be used in both commercial and defense aerospace products. Common components can be used for many defense and commercial display applications. Commercial aerospace needs in displays and materials often overlap with all but the most demanding defense needs. Some pumps and valves can be used on both commercial and military ships.

The fact that many technologies are converging is also having an impact on markets, where the commercial markets are demanding products that are lightweight, rugged, and reliable—attributes long prized in the defense sector.

An even more important market factor clearly evident in all three cases is the growing gap between worldwide levels of spending for commercial and defense purposes in industries such as FPD. This trend makes it more difficult for defense to influence more than small portions of the industries, and increases the importance of integration if DOD is going to have access to essential technology.

Finally, recent government policy initiatives already mentioned (e.g., changes in the use of military specifications and standards, changes in acquisition practices, and initiatives aimed at exploiting commercially available technologies) all favor increased CMI.

Implications of Increased CMI

Interviews and workshops resulted in an overall consensus that both increased access and reduced costs are likely—if greater CMI is achieved in these three industries. Yet it is difficult to quantify either the amount of DOD's increased access to newly developed commercial technology, or the potential savings from increased integration.[7] *Assessing the Potential for Civil-Military Integration* estimated some of the potential savings based on survey interviews and estimates of the potential for increased integration in 16 randomly selected sectors supplying goods and services to national defense.

Estimates of overall possible savings ranged from a few percentage points off expected baseline expenditures to a high of 15 to 20 percent of expected baseline expenditures. Analysis indicated that a range of 5 to 10 percent savings off expected baseline expenditures appeared most probable. Interviews supported the conclusion that many rapidly evolving technologies might not be available to the defense effort in a timely fashion without increased CMI. Considering the relatively low risks and costs of pursuing a CMI policy that were identified in *Assessing the Potential for Civil-Military Integration*, these potential returns appear to favor pursuing policies that will enhance CMI.[8]

[7] Ibid., pp. 23-42. *Assessing the Potential for Civil-Military Integration* does make some estimates based on surveys and estimates on the speed of likely introduction of CMI policies.

[8] Ibid., p. 17.

Case Study 1: Flat Panel Displays: Assessing the Potential for Civil-Military Integration

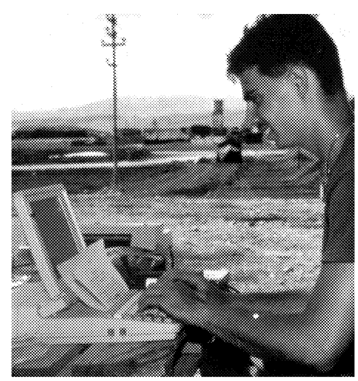
Flat Panel Displays (FPDs) are finding their way into increasing varieties of products, from laptop computers to individual airline movie displays. In some products, they are replacing bulky cathode ray tubes (CRTs); in others, they are making a new product possible. They are used in a wide variety of U.S. weapons systems. A recent Department of Defense (DOD) report noted that:

> Demand for FPDs throughout the world will grow explosively for the foreseeable future. The lowest credible estimate projects a twofold growth in the $6.5 billion 1993 FPD market by the turn of the century.[1]

More optimistic estimates are forecasting growth of three to six times the 1993 market by the year 2000, reaching $20 billion to $40 billion.

The DOD report noted that demand is overwhelmingly driven by commercial products, but that FPDs are becoming increasingly important for meeting military requirements. The United States' FPD industry is small and largely research oriented. The U.S. currently relies on foreign suppliers (principally the Japanese) for most of its commercial and defense needs. DOD has stated that it:

> . . . cannot currently rely on the overseas supply base to furnish customized or specialized products or capabilities that will be required to support future DOD needs, or to provide leading edge technology to DOD before it is in widespread commercial use.[2]



[1] Flat Panel Display Task Force, *Building U.S. Capabilities in Flat Panel Displays* (Washington, DC: U.S. Department of Defense, October 1994), pp. I-2 to I-3.

[2] Ibid, p. I-6.

In April 1994, DOD announced a National Flat Panel Display Initiative (NFPDI) aimed at providing early, assured access to FPDs for DOD. The initiative envisions an integrated domestic FPD production base capable of servicing both commercial and military markets, almost interchangeably.

This case study briefly describes FPD technology, the structure of the FPD industry, current trends in the industrial base, and the factors favoring and constraining civil-military integration in the FPD industry.

TECHNOLOGY AND USE OF FPDs

Varieties of FPDs

There are many different, competing FPD technologies. The Department of Commerce has grouped current FPD technologies into four broad categories: liquid-crystal displays (LCDs), electroluminescent displays (ELDs), plasma-display panels (PDPs), and field-emission displays (FEDs). Table 2 outlines the technologies, their strengths and weaknesses, and the state of the supporting industrial base. Since then, the extent of the growing Korean capability has become more evident. These technologies, and the Korean capabilities, are discussed in more detail in a forthcoming OTA report on the FPD industry.[3]

Another technology, the digital micromirror device (DMD), is of interest and discussed in this paper because it has the potential to provide large displays and is also receiving heavy investment in the United States from Texas Instruments.

Liquid-Crystal Displays

LCDs are by far the most common class of FPD. Liquid crystals are organic molecules that have crystal-like properties but are liquid at normal temperatures. The molecules can be realigned by weak electromagnetic fields.

An LCD consists of a layer of liquid-crystal material, measuring a mere 1.5 to 6 microns thick, sandwiched between two substrates made of a high-purity glass or a transparent polymer. The inside surface of the glass—that is, the surface in contact with the liquid crystal material—is a thin layer of an alignment material, typically a polymer. The liquid crystal material is said to have a *preferred orientation* when it touches this layer. Etched onto the substrate's outer face is a grid of electrodes. Through various *addressing* schemes, voltages are applied to this grid, turning local areas of liquid-crystal material ON or OFF. The entire sandwich—liquid crystal material, glass substrates, etched electrical grid, and color filters—is in turn flanked by a pair of polarizing filters that selectively absorb visible light. When an electrical field is applied in quick succession to different areas of material, the display produces the illuminated dots known as pixels.

The least expensive LCDs reflect ambient light that strikes the front surface, hits the display's coated rear surface, and is reflected back. More expensive LCDs are artificially illuminated from behind, typically by a diffuse fluorescent bulb. In such backlit LCDs, the screen remains readable when available light is low or glare is high.

LCDs can also be differentiated by the way the liquid-crystal area is electrically addressed (passive vs. active). Passive-matrix liquid crystal displays (PMLCD) are currently the most common. In the liquid-crystal molecules used in passive-matrix LCDs, the switching of the polarization of the light is accomplished by passing the light through crystals that may be aligned in twisted (90°) or supertwisted (270°) configurations when no voltage is applied. When voltage is applied, the liquid crystals align to the electric field creating the display. In a passive-matrix LCD, multiple display points (pixels) are turned on, and like a CRT, it essentially "paints" the display in swift horizontal strokes. In early versions of passive-matrix LCDs, as the number of lines increased, contrast—the difference in brightness between lit and unlit pixels—became increasingly weak. This

[3] U.S. Congress, Office of Technology Assessment, *Flat Panel Displays*, forthcoming, September 1995.

TABLE 2: Flat Panel Display Technologies[a]

Technology	Companies	Type/status	Maximum size (brand)	Manufacturing status	Strengths	Weaknesses
Liquid-Crystal Display (LCD)						
a-Si TFT LCD	~ 15 Japan, 3 U.S. (OIS, Xerox, IBM)	Active/manufacturing	71" (Sharp)	Infrastructure in place; difficult to manufacture; yields of 30-60 %0	Excellent color, resolution; market penetration	Expensive, power-hungry backlight; not scalable over 17"
p-Si TFT LCD	1 Japan (Seiko-Epson) 2 U.S. (Xerox, DSRC)	Active/developing	13" (Xerox)	Planned for 1995, possible successor to a-Si	High resolution, saturated color	New technology; expensive substrate
x-Si TFT LCD	1 U.S. (Kopin)	Active/developing	1.5" (Kopin)	Uses proprietary manufacturing process	Great electron mobility; easily integrated drivers	Expensive
"FLC" ferro-electric LCD	1 Japan (Canon) 1 Europe (EMI)	Passive/developing	15" (Canon)	Canon started manufacturing in 1993	Scalable to large sizes; good viewing angle	Expensive; limited gray-scale
TN LCD	~20 Japan, ~6 U. S., Many Asian	Passive/ manufacturing	10.5"	Several large facilities for small sizes	Low-cost, easily manufactured	Limited viewing angle, slow; not scalable
Active-addressing (AA) STN	1 U.S. (Motif)	Passive/ manufacturing	6"	Ramping up as of January 1994	High resolution, video rate; wide viewing angle	Not scalable, new tech; complex drivers
STN LCD, including FSTN, TSTN, others	~20 Japan, ~6 U. S., ~15 Asian	Passive/ manufacturing	11"	Many large facilities	Excellent $/performance ratio	Slow; dull colors, limited viewing angle; backlight
Metal-insulator-metal (MIM)	2 Japan (Seiko-Epson, Stanley)	Passive/ manufacturing	10" (S-E)	For computers, videophones	$/performance ratio	Slow; cross-talk; flicker
Electro-luminescent Display (ELD)	1 Japan (Sharp) 1 U.S. (Planar	ELD/manufacturing	19" (Planar)	Three volume facilities	Bright, low power, easy	Not fully saturated colors

(continued)

TABLE 2: Flat Panel Display Technologies (Cont'd.)

Technology	Companies	Type/status	Maximum size (brand)	Manufacturing status	Strengths	Weaknesses
Plasma-Display Panels (PDPs)						
PDPs for computers	~5 Japan, 3 Us.	PDP/manufacturing	19" (Plasma-co)	Several large facilities	Bright; multi-colored; scalable	High voltage; limited gray scale
PDPs for televisions	'6 Japan, 2 U.S.	PDP/manufacturing	45" (NHK)	No proven process	Scalable	Power hungry; high voltage
Field-Emission Display (FED)	~4 U.S., ~6 non-U.S.	FED/prototype	9" (CNET)	Planned for late 1994	Believed to be scalable	New technology

assessment by Department of Commerce based on review of literature and industry discussions. Does not include all FPD technologies, particularly those in R&D stage or just moving into product development, a-Si = amorphous silicon; TFT = thin-film transistor; p-Si = polysilicon; x-Si = single crystal silicon; FLC-ferro-electric crystal; TN = twisted nematic crystals; STN = supertwisted nematic crystal; FSTN = film-compensated STN.

SOURCE: U.S. Department of Defense, *Building Capabilities in Flat Panel Displays,* table 2-1, problem was largely eliminated in the early 1980s with the invention of the supertwisted nematic (STN) LCD, which provide greater contrast.

The passive-matrix LCDs (PMLCDs) main rival is the active-matrix LCD (AMLCD). PMLCDs consume less power and are less costly and therefore continue to dominate the flat panel display business in low-information-content displays—particularly those in watches, instrument readouts, and other devices that must be on continuously. But in many applications, PMLCDs are increasingly losing ground to AMLCDs as the latter's costs decline.[4]

Active-matrix displays do not need to be multiplexed, but are individually activated in one of a number of ways.[5] The result is a colorful, high-contrast image. AMLCDs are used where the desire for high intrinsic brightness, ghost-free moving images, or a rich color palette[6] justifies the price.

The predominant AMLCD technology is the amorphous-silicon thin-film transistor (TFT).[7] It offers good gray shades and color, fast response, and a wide viewing angle. Furthermore, AMLCDs can be made to remain readable when bathed in sunlight and can display information in full color. Compared with current cockpit displays (typically CRTs), AMLCDs are shallower, weigh less, consume less power, are more reliable, and are believed to be easier to maintain.

In several key respects, TFT substrates are processed like integrated circuits (ICs). Both products are made by photolithography, a process that requires a large capital-equipment investment. Both products use thin-film processing and face manufacturing economies that are closely tied to yields. But there are also differences. AMLCDs are larger than typical silicon wafers for integrated circuits. Furthermore, the entire display screen must be free of defects, while the die in defective areas of a silicon wafer used in integrated circuits can be discarded. Finally, the AMLCD manufacturing process generates particulate contamination that necessitates frequent cleaning. AMLCD have thus been more difficult and costly to produce, so their use has been reserved for display types where a passive LCD would be too dim or too low in contrast. Nevertheless, Japanese and Korean firms have made major commitments to improvements and production. Yields are improving steadily and prices are expected to fall as processes improve and supply increases.

The major companies currently producing AMLCDs are Japanese. The market leader in 1993 was Sharp Corp., with 55 percent of the market. The next two largest producers, Nippon Electronic Corp. (NEC) and Display Technologies Inc. (DTI), a joint production venture between IBM and Toshiba, shared about 35 percent of the market.[8]

Electroluminescent Displays (ELDs)

Electroluminescent displays (ELDs) are touted for their ability to be driven at high refresh rates so that high-resolution images can appear flicker-free. Visually, they are highly readable and bright,

[4] New developments in scanning techniques have, however, reportedly brought some renewed interest in PMLCDs.

[5] The terms *multiplexed* and *active* refer to the alternative ways in which individual display points, or pixels, are turned on. In multiplexing, multiple pixels are stimulated by a voltage supplied by a row and a column driver. In an active-matrix color display, there are individual switches and storage devices—thin-film transistors (TFTs), or diodes—attached to each pixel. In a full color AMLCD, each pixel has three subpixels (representing red, green, and blue), each of which can be driven independently.

[6] In theory, AMLCDs have long been able to display thousands of colors. In practice, however, consumers could not buy an active-matrix notebook computer that showed more than 256 colors until late 1993. In October of that year, Apple introduced a color notebook that could display 32,768 colors. The display was made in Japan. Displays with 16.7 million shades of color are available in 1995.

[7] AMLCD made of polysilicon TFT LCDs are being developed. The polysilicon promises to allow circuitry to be integrated directly onto the substrate, potentially greatly reducing manufacturing costs. D. Lieberman, "Hughes Lands Poly LCD," *Electronic Engineering Times*, May 25, 1992 (Issue 694, p. 14).

[8] Flat Panel Display Task Force, op. cit., footnote 1, p. IV-1.

with wide viewing angles and fast response; physically, they are reliable, long-lived, and extremely thin. In producing ELDs, layers of thin phosphor films are deposited onto a sheet of glass, then covered with another sheet. One of the films is luminescent, emitting light when struck by high-voltage electrons.

The use of ELDs has been constrained, however, by difficulties in identifying phosphors with high brightness and the need for costly high-voltage drivers. ELDs are currently used by the military in tanks and command centers and commercially in financial and ATM machines, but there is little current use of ELDs in computers and consumer electronics.

Plasma Displays

Plasma-display panels (PDPs) are composed of front and back substrates with phosphors deposited on the inside of the front plates. An inert gas placed between the glass plates of each cell generates light, with the color depending on the phosphors used. PDPs are rugged, high in contrast, and have a wide viewing angle. Currently, plasma displays are used in submarines and command centers, in engineering workstations, and in portable medical equipment. Their use is limited by their production, relatively high power consumption, and low color brightness.

Field-Emission Displays

The traditional CRT with its deep neck and boxy appearance can make delivery and placement difficult. U.S. researchers are pursuing a radically new breed of CRT. Known as a field-emission display (FED), it may make even large-screen CRT displays thinner than a cigar box. A conventional CRT illuminates all pixels with one or three electron guns. An FED uses a separate tiny electron gun for each pixel. Each electron source contains a large number of very fine microtips; electrons released from the tips are accelerated onto the phosphor, generating light. A conventional CRT must scan each row, illuminating each pixel only for a moment; an FED illuminates each pixel continuously. Proponents argue that FED will bring high resolution to portable, low-power devices.

Digital Micromirror Device (DMD) Displays

Digital Micromirror Device Displays are being developed by Texas Instruments (TI) Inc. The DMD covers each memory cell of a CMOS static RAM with a movable micromirror. Electrostatic forces based on the data in the cell tilt the mirror either +10 degrees (on) or -10 degrees (off), modulating the light incident on its surface. Light reflected from on-mirrors passes through a projection lens and creates images on a screen. Light from the off-mirrors is reflected away from the projection lens and trapped. Shades of gray are determined by the on-state of the mirror. Color can be added.

The Advanced Research Projects Agency (ARPA) has been involved in the development of DMD, but TI is making significant investments in the technology on its own. Large systems (diagonals of 16 ft.) have been demonstrated. Although there are concerns about the durability of the mirror hinges, the company claims that the DMD should meet the temperature and environmental requirements for both commercial and military application. TI also touts the commonality of production with conventional memory chips.

But there are also several challenges to be addressed. One of the biggest is actually developing the lithography to fabricate the chip.

Other Kinds of Flat Panel Displays

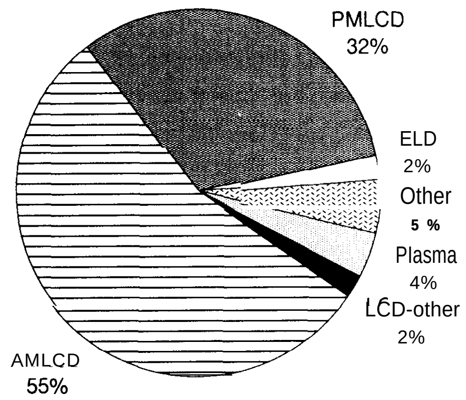
The aforementioned varieties of FPD are geared toward products requiring high information content, multiple colors, or both, in their displays. That class of display is the focus of this study, but other FPD technologies will probably have a place in the future. Light-emitting diodes (LEDs), for example, appeared in the 1960s as an extension of the semiconductor revolution. The first digital watches used LEDs to display the time. By selectively doping crystal materials, engineers can obtain a wide range of visible colors. Two factors have hindered the progress toward using LEDs, however. First, blue LEDs were dimmer than the other two colors of the color triad. This is reportedly no longer true, with CaN LEDs produced by Nichia Chemical of Japan now very bright. Second, all LEDs would have to be processed on a single gallium-arsenide wafer; so far, attempts to do this have failed. As a result, many companies have shelved the idea.

In the United States, the main producer of LEDs is Hewlett-Packard (HP). Together with Los Alamos National Laboratory, HP is exploring new materials—such as polymers instead of inorganic materials—to make more efficient, longer lived LEDs.[9]

From the standpoint of civil-military integration in FPD, DOD faces two broad problems. One is the perceived need for a domestic industry. The other is selecting technologies for military application that both meet military performance needs and will be commercial winners. In the world of competing FPD technologies, this will certainly be difficult.

The projected global use of various FPD technologies is shown in figure 3.

FIGURE 3: Flat Panel Display Demand: Year 2000 Projected Global Market Share for All Technologies.



SOURCE: U.S. Department of Defense, *Building U.S. Capabilities in Flat Panel Displays,* based on data from Stanford Resources, Inc.,1994

▮ The Flat Panel Display Market

Defense Applications

The military relies on a broad range of devices that use high-resolution FPDs. The Department of Defense has estimated that DOD will need a total of approximately 75,000 units by the end of the decade,[10] with annual DOD demand expected to average 25,000 between 2000-2009 and 90,000 between 2010-2019. These figures pale beside the civilian market, but FPDs are increasingly important to the U.S. defense effort. Military flat panel displays are found in surface warships, submarines, fixed-wing aircraft, helicopters, and ground fighting vehicles, as well as in airborne warning and control systems (AWACS) aircraft and in many garrison situations, and are expected to find their way into soldiers' helmets. According to DOD's 1992 Key *Technologies Plan:*

> Particularly needed are high-information-content displays that range from miniature, helmet-mounted devices, through portable and vehicular systems, and up to large screen displays for command post, shipboard, and command centers. Sought are flat-panel displays that offer megapixel resolution, consume low power, and provide virtual reality to the "man in the loop."[11]

Generally speaking, military FPDs are aimed at the five applications shown in table 3.

FPDs are expected to replace CRTs and mechanical displays in virtually all new DOD aircraft, and will be retrofitted into existing cockpits to help give new life to aging aircraft. The prototypes of Lockheed's YF-22 Advanced Tactical

[9] M. Ryan, "Government Labs Go Commercial," *Electronic Engineering Times, Nov. 8, 1993* (Issue 769, p. 49).

[10] Flat Panel Display Task Force, op. cit., footnote 1, p. III-14.

[11] Director of Defense Research and Engineering, *DOD Key Technologies Plan,* July 1992, p. 5-7.

TABLE 3: Flat Panel Display Defense Applications

- Primary military cockpit and flight instruments
- Militarized computers
- Military ground vehicles
- Military helmet-mounted systems
- Military command-and-control-center systems

SOURCE. Office of Technology Assessment, 1995

Fighter (ATF) and those of Northrop's YF-23, for example, each used six active-matrix LCDs. All the displays were built by General Electric (GE).[12]

The production-version F-22 cockpit will require seven AMLCDs At the end of 1994, some 422 F-22s were slated to be built, requiring some 3,000 AMLCDs including spares. However, like all major weapon systems, the F-22 faces an uncertain procurement cycle and final numbers are uncertain. These displays are currently to be built by Optical Imaging Systems, Inc. (01 S), in Troy, Michigan.

In the first decade of the 21st century, some 1,034 AH-64 Apache helicopters are eligible to be re-instrumented or at least to have their cockpits retrofitted with AMLCD displays as part of an Army program to lengthen the service life of deployed Apaches. DOD will also need other large flight instruments and displays, such as those needed on the AWACS aircraft. These must deliver high resolution over screens measuring 20 inches or more in diagonal.

The ground soldiers fighting the Persian Gulf War owed part of their victory to the ease with which they were able to receive character-based and graphical data in the field. Lap-top computers became the information lifeline to the command-and-control structure. As DOD analyzes the strengths and weaknesses of these machines, a new generation, sporting higher color resolutions and high-speed wireless data links, will almost certainly be developed.

Flat panel displays are being planned for future tanks as well as for several tank, armored personnel carrier (APC), and mobile command-and-control station upgrade programs. CRTs take up too much space in a tank's cramped interior. For such punishing applications, it is thought that the more rugged plasma and electroluminescent displays may be used.

The Army has been developing the Soldier's Integrated Protective Ensemble (SIPE) and a follow-on production program. The goal is to equip each soldier's helmet with a flat panel display of tremendous information density. Such a development would greatly increase the number of displays required.

Command-and-control FPDs are needed in all environments (i.e., air, land, and sea). Large-area FPD screens are needed for AWACS and airborne command posts such as Looking Glass and J-STARS as well as for ground and sea control stations and command centers. These operations centers must monitor huge amounts of information over hundreds of cubic miles of space, air, sea, and vast stretches of land. Such applications have driven ARPA to fund a wide range of ideas for large, high-resolution displays.

Command and control, however, is not the only reason that DOD needs large, flat screens. A concomitant need is to accurately simulate operations or the performance of a new weapon system in the heat of battle. Simulation might dramatically speed the development process by creating a prototype of a weapon system on-screen. Simulated battlefield scenarios might allow a mission to be rehearsed just hours before it begins. The trend is to replace electromechanical simulators with panoramic displays that tie together warfare environ-

[12] Subsequently, GE sold its AMLCD production facility to the French company Sextant through Thomson CSF, and the plant is now in France.

ments seamlessly in a virtual reality.[13] Under current planning, by the end of the decade a new concept, Distributed Interactive Simulation (DIS), would be used in performing extensive joint-service training and readiness exercises.[14] Such simulations could radically compress development and training cycles while saving dollars and lives.

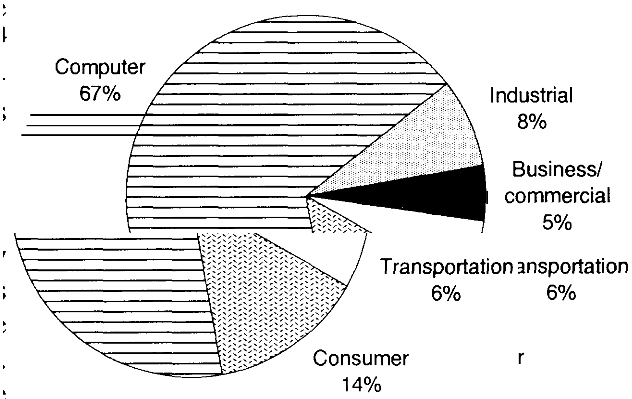
Commercial Applications

As noted earlier, commercial flat panel display sales are expected to more than double in 10 years from their 1993 level of $6.5 billion, with more optimistic estimates reaching $20 to $40 billion. The current demand for AMLCDs is intense. The broad demand categories estimated for the year 2000 are shown in figure *4.*

Computers are expected to continue to comprise the greatest market share. Indeed, displays (whose production is dominated by the Japanese) represent the largest single portion of manufacturing value added in portable computers. In 1993, portable computers became the fastest-growing niche in personal computers. Industry analysts say the market for portables is growing nearly four times as fast as that for desktop computers.[15]

Lap-top, notebook, and subnotebook computers all use flat panel displays. The changing nature of the market is illustrated by what has been happening in subnotebooks. These computers weigh less than 5 pounds. Because of their small battery supplies, the displays of subnotebooks were initially dull and monochromatic. But these too now have active-matrix color screens. AMLCDs are widespread on all portable computers, and the number of color portables sold is expected to increase from about 4 million units in 1993 to 15 million by the year 2000.

FIGURE 4: Flat Panel Display Demand: Year 2000 Projected Global Market Share by Application



SOURCE: U.S. Department of Defense, *Building U.S. Capabilities in Flat Panel Displays,* based on data from Stanford Resources, Inc. ,1995

FPDs may also eventually displace color CRTs in desktop computers, but cost is currently an inhibitor. Most CRT monitors sell for between $350 and $1,000. Initial FPDs would be much more expensive, but the prices would surely fall with increased production volume.[16]

Consumer applications of FPDs include televisions, games, personal assistants, videocassette recorders, and camcorders. Video communications might be an area of explosive growth. Projection TVs based on CRTs currently dominate applications for large screens, but DMD and some of the other FPD technologies are aiming at this market. Indeed, when consumers think of flat-panel displays, many imagine the wall-hung tele-

[13] See U.S. Congress, Office of Technology Assessment, *Virtual Reality and Technologies for Combat Simulation--Background paper,* OTA-BP-ISS-136 (Washington, DC: U.S. Government Printing Office, September 1994), for a discussion of developments.

[14] M. Tapscott, "Paradigm Change: from Simulators to Si... *Defense Electronics,* September 1993, p. 36.

[15] K. Pope, "Changing Work Habits Fuel Popularity of Notebooks," *Wall Street Journal, Nov.* 11, 1993, p. B-1. New reports estimate these shipments even higher and note that the rapid improvement in color flat panel display quality is helping to fuel user demand.

[16] Some manufacturers are already introducing FPDs as desktop monitors. In 1993, IBM introduced a premium-priced desktop PC that included a flat-panel color display. That fall, CTX International, Inc., introduced a 9.4-inch VGA desktop color monitor, featuring a color AMLCD, with a list price of $3,395. Key advantages are said to be portability and lower power consumption.

vision that has been the subject of *Popular Science* cover stories for many years. Such displays might promote the spread of high-definition television (HDTV). According to James E. Carnes, president and CEO of the David Sarnoff Research Center:

> The success of HDTV is dependent on displays. HDTV will become a very popular medium if we have a flat-panel display that provides bright pictures, with a screen size greater than 70 inches, that fits inside the door, for $2,000. The problem is that we don't know how and when it's coming.[17]

Again, no single technology holds an undisputed lead in this application area. The DMD appears promising. Other firms tout plasma displays. In the United States, Photonics Imaging has been working on the problem and has developed a 30-inch high resolution full color, video rate plasma display with ARPA support. In Japan, some 50 companies have allied to form the Japanese Plasma Display Technical Forum. As its organizer explains, "The display industry has already accepted the idea that the plasma display is the way to go for over 20-inch flat-panel displays."[18] Fujitsu has announced an $800 million investment in a plasma plant. Plasma-display makers believe they can bypass the dismal yields that have long plagued the AMLCD makers, but they have not yet demonstrated a high volume capability to do so.

Automobiles offer additional commercial opportunities for the use of FPD. The Nippon Electric Corp. (NEC), for example, has estimated that by 1996, automotive display panels and videophones will fuel a rise in demand for commercial AMLCDs.[19] Car-based displays share with military displays the need to operate in temperature extremes.[20]

Manufacturers are also developing flat-panel touch-screen displays that will be used in the interactive information kiosks found in airports, museums, and stores, where space can be costly. The displays would be built into walls or counters, freeing up floorspace for merchandise. Such displays are used in automatic teller machines; they are also likely to find a home on the control consoles of machine tools and in crowded financial trading centers, where (as a manager at Sharp Corp. explained) "traders have no time for keyboards and no space for a CRT, but they do want a bright, colorful, high-resolution display."[21]

Industry Structure and Leadership

The DOD Flat Panel Display Task Force reported that while there are over 50 firms worldwide producing flat-panel displays, Japanese firms dominate the market.[22] The U.S. FDP industry remains quite small.

The global FPD industry, by most definitions, exhibits a good deal of civil-military integration because so many of the component parts of military FPDs come from Japanese commercial firms. Although more than a half-dozen domestic manufacturers offer military specification (Mil-Spec) AMLCDs with diagonal sizes as high as 10.4 inches, the display itself is usually made in Japan. LCDs (PMLCDs and AMLCDs) accounted for about 87 percent of global FPD shipments in 1993. One company, Sharp Corp.,

[17] D. Lieberman and J. Yoshida, "Flat Panels Jockey for HDTV Position," *Electronic Engineering Times*, May 24, 1993 (Issue 747), p. 1.

[18] Ibid., p. 62.

[19] D. Lammers, "No Letup in Japan's LCD Investments," *Electronic Engineering Times*, p. 20, Mar. 15, 1993 (Issue 737).

[20] According to the Armor All Products Corp., when a car is parked in direct sunlight on a 105 °F (41 °C) day, the interior temperature can soar to 240 °F (116 °C) on the dashboard. Sharp reports that an LCD screen will be permanently damaged through irreversible chemical changes when it approaches 212 °F (100 °C). For this reason, Sharp and other LCD makers are developing temperature-resistant displays for car dashboards. C. Lu, "Taking Care of Your PowerBook," *MACWORLD*, January 1994, pp. 178, 180.

[21] D. Lieberman, "Color Flat Panels Make Comdex Scene," *Electronic Engineering Times*, Nov. 15, 1993 (Issue 772), p. 52.

[22] Flat Panel Display Task Force, op. cit., footnote 1, p. IV-1-IV-2.

claimed 55 percent of the world AMLCD market. Japanese dominance of the AMLCD market is reportedly the result of very large capital outlays, estimated to be $3 billion for manufacturing facilities.[23] Such outlays demand long-term corporate commitments since FPD production-line investments are large and cannot be recouped over short periods.

While research and development in high-information-content flat panel displays is accelerating in the United States, there is still only a small production capability. A major reason for this is said to be a lack of American investment capital. IBM, for example, reportedly established its AMLCD joint-production venture with Toshiba (DTI) in Japan partly because of the low capital costs then available in Japan and the access to Japanese capital markets.[24]

U.S. production of FPDs is currently concentrated in "niche products" largely designed and manufactured for DOD procurement. U.S. defense contractors point to the Japanese technological lead and lower prices as the reasons for why they have turned to Japan when choosing an AMLCD source.

Between 1987 and 1994, much of the domestic AMLCD production base disappeared or became internationalized. When Thomson purchased GE's consumer electronics operations in 1987, it also acquired the process that GE developed for making amorphous-silicon AMLCDs. Thomson moved the plant to France. And in another move, Litton purchased PanelVision and moved it from Pittsburgh to Canada. In each case, when the U.S. company's management was faced with deciding between selling the pilot plant and spending up to a hundred million dollars to ramp up from pilot to volume production, they opted to sell the pilot plant. IBM, as noted above, decided to work jointly with Toshiba in Japan.

U.S. production of AMLCD (low volume), is largely concentrated at OIS, Image Quest, Xerox, and Litton (Canada).[25] OIS has been making all its displays essentially by hand with a capacity of about 3,000 AMLCDs per year.[26] It has a new $100 million ($50 million from ARPA) automated facility in Wayne County, Michigan, coming on line in mid-1995. Its 40,000 units per year capacity is still only a fraction of the Japanese capability.

A partnership between AT&T, Xerox, and Standish also plans a domestic AMLCD production testbed. Raytheon reportedly plans to produce FEDs at its Quincy, Massachusetts plant. TI is making investments in FED, as well as in DMD.

The flat panel display industry in Europe is highly fragmented. Its capabilities thus far are predominantly in research, not production. Despite an established presence in video consumer electronics, the major European electronics firms are far behind the Japanese in the development of advanced displays.[27] Companies involved in the field include AEG (Germany), which is working on AMLCDs; Philips (The Netherlands), which is working on AMLCDs for a range of products, including televisions, with Sharp (Japan); Olivetti & Co. (Italy), which is working with Seiko (Japan); and Thomson S.A. (France). A consortium of four firms (Philips, CNET-SAGEM,[28] Merck, and Thomson) has invested a reported $70 million

[23] The DOD FPD Task Force and others have estimated that Japanese production investments will increase dramatically in the future.

[24] Flat Panel Display Task Force, op. cit., footnote 1, pp. VI-7 and -8.

[25] "How to Build AMLCD at Home," *The Clock*, vol. 3, No. 2 (Santa Monica, CA, May 1995), pp. 16-19.

[26] B. Robinson, "U.S. Flat Panels Could Take Off with AF," *Electronic Engineering Times*, Mar. 2, 1993 (Issue 682), p. 20.

[27] M. Borrus and J.A. Hart, "Display's the Thing: The Real Stakes in the Conflict over High-Resolution Displays," Working Paper 52, Berkeley Roundtable on the International Economy, Berkeley, CA, March 1992, p. 29.

[28] Centre National d'Etudes des Telecommunications is the research arm of France Telecom; SAGEM is Societé d'Applications Generales d'Electricité et de Mechanique.

in an AMLCD plant in Eindhoven, The Netherlands.

A number of Korean and Taiwanese firms are also entering the market. Samsung and Goldstar (Korea) are said to be well into production.

Industry Trends

American firms have been very active in flat-panel-display R&D. U.S. AMLCD research and development has been directed toward a broad spectrum of activities. R&D has received a further boost as a result of the National Flat Panel Display Initiative. The NFPDI promises to provide, on a competitive basis, 50 percent of the R&D costs for next generation process and manufacturing procedures for firms that will build high volume current generation manufacturing factories now.[29]

The outlook for increased domestic production is improving with the OIS production, the pilot facilities, and the interest by large firms like TI. But the big production investments appear to be occurring in the Far East—Japan and Korea. No U.S. firm has yet made a large production commitment of the size occurring in those two countries.

There are clearly trends toward cooperation among firms, both domestically and internationally. The IBM/Toshiba joint production at DTI in Japan is one example.[30] Hughes Aircraft has launched a manufacturing and marketing agreement with Japan Victor Co. (JVC) to develop, manufacture, and market liquid-crystal light-valve (LCLV) projectors, also known as hybrid image-light amplifiers (ILAs).[31] The Advanced Display Manufacturing Partnership (ADMP) involving AT&T, Xerox, and Standish is another example. Several consortia, such as the U.S. Display Consortium, are aimed at establishing the industrial infrastructure of fundamental knowledge, process technology, and mass-production techniques that are needed for U.S. firms to become globally competitive.

U.S. companies are also licensing technology from several foreign firms. TI, for example, gained access to a 25-inch color plasma display developed by Oki Electric Industry Co. and NHK in 1992 under an agreement with NHK, Japan's national broadcasting company.[32] TI and Raytheon have also licensed FED technology developed by France's Laboratory de Technologie et d' Instrumetation from Pixel International.[33]

CIVIL-MILITARY INTEGRATION

As noted earlier, the civil and military components of the *global FPD base* are considerably integrated. There is, however, little integration in the United States base at the production level, since almost no U.S. FPD production base exists. The DOD is interested in developing an *integrated U.S. base* because, the Department argues:

> DOD cannot currently rely on the existing overseas supply base to furnish customized or specialized products or capabilities that will be required to support future DOD needs, or to provide leading edge technology to DOD before it is in widespread commercial use.[34]

Even in the United States, however, there is some level of integration. OIS's AMLCDs, for example, are not exclusively for the military. Commer

[29] "Into the Wild Blue Yonder," *The Clock* 2(3):1 (Santa Monica, CA: September 1994).

[30] IBM reported that when the decision was made in 1989, Japan was the only place to locate that made business sense. Flat Panel Display Task Force, op. cit., footnote 1, pp. VI-7 and -8.

[31] In the LCLV system, a CRT photoelectrically transfers an image onto the liquid-crystal layer of a light valve. The image then travels through a polarized-beam splitter. After being amplified with the light from a xenon arc lamp, the image is fed through a projection lens and onto a screen.

[32] J. Yoshida and D. Lieberman, "At SID: Color Plasma Takes on LCD Panels," *Electronic Engineering Times*, May 18, 1992 (Issue 693), p. 1.

[33] Flat Panel Display Task Force, op. cit., footnote 1, p. VI-10.

[34] Ibid., p. I-6.

cial airlines have shown interest in the company's cockpit displays. Indeed, only about half of the 14 displays that OIS was developing in early 1993 were designed for the military market.[35] OIS displays are also used in Boeing's 777 aircraft.

Factors Favoring Integration

Certain technical, market, and policy factors favor integration.

Technical Factors

The current Japanese ability to produce many of the components used in both American military and civilian FPD applications in the same facility makes it clear that technical barriers to such integration are not a major problem. Because many technologies have both defense and commercial uses, there are few technical reasons for separating the R&D functions. Indeed, U.S. firms often currently combine the research on their defense and commercial displays at one facility, but because of acquisition rules, often separate defense and civilian production.

Trends in design and manufacturing, such as the use of computer-aided design (CAD) and computer-aided engineering (CAE) systems, allow firms to design and develop flat-panel displays in alternative (e.g., military and civilian) versions quickly.

Acceptance of common standards by suppliers and flat-panel manufacturers alike would also aid integration. For example, if equipment manufacturers standardize substrate sizes, products such as chemical-vapor-deposition machinery, inspection stations, and material-handling lines will be able to work with a greater range of ancillary equipment. Standardized pinouts will reduce the variety of connections, bringing economies of scale. The Air Force Cockpit Office is working on an AMLCD standard. In a 1992 survey exploring where FPD standards would be most useful, Japanese LCD manufacturers cited channel number, pin arrangement (number and pitch), methods for evaluating reliability, and methods for packaging.[36]

The Semiconductor Equipment and Materials International (SEMI) North American Flat-Panel Display Division was created to serve as the equipment and materials liaison body to the U.S. Display Consortium (USDC). In close cooperation with the USDC, SEMI is leading a domestic initiative to create physical and process standards for FPD equipment, materials, and components. Standardization can catalyze product development and—by allowing the economies that come from large-volume component production—and expand market opportunities. By helping to make equipment and processes interoperable, SEMI and USDC hope to help the U.S. FPD industrial base capture economies of scale.

Market Factors Favoring Integration

Military displays are typically tailored for specific applications. They are often square, a shape suited for all-aspect radar tracking. As commercial applications for flat displays expand beyond lap-top computers, square displays will become more common. Automated teller machines, for example, use square displays. Because such machines are often difficult to shield from the sun, they may also need bright displays such as those used in cockpits.

Civil-military integration market opportunities also appear possible for large displays in the emerging sector of simulation. Civilian demand for large, flat displays may be driven by HDTV. Military demand is likely to be driven by the growing need to simulate the complex environments of the battlefield. Large flat displays have been sought by the Director of Defense Research

[35] Robinson, op. cit., footnote 34.

[36] R. Kawano and K. Fujita, "TFT Driver Standardization Urgently Needed," *NIKKEI MICRODEVICES*, Dec. 10, 1992, pp. 183-185; reprinted in English in *Science & Technology, Japan, Flat Panel Display 1993,* JPRS Report, Foreign Broadcast Information Service, Nov. 16, 1993, JPRS-JST-93-093-L, pp. 50-52.

and Engineering (DDR&E) for several years. The defense rationale was explained in DDR&E's 1992 *Defense, Science, and Technology Strategy*:

> A new generation of distributed, seamless simulations can create realistic, "synthetic" battlefields to better understand the complexities of future power projection roles and missions. They then can communicate these needs in an operational context more clearly to the development community, which is also on the "net." As candidate solutions are proposed across the community, they can be tried out synthetically and shown to all concerned.[37]

Similarly, large displays are needed by industry to simulate factory floor operations before building new products and facilities. Other areas of the common civil and military interest have been suggested by Brian Kushner, Vice President of MCC:

> Many other partnership priorities could help smooth the integration of commercial and defense industrial sectors and create an effective network of public-private coordination. For example, the DOD's recently published *Defense, Science, and Technology Strategy* emphasizes the creation of "synthetic environments" through simulation technology as a means of "involving the war fighters" in the development and implementation of technology. There is a substantial overlap with commercial requirements for improved graphical interfaces and artificial environments that can support a wide range of business and consumer transactions. Cooperative efforts here could result in substantial leverage for both sectors.[38]

Market demand for high-resolution color images in small head-mounted or helmet-mounted flat-panel displays is also developing in both the defense and commercial sectors. The emerging civilian market for "virtual reality" is fueling a quest for head-mounted displays. Such displays would be used in recreational activities, such as computer games. Real-estate agents, architects, and builders also seek to use small helmet-mounted FPDs to help clients more accurately determine their wants and needs by "walking through" a building even before the first cornerstone is laid.

The military market, meanwhile, is driven by the need for soldiers to be able to view maps, targets, and alphanumeric characters in great detail on displays no larger than 2 inches diagonally. Technologies allowing circuitry to be integrated directly on the glass may possess great promise here.

Policy Initiatives

One of the objectives of the National Flat Panel Display Initiative is an integrated "domestic" FPD base. But the DOD is also interested in global acquisition—if it provides early, assured access to techgnology. Even before this latest initiative, the U.S. government pursued an international integration strategy that sought access to Japan's essentially commercial FPD technology.

In October 1993,[39] for example, a DOD team, led by the Department's Undersecretary for Acquisition and Technology, visited Japan to examine the potential for exchanging U.S. military technologies, including sensors and smart weapons, for Japanese expertise in mass-production technologies, including flat-panel displays. Such ideas have met with some Japanese resistance because they match commercially useful technology developed by Japanese firms—with their own money—with technology developed with U.S. government money. Still, officials express some optimism about increased cooperation. Developments in Korea may offer other opportunities for cooperation and assured access to technology.

Government funding of R&D efforts that might affect civil-military integration in the FPD industry includes the Defense Advanced Research Projects Agency (DARPA, now ARPA) support for

[37] Director of Defense Research and Engineering, *Defense Science and Technology Strategy,* July 1992, p. I-12.

[38] B.G. Kushner, "Dual-Use Concept Gains Respect," *Electronic Engineering Times,* Nov. 9, 1992 (Issue 720), p. 54.

[39] G. Leopold and M. Ryan, "Exports Enter Eastern Endgame," *Electronic Engineering Times,* Nov. 8, 1993 (Issue 769), p. 50.

research and development related to high-definition displays involving work in display technology, multimedia computer systems, video-signal compression, high-resolution graphics, and corollary fields going back more than two decades. Many believe that without government support, the U.S. flat-panel display industry would have ceased to exist or would have been bought out by Japanese or Korean companies.

In recent years, the government has spent about $100 million annually on FPD R&D. The National Flat Panel Display Initiative builds on this experience. It uses focused government R&D investments to encourage private investment in FPD production, because government decision-makers believe:

> U.S. companies are at the leading edge in understanding the functioning and design of FPDs of all types and technologies, (but) U.S. industry lags considerably behind the leading edge in its understanding of the manufacturing processes and controls necessary to produce FPDs in high volumes at sustainable yield rates.[40]

In 1992, DARPA began Phase 2 of its three-phase High-Definition Systems (HDS) program, designed to help U.S. FPD manufacturers to develop the capability to produce such displays on assembly lines. In February 1993, ARPA awarded $10 million to each of four universities to establish Phosphor Technology Centers of Excellence, with additional funding coming from the participating universities. In December 1993, under its Technology Reinvestment Project, ARPA awarded funding to the University of Central Florida (Orlando) to launch a National Alliance for Photonics Education.

At the same time, ARPA committed $20 million to the U.S. Display Consortium. The consortium's interim chief executive officer called the investment "a great example of ARPA leading the way in the development of dual-use technology. The importance of display technology in both commercial and military applications makes absolutely critical the funding of a U.S.-based infrastructure to serve domestic manufacturers."[41] ARPA is scheduled to fund a decreasing share of USDC's operating expenses, and the consortium is expected to be self-supporting by 2003.

Under the Bush Administration, officials in DARPA's HDS program were careful not to tout commercial applications as a goal of their funding.[42] All that changed under the Clinton Administration, which has made it clear that it views FPDs as a strategic technology.

The National Flat Panel Display Initiative includes efforts that will establish an infrastructure of basic technology, equipment, low-cost manufacturing processes, standards, and quality-assurance techniques that will allow U.S. manufacturers, should they choose, to produce flat-panel displays domestically in high volume.

Factors Inhibiting Integration

The greatest single inhibitor to the civil-military integration of a U.S. FPD industry is the lack of a commercially viable domestic industry. Domestic CMI in this industry, as in shipbuilding, requires the development of a commercially viable component. However, in contrast to the shipbuilding industry in the United States, where few large commercial ships have been produced even with

[40] Flat Panel Display Task Force, op. cit., footnote 1, p. I-8.

[41] B. Robinson and D. Lieberman, "Consortium Wins DARPA Flat-Panel Award," *Electronic Engineering Times*, Feb. 8, 1993 (Issue 732), p. 10.

[42] Explaining the reasoning behind the Phosphor Centers of Excellence, Lance Glasser, director of the Agency's Electronic Systems Technology Office, explained, "It's more to provide the capability than anything else. We want to be in the position a few years from now for U.S. manufacturers to be able to decide whether they want to manufacture in the U.S. themselves or not." B. Robinson, "DARPA in Flat-Out Panel Push, *Electronic Engineering Times*, Aug. 3, 1992 (Issue 704), p. 60.

foreign components, there is a developing indigenous FPD industry here.

Technical Factors

Although technical factors do not appear to be a major inhibition to integration, there are some technical factors that constrain the degree of integration. For example, although a military flat-panel display may not look much different from its commercial counterpart, the users of military displays seldom enjoy ordinary viewing conditions or benign environments. Thus, although by many performance yardsticks commercial electronics have overtaken their military counterparts, that is not true of flat-panel displays. Military FPDs must satisfy performance demands that commercial products do not need to meet. Nevertheless, some of the gap can be bridged by repackaging, possibly as a separate activity so it does not add to commercial costs.

Difficult lighting conditions

Military displays must be able to be read when bathed in midday sunlight. This requirement calls for brightness levels as high as 10,000 foot-lamberts—some 200 times the brightness of commercial displays. Because color is used to represent threats and conditions, the display's colors must remain stable when exposed over long periods to ultraviolet light. If the display is backlit (as most AMLCDs are), there must be a fail-safe backup so that the pilot can always read the display in the blinding sun.

Superior viewing

In battle, seconds count; pilots and soldiers must be able to pick information off their displays instantly and from oblique angles. Backgrounds must be jet black to absorb stray light. The backlight must be adjustable to provide satisfactory viewing over a wide combination of available light and available power. Commercial resolution (typically 80 to 96 pixels per inch) is too coarse to render finely detailed maps. Military displays need as many as 128 color pixels per inch.

Extreme environmental conditions

To ensure that they will operate reliably in temperatures ranging from Arctic winters to Sahara summers, military flat-panel displays are typically equipped with built-in heaters for the panel itself; backlit displays include a second heater to keep the backlight from failing. They must also withstand the shock and vibration of daily life in aircraft and armored vehicles. Displays used on Navy airplanes, aboard ships, and in submarines must withstand humid, salt-spray conditions that would quickly corrode commercial displays.

Low power

Many military displays draw their power from small, soldier-carried battery packs. Commercial displays may draw too much power to serve in the field. Accordingly, soldier-carried military displays must have extremely efficient backlights and glass that transmits unusually high amounts of light.

Voltage differences

Many DOD communication systems are designed to draw current at 12 or 24 volts. These levels differ starkly from the consumer sector, where the standard device voltage long ago migrated from 12 to 5 volts. By 1995, led by the demand for long-lived portable computers, 3.3-volt systems will begin to outsell 5-volt systems. With consumers demanding ever-longer battery life, the industry is heading toward 2.2 volts. In the face of these changes, the military may adopt lower voltage sources. There are several technical hurdles to overcome in this area.

Interconnections

Many weapon systems use the MIL-1553D data bus. Military flat-panel displays must possess the necessary connectors to receive data from this bus, and the bus connectors, as well as the power connectors, must be rugged and highly reliable. These connectors are seldom used in commercial flat panel displays.

Market Factors

Much of the FPD used by consumers are likely to remain extremely price-sensitive. However, there is little chance that the price pressures on military cockpit displays will ever come close to the commodity pricing that these devices call for. On the other hand, there may be a great deal of overlap between defense and commercial aircraft FPD needs. In this case, the need is to examine markets that are driven by similar performance need.

Policy Factors

Acquisition law and regulations still inhibit the purchase of many commercial items. While the Federal Acquisition Streamlining Act of 1994 (FASA) will eliminate many of the barriers to integration relating to commercial products (e.g., it will drop requirements for cost and pricing data), FASA does not address many of the constraints that exist with militarily unique items. Thus, acquisition procedures such as government cost-accounting rules and in-plant oversight will still have an impact on the level of integration within firms and facilities.

DOD's changes in the use of military specifications and standards may greatly reduce the barriers to CMI. This, however, remains to be seen and will depend on how changes are implemented. Few of the current military specifications would be of value to most consumers. Hence, it may be difficult for a display that met these specifications to find a broad commercial acceptance. Nevertheless, much of the ruggedness that certain Mil-Specs require can be, and indeed is, provided by careful packaging (e.g., hermetic seals and durable housing). Thus, there is no reason that ruggedization requirements, by themselves, must preclude commercial FPDs from showing up in cockpits and on the battlefield.

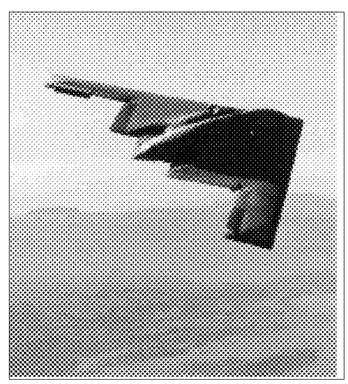
Implications of Enhanced Integration

The relatively small military market, representing, by some estimates as little as 1 percent of the total market for flat-panel displays, makes some integration with the commercial market imperative—if the military is going to have early access to new technology. Because of the military's special performance needs, the commercial base might also benefit from selected developments—even if the overall military effort remains quite small.

Whether the integration needs to occur in a domestically based industry or an internationally based industry is a question that continues to be debated. Many argue that there are strategic reasons for ensuring a healthy, integrated domestic production base. There is concern among U.S. observers that loss of the AMLCD market by U.S. firms may also result in a significant loss of the U.S. IC industry as more functions (such as logic, display driving, and diagnostic testing) are embodied within the AMLCD structure in lieu of being manufactured as separate elements. The observers also fear that a lack of manufacturing experience may lead to a situation where the military will not have access to the best technology. Others argue that a globally robust and dispersed FPD industry can provide the Nation with its military needs. What is needed, according to these observers, is the capability to maintain access to global technology developments and the design talent to incorporate these developments into military systems. Whichever argument is correct, it is clear that some level of integration is preferred.

Case Study 2: CMI in the Polymeric Composites Industry

Composite materials are quite common today and are used in nearly every segment of civilian and military industry. Composite materials consist of two or more identifiable constituents that together exhibit properties that are generally superior to the properties of the individual constituents. These materials are certainly not new; the early inhabitants of Egypt, for example, used composite bricks of mud and straw to construct many dwellings. Reinforced concrete, the carbon-epoxy used in some fishing rods and tennis rackets, the light-weight composite used in some armor, and the fiberglass-epoxy used in fishing and racing boats are all examples of various types of composite materials. A 1993 study by the Strategic Analysis Division of the Department of Commerce found that the value of the U.S. market for polymeric-matrix, metal matrix and carbon/carbon composites in 1991 was $2.6 billion, and the worldwide total value was $4.7 billion.[1] (See box 3.)



A wide variety of fiber-resin combinations is in use today, and the market for polymeric-matrix composites—especially for aerospace and military-related products—is large. Until recently, the military applications of polymeric composites were driven mostly by performance advantages. However, over the past few years, cost has become an increasingly important factor in mili-

[1] U.S. Department of Commerce, *Critical Technology Assessment of the U.S. Advanced Composites Industry* (Washington, DC: U.S. Government Printing Office), December 1993.

BOX 3: Composite Materials

Ceramic-Matrix Composites

Ceramic-matrix composites are composed of reinforcing ceramics embedded in a ceramic-matrix. For example, the reinforcements can be long, continuous fibers; short fibers; small, discontinuous whiskers; particulate; or platelets, Typical reinforcements include alumina, cordierite, mullite, silicon carbide, silicon nitride, zirconia, titanium diboride, fused silica, and graphite, Common matrix materials include alumina, cordierite, mullite, silicon carbide, silicon nitride, zirconia, and titanium diboride,

Ceramic-matrix composites have excellent corrosion resistance, excellent high-temperature resistance, high levels of hardness, relatively high elastic moduli, and low relative weight, They can be classified into three general categories: monolithic or single-phase ceramics (those with no discrete reinforcements); discontinuous fiber-, whisker-, or platelet-reinforced ceramics; and long, continuous-fiber-reinforced ceramics, Unlike polymeric-matrix composites, which need reinforcements primarily to enhance structural properties, ceramic-matrix composites use the reinforcements to improve fracture toughness, reliability, and durability, as well as to enhance structural properties,

Metal-Matrix Composites

Metal-matrix composites (MMC) consist of matrix materials, such as lightweight alloys of aluminum, magnesium, or titanium, reinforced with ceramic particulate, whiskers, or fibers. As is the case with ceramic-matrix composites, reinforcements can be continuous or discontinuous, Carbon fibers and ceramic fibers are used as continuous reinforcements in metal-matrix composites, Typical ceramic fibers used as continuous reinforcements are alumina, silica, boron, alumina-silica, zirconia, magnesia, mullite, boron nitride, silicon nitride, and titanium diboride. Typical discontinuous reinforcements include particulate and whiskers, The most common types of particulate are alumina, titanium carbide, silicon carbide, boron carbide, and tungsten carbide, The most common types of whiskers are silicon carbide, silicon nitride, and alumina,

Carbon-Carbon Composites

Carbon-carbon composites consist of carbon fibers as the reinforcing fiber and a carbonaceous material as a matrix material, Carbon-carbon composites are usually classified into two types: structural and nonstructural, The reinforcing fibers can have many forms: chopped, continuous, two-dimensional woven, and three-dimensional woven, The choice of reinforcement depends on the application,

The process of depositing carbon into a carbon-fiber preform to act as a matrix material is called *densification.* The carbonaceous matrix material is deposited in the carbon fiber preform in two general ways, The most common method is chemical-vapor deposition (CVD), also known as chemical-vapor infiltration (CVI). In this method, the pyrolitic carbon is deposited by the chemical cracking of natural gas at very high temperatures and very low pressures. The second method is referred to as liquid impregnation, In this method, a relatively high-char-yield liquid resin is impregnated into the carbon preform and then carbonized at high temperatures to form the carbon matrix. Both processes must be repeated many times to achieve usual levels of densification, making carbon-carbon composites rather expensive.

The microstructure of the carbonaceous matrix material has an important effect on the properties of the final composite. Microstructure range from small, randomly oriented crystallite known as isotropic crystals to larger, highly oriented lamellar crystallite structures, A significant amount of research work is under way to develop quantitative correlations between microstructure and mechanical and thermal properties of carbon-carbon composites.

SOURCE: U.S. Congress, Office of Technology Assessment, 1995,

TABLE 4: Comparative Properties of Fiber Reinforcements

Material	Density (lbs./in.^{3})	Tensile strength (KSI)	Tensile modulus (MSI)	Specific tensile strength x10^5[lbs/in^2/lbs/in^3]
S-Glass	0.09	665	12,4	73.8
Carbon (T-300)	0.06	450	34	75
Carbon (T650-42)	0.06	730	42	121
Aramid (K-49)	0.052	550	18	105
Boron	0.09	510	58	56.7
Silicon carbide	0.086	400	28	46.5
Aluminum (7075-T6)	0.101	81	10,4	8.1

SOURCE: M.Y.C. Niu, “Composite Airframe Structures” (Hong Kong Conmilit Press, 1992)

tary acquisition. In some instances, cost is now more important than incremental improvements in performance. As competitive pressures increase, cost will play a greater role in the civilian and military markets.

In the commercial sector, cost, coupled with unique function, has long been the major force behind the use of polymeric-matrix composites. For example, fiberglass boats are not only superior to wooden boats in many measures of performance, they are also less expensive to purchase and maintain than wooden boats. Enclosures for electronic devices manufactured from injection-molded composites can also be significantly less expensive than their machined metal counterparts.

The focus of this study is polymeric-matrix-composite materials made by combining short or long fibers or particulate and an organically based matrix material, which binds the fibers or particulate together. Normally, the reinforcements (i.e., the fibers or particulate) are used to carry structural loads, and the matrix material, or resin, is used to hold the fibers together, to protect the fibers, and to transmit structural loads between the reinforcing fibers. This study briefly examines the potential for civil-military integration in the polymeric composites industry. It considers the technology and discusses the current structure and trends of the industry. Finally, it considers factors that enhance or detract from the potential for integration.

TECHNOLOGY AND USE OF POLYMERIC-MATRIX COMPOSITES

Fiber Technology

The typical fibers used in today’s polymeric-matrix composites are carbon, aramid fibers, and glass. Fibers come in many forms, such as particulates and short and long fibers. They are primarily responsible for the structural properties of the composite, such as strength and stiffness. The fiber form is usually selected to meet the particular structural requirements of the item being manufactured.

The specific tensile strength (defined as tensile strength divided by density) of composites compared to aluminum is shown in table 4. The higher the specific tensile strength, the lighter the material and the better the structural application for a particular load carrying capability.

Resin Technology

The organic matrices, or resins, most often used in composites can be divided into two major classes: *thermoses* and *thermoplastics.* The choice of resin is largely based on ultimate-use temperature, toughness, environmental resistance, and ease of manufacture. (See table 5.)

TABLE 5: Properties of Thermosets and Thermopla

Resin type	Process temperature	Process time	Service temperature	Solvent resistance	Toughness
Thermoset	Low	High	High	High	Low
Thermoplastic	High	Low	Low	Low	High

SOURCE U S Congress, Office of Technology Assessment, *New Structural Materials Technologies, OTA-TM-E-32* (Washington, DC U S Government Printing Office), September 1986.

TABLE 6: Properties of Thermoset Resins

Material type	Mechanical properties	Upper use temperature	Processibility	cost
Epoxy	Excellent	200-250 “F	Good	Low-medium
Polyester	Fair	180 OF	Good	Low-medium
Phenolic	Fair	350 OF	Fair	Low-medium
Polyimide	Good	500-600 ‘F	Fair-difficult	High
Bismaleimide	Good	350 OF	Good	Low-medium

SOURCE: M.Y.C. Niu, ''Composite Airframe Structures” (Hong Kong: Conmilit Press), 1992.

Thermoset resins change their chemical composition when they are heated (called curing) to form high-strength, high-stiffness, rather brittle cross-linked networks. This process is irreversible. Thermoset resins have been used for many structural applications. The most commonly used thermoset resins are epoxies, polyesters, phenolics, and polyamides, which includes bismaleimides. (See table 6.) Polyamides can also exhibit some thermoplastic behavior at high temperatures. (See box 4.)

Thermoplastic resins differ significantly from thermoset resins and are gaining in popularity. They are expected to be used in the Air Force’s Advanced Tactical Fighter. Thermoplastic resins are usually rather high-molecular-weight materials that, rather than being cured to shape, are heated and then formed into shape. No (or very little) chemical reaction takes place in the manufacturing process. The manufacturing process is reversible to some extent, and thermoplastics can be reused and reformed into other shapes. Thermoplastics fall into four general subclasses: amorphous, crystalline, liquid crystal, and pseudothermoplastic.

Polymeric Composites as Structural Material

The enormous number of available fibers, fiber forms, and matrix resins allows nearly unlimited freedom and creativity in engineering an optimum material for any given application. While this variety provides a tremendous opportunity for creative problem solving, it challenges traditional thinking about structural design and certification.

Once the fiber is combined with the resin matrix to form a structure, the *interphase* is created. The interactions of the fiber and the resin, which result in the interphase, range from very weak, in the case of electrostatic forces, to very strong, in the case of actual chemical bonding. The nature of the interphase profoundly affects the resultant properties of the composite, and plays a key role in properties such as compressive strength, resistance to fatigue, solvents, heat, and moisture.

The advantages of composites as structural material can be better understood by examining some typical properties of these materials and comparing them with those of conventional materials. (See table 7.) For example, a comparison of spe-

BOX 4: Commonly Used Resins

Thermoset Resins

Epoxy resins are widely used in composite applications. Epoxies in general use are reactive polymers that begin as low-molecular-weight materials and progress to highly cross-linked dimensionally stable materials as they are cured. They generally provide very good resistance to chemicals and solvents, but the mechanical properties are adversely affected by moisture. Epoxies adhere well to most commonly used fibers and exhibit low shrinkage, but they are brittle and subject to impact damage that is not always observable to the naked eye.

Polyesters are formed from the polymerization of a diacid and a diol, which react together to form many ester linkages. Curing agents are then added to the basic formula to provide a rigid cross-linked polymer. Polyesters are relatively inexpensive compared with standard epoxies. They can be cured at low temperatures to provide good mechanical and electrical properties. Like the epoxies, however, they tend to absorb water, which can adversely affect mechanical performance, especially at elevated temperatures. Polyesters possess exceptionally good resistance to acids. They are used in the manufacture of radomes, bowdomes, and other submarine structures, as well as in hulls and masts.

Phenolics are one of the oldest commercially used resins. These very complex materials are formed from the reaction of phenol and formaldehyde. If the reaction is run with excess formaldehyde under basic conditions, the product is called a resole. If the reaction is run with excess phenol under acidic conditions, the product is called a novolac. A resole can be converted to a phenolic with heat only, whereas converting a novolac to a phenolic requires the addition of an amine hardener (or catalyst) and heat. Phenolics are used for aircraft-interior applications and rocket-motor exit nozzles

Polyamides tolerate higher use temperatures than do standard epoxies and polyesters. These materials are used for applications in the 400 to 500 ‘F range and are quite difficult to process. However, they exhibit fair damage tolerance, good temperature resistance, and good mechanical properties. Polyamides are used in the manufacture of missile fins, the Global Positioning Satellite, and printed circuit boards.

Bismaleimides are a subclass of polyamides. They are more easily processed than are the conventional polyamides because they can be processed at lower temperatures. However, to develop their mechanical properties to the fullest extent, they must be subjected to an additional heating cycle (a postcure) of approximately 475 F. Bismaleimides are used for aircraft body skins on the AV8-B Harrier and the Advanced Cruise Missile and for the structure of the Advanced Tactical Fighter.

Damage tolerance has become more important with the ever-increasing use of composites. Producers have made significant improvements in damage tolerance. “Toughened” systems have been developed, and some of the newer systems approach the damage-tolerance capability of thermoplastics.

(continued on next page)

cific tensile strengths and specific shear moduli helps explain the structural advantages of composites.[2]

Differences in specific properties provide designers with a range of choices. For instance, if tensile strength is critical to a particular application—for example, for cables to support a bridge deck structure—the most efficient material for that application would have the highest specific tensile strength, which results in the lightest-weight product. In table 7, that material is the unidirectional carbon-epoxy composite. If shear

[2] Specific properties, such as specific tensile strength, are calculated by dividing the property, by the material’s density. For example, aluminum’s specific tensile strength is calculated by dividing its tensile strength by its density.

BOX 4: Commonly Used Resins (Cont'd.)

Thermoplastic Resins

Amorphous thermoplastics have no regular order in their molecular structure, have no definite melting point, and are not normally affected by moisture pickup, but they can be affected by solvents, Although they do not possess rigid three-dimensional chemical links, as do thermoses, they typically have long, loosely intertwined molecular chains that serve to enhance their mechanical properties, They exhibit good damage-tolerance properties,

Crystalline thermoplastics have crystalline regions that exhibit some amount of definite order, as well as an amorphous structure overall. These materials possess a definite melting-point range and can have better mechanical properties than do purely amorphous thermoplastics. They exhibit good resistance to solvents, low moisture pickup, and excellent damage tolerance, The materials, however, often show some variability in terms of mechanical properties because the amount of crystallinity present in the end product (which affects mechanical characteristics) is a function of processing and can be difficult to control, They are used in the rudder assemblies of the F117-A (Stealth) fighter.

Liquid-crystalline thermoplastics possess a molecular structure that is often highly anisotropic and aligned in one particular direction. This alignment has profound effects on the mechanical properties of these materials, Typically, the mechanical properties are quite outstanding along the axis of alignment and not as good along the off-axis, Liquid-crystalline thermoplastics are in the early stages of development but hold great promise for tailoring the properties of a composite at the molecular level, They will probably be used in injection molding to create such products as electronic enclosures.

Pseudothermoplastics exhibit some characteristics of both thermoses and amorphous thermoplastics, These materials are often condensation polymers formed by a chemical reaction during the curing or forming process, However, the degree of cross-linking is very low, enabling these materials to be reformed and reused, Many psuedothermoplastics are in the very early stages of development.

SOURCE: U.S. Congress, Office of Technology Assessment, 1995,

strength is critical—for example, the rib webs in an aircraft wing structure-the most efficient material would be the quasi-isotropic carbon-epoxy composite. Real-world structures are usually subjected to rather complex loading schemes, and the best choice of a material for a given application is often determined by a combination of properties.

▮ The Polymeric Composites Market

According to the Composites Institute, a division of the Society of Plastics Industry, Inc., the composites market in the United States produced 2.68 billion lbs. in 1993, an increase of 5.2 percent from 1992. The data are compiled from over 410 firms, including raw materials and equipment suppliers and producers of composite products, and are segregated into nine market segments: aircraft, aerospace, and military; appliance and business equipment; construction; consumer products; corrosion-resistant equipment; electrical and electronic; marine; transportation; and other. (See figure 5.) In the aircraft, aerospace, and military segment, by far the most important single market, shipments in 1993 were 19.5 percent less than those in 1992. (See figure 6.)

The use of composites is driven by requirements falling into three broad categories: performance and function, quality and reliability, and cost. Some examples of unique performance and function requirements in defense systems include reduced weight, transparency to electromagnetic radiation (stealth), dimensional stability, and resistance to ballistic penetration.

Weight reduction in aircraft systems, for example, can result in increased maneuverability, increased range, increased payload, increased speed

TABLE 7: Comparison of Common Composites with Metals

Material	Tensile strength (KSI)	Shear modulus (MSI)	Density (lbs./in^3)	Specific tensile strength x10^3[lbs/in^2/lbs/in^3]	Specific shear modulus x10^6[lbs/in^2/lbs/in^3]
Aluminum (6061)	42	3.8	0.098	428.57	38.78
Steel (4340)	260	11	0.284	915.49	38.73
Cast iron	44	7	0.26	169.23	26.92
Unidirectional EGlass epoxy	150	0.8	0.075	2000	10.67
Unidirectional boron-epoxy	180	0.7	0.073	2465.75	9.59
Unidirectional aramid-epoxy	180	0.3	0.05	3600	6.0
Unidirectional carbon-epoxy	200	0.7	0.055	3636.36	12.73
Quasi-isotropic carbon/epoxy	80	2.8	0.055	1454.66	5091

SOURCE "Design Guide for Advanced Composites Application," *Advanced Composites Magazine, 1993*

(for a given thrust capability), and decreased fuel consumption, and it has led to the use of polymeric composites that are stiffer and stronger than metals at equivalent weights. The increased fatigue resistance of composites also leads to longer service life.

Many polymeric composite structures have been more expensive than their metal counterparts, especially in terms of acquisition costs. However, recent advances in design practices and composites manufacturing technologies have reduced this cost differential. In some cases, especially where several smaller-parts can be combined into one larger composite part because of a particular property advantage or better manufacturing technology, the composite part is now less expensive than the metal part.

Commercial uses of polymeric-matrix composites are very diverse. Some specific examples include weight in the transportation industry; x-ray transparency and biocompatability in the medical industry; corrosion resistance in the automotive, chemical, and oil industries; tailorable mechanical properties in the sporting goods industry; and electrical resistance and electromagnetic shielding in the electronics industry. In many cases, the materials used for defense applications are identical to those used for commercial applications. The quality specifications for commercial applications are, however, often less strict than those for military applications.

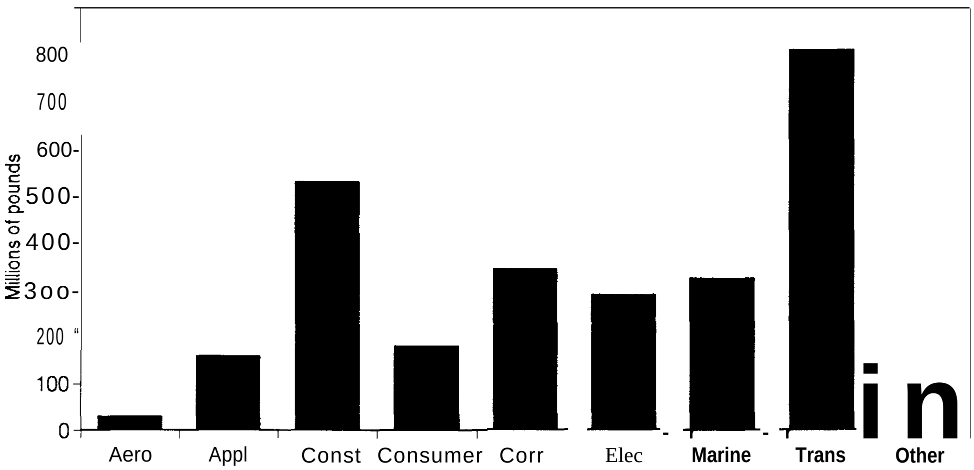
Defense Applications

Polymeric composites are used in a wide variety of defense applications and are found in almost every major weapon system produced. In many cases, weapons systems could not perform their missions without polymeric composite materials. (See table 8.)

The Army uses composites in its helicopters, land vehicles, missiles, munitions, and support equipment. The excellent fatigue and damping characteristics of composites make them ideal for helicopters. Carbon-epoxy materials, for example, are used in the construction of helicopter airframes, refueling booms, skin panels of various types, lightweight bridging, antenna masts, and munitions. Aramid (Kevlar) epoxy is used in helicopter rotor blades, span liners (to protect personnel from shrapnel), launch tubes, helmets, and tactical shelters. Glass-epoxy (both S-Glass and E-Glass) is used in items such as fuel tanks, span liners, rotor blades, launch tubes, motor cases, and bore evacuators. Composites have extended the service life of helicopter rotor blades by a factor of 2 to 3 and have enabled designers to improve the design of the blade. Finally, the airframes of the new generation of helicopters will be largely made of polymeric composites.

The Navy uses polymeric composites in its fixed-wing aircraft, rotary aircraft, ships and submarines, missiles, and satellites. Carbon-epoxy is

FIGURE 5: 1993 Polymeric Composite Shipments



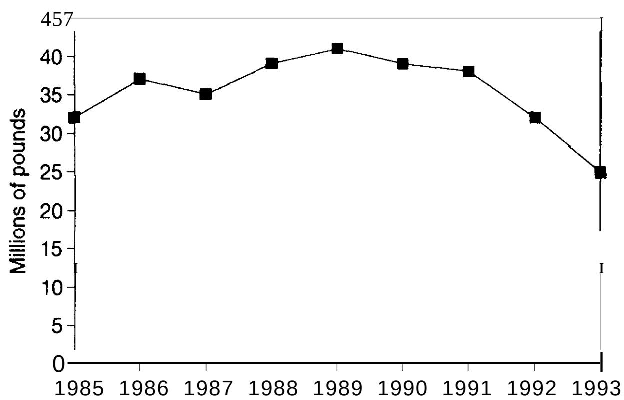
SOURCE: Society of Plastics Industry, Inc. , *Composites Institute Semi-Annual Report, New* York, NY, August 1993

used for wing skins and doors, stabilizer skins, leading and trailing edges, basic airframe structures, refueling booms, and skin panels. The upper wing skin of the Marine Corps AV-8B, for example, is one of the largest one-piece carbon-epoxy aircraft structures made. Over twenty-six percent of the AV-8B's structural weight is polymeric composite material. The Navy also used polymeric-matrix composites to rewing A-6 aircraft. Carbon-epoxy is used in the fabrication of the aircraft ribs, spars, and skins. Aramid (Kevlar) epoxy is used for fairing, spoilers, rotor blades, and launch tubes. Glass-epoxy is used in fairings, spoilers, radomes, rotor blades, fuel tanks, sonar domes, ship hulls, launch tubes, and electromagnetic windows. The V-22 Osprey tilt-rotor craft will use a significant amount of carbon-epoxy composite as primary structural material: approximately 50 percent (by weight) of the fuselage structure, the wing leading and trailing edges, the wing itself, and the empennage. Composites are used in many marine applications because of their acoustical properties.

The Navy has the largest and heaviest (65,000 lbs.) single-piece composite structure of any of the U.S. armed Services: the glass-toughened epoxy bowdome used in the SSN-21 Seawolf submarine. The MHC-51 coastal mine hunter has an all-composite hull.

The Air Force uses composites in a wide variety of aircraft, missiles, launch vehicles, and satellites. Carbon-epoxy structures include wing skins, access doors, stabilizer skins, leading and trailing edges, motor cases, storage spheres,

FIGURE 6: Trends in Aircraft, Aerospace, and Military Composite Shipments



SOURCE: Society of Plastics Industry, Inc., *Composites Institute Semi-Annual Report, New* York, NY, August 1993,

TABLE 8: Defense Aviation and Space Use of Composite Materials	
Rotary-wing aircraft	OH-58, OH-6A, UH-60A, CH-46, CH-47D, AH-IS, MH-60, RAH-66, AH-64A
Fixed-wing aircraft	B-2, B-52, B-1 , AC-130U, C-135, C-26A, C-135, C-26, A-10, TR-1 , F-15, F-1 17A, F-16, F-22, F-111, C-17, C-58, KC-10, V-22, AV-8B, F/A-18, F-14, A-6
Missiles	LGM-118A, AGM-129A, AGM-131, MGM-134A, Hellfire, AMRAAM, Patriot, AGM-65, MLRS, HARM, AT-4, TOW-2, AAWS-M, Stinger, D-5, Tomahawk
Satellites	MILSTAR, Defense System Communication Satellite II, Defense Support Program, Global Positioning System

SOURCE: Office of Technology Assessment, 1995, based on information from H. Reinert and P Hauwiller, *Horizontal Assessment of the Organic Composites Industrial Base,* WL TR 928044 (Beavercreek, OH: Universal Technology Corp. , July 19, 1992), and other sources

adapter skirts, longerons, struts, and trusses. Aramid (Kevlar) epoxy is used in fairings, spoilers, ducting, leading and trailing edges, motor cases, rings, insulation, face sheets, and antennas. Glass-epoxy is used in fairings, spoilers, wing tips, radomes, electromagnetic windows, antennas, and struts. About 40 percent, by basic structural weight, of the airframe of the F-22 tactical fighter will be composite materials.

Commercial Applications

Polymeric-matrix composites have both aerospace and nonaerospace commercial applications. As in the military, strength and light weight enhance aerospace applications.

Aerospace use

Polymeric composite structures have a wide variety of applications on large civilian-transport aircraft. For example, the Boeing 747 uses a 6-ft.-high winglet, carbon-epoxy front- and rear-wing spars, and spar covers made from a carbon-epoxy honeycomb-sandwich structure. The inboard and outboard spoilers, aileron, rudder, elevator, and inboard trailing-edge flap of the B757 are all made from carbon-epoxy composites. The B767 uses carbon-epoxy in the inboard and outboard ailerons, the rudder, the vertical fin tip, and the inboard and outboard spoilers. Carbon and Kevlar-epoxy are used in the trailing-edge-flap track-support fairings, the fixed trailing-edge panels, the vertical-fin fixed trailing-edge panel, the horizontal stabilizer tip, the outboard-flap trailing-edge wedge, the main landing-gear doors, and wing-to-body fairing. Glass and carbon-epoxy are used in the nose-landing-gear doors.

The choice of which composite to use for a particular structure depends on the complex interaction of many factors, including critical loading strength and stiffness criteria, damage tolerance, repairability, ease of manufacture, and cost. Cost and "acceptance and understanding by structural designers" are cited as two reasons why U.S. manufacturers do not make more use of composites on large commercial transport aircraft.

Smaller civilian aircraft use polymeric-matrix composites much more extensively than large aircraft. The Beech Starship, a twin-pusher canard aircraft, is an outstanding example of the full utilization of polymeric composite materials. The airframe is made of carbon-epoxy facesheets bonded to a low-density Nomex honeycomb core. This sandwich structure is very lightweight and extremely efficient. The structural weight of the aircraft is about 15 percent less than a conventional aluminum airplane, and the cost of producing the composite structure is approaching the cost of fabricating an aluminum structure.

Non-aerospace use

Polymeric composites have a wide variety of non-aerospace applications. The sporting goods industry, for example, represents a significant commercial market: tennis rackets, golf clubs, high-performance racing bicycles, canoes, kayaks, canoe and kayak paddles, bobsleds, and snow skis are a few of the applications. Sporting goods companies have taken composite design and manufacturing technologies to very high levels. Indeed, most tennis rackets are currently designed and manufactured using sophisticated hybrid composite technologies to create very specific properties. Carbon fibers and aramid fibers, for example, are combined to tailor the stiffness (primarily from the carbon) with the energy-damping characteristics of aramid to produce rackets with certain *power and feel* or control characteristics. Some manufacturers use a combination of ceramic and carbon fibers in their rackets to achieve a particular balance of properties. No professional tennis player could be competitive today with the wood, steel, or aluminum rackets of the past.

Many cars and trucks now have polymeric composites body panels, hoods, bumpers, cabs, fairings, air deflectors, and truck sleeping compartments. These applications represent *secondary* structure, that is, structure that does not carry primary loads in the vehicle. Several companies are involved in producing specialty vehicles, such as mass-transit vehicles and extremely lightweight commuter and delivery vans, that incorporate composite materials, primarily glass-polyesters, in their primary structural components. The design philosophy is to produce one-piece structures that greatly reduce assembly costs. However, these vehicles are being manufactured in small numbers by fabrication techniques that require hand custom work, rather than in the large volumes associated with the mainstream light-car, light-truck market.

Successful prototypes of cargo-carrying rail cars have been produced by using filament-winding manufacturing techniques appropriate for small production volumes at a cost comparable to that of metal cars. However, no major market for these cars materialized, the company that developed the techniques was sold, and the new owners elected not to market the product.

The medical uses of polymeric-matrix composites include x-ray tables, prostheses, and implants. The potential liability associated with the latter applications has hindered their use, however.

The commercial marine industry represents a large potential market for the application of polymeric matrix composites. Major uses are glass-polyester powerboats, pleasure yachts, and recreational watercraft such as jet skis. The very sophisticated America's Cup yachts use carbon, aramid, and glass composites extensively in their construction.

The infrastructure market is increasingly important and potentially very large. Polymeric composite materials, for example, can solve some of the problems resulting from the deficiencies of conventional steel-reinforced-concrete materials. Applications include vehicular and pedestrian bridge decks (DOD's Technology Reinvestment Project has funded a demonstration project), associated structural components such as pins and hangers, light poles, in-ground gasoline storage tanks, and over-wrappings to prolong the structural life of existing bridges and to increase their resistance to failure from earthquakes. Gasoline retailers now use composite gasoline tanks to replace older, corroded, leaking steel tanks.

Applications of polymeric composites in the construction industry include composite tub and shower units, panels for interior partitions, prefabricated equipment shelters, ladders, and glazing for institutional buildings.

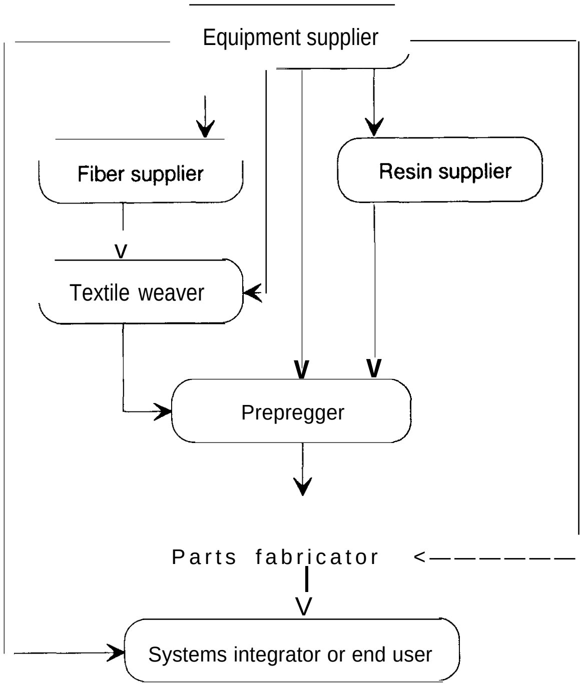
THE STRUCTURE OF THE POLYMERIC COMPOSITES INDUSTRY

U.S. Structure

The polymeric composites industry is composed of resin-matrix suppliers, fiber suppliers, prepreggers,[3] textile weavers, equipment suppliers, parts

[3] Prepreggers take their name from their process: the impregnation of reinforcing fibers with the resins under controlled conditions.

FIGURE 7: Structure of the Polymeric Composites Industry



SOURCE: Office of Technology Assessment, 1995, based on information from Off Ice of Technology Assessment, "The Advanced Composites Industry," *Holding the Edge. Maintaining the Defense Technology Base,* Vol *2.* Appendixes.

manufacturers, systems integrators, independent consultants, and end users. (See figure 7.) The industry has a fair amount of vertical integration. (See table 9.)

Resin-matrix suppliers tend to be large chemical companies that supply the basic resins and additives to prepreggers. Fiber suppliers also tend to be large chemical companies that provide various fiber forms to prepreggers and independent textile weavers, who weave the fibers into fabrics for various applications. Equipment suppliers provide such things as fabrication equipment and consumable items used in the manufacture of end-item parts. Prepreggers combine the fibers with the resins to form prepreg, which is generally used as the "raw material" for the fabricators. Parts manufacturers actually manufacture component or end-item parts. Systems integrators integrate the subassembly parts into a final product.

Global Structure

European polymeric composite firms, like U.S. firms, have forward integrated into the prepreg and structures manufacturing business to gain the value added in the business process. In the early 1990s, British Petroleum, for example, worked in fibers, resins, fabrics, prepreg and structures. Ciba-Geigy worked in everything except fibers, as did Shell and Imperial Chemical Industries. (See box 5.)

As in the United States and Europe, many different companies in Japan produce composite products. These companies include Toray Industries, Sumitomo, Toho Rayon, Mitsubishi Rayou, Asahi Hasei Carbon Fiber, and Nippon Polyimide. Japanese companies that typically started as material suppliers continue to forward-integrate to expand their business both domestically and in the United States. In Japan, sporting goods and leisure products constitute the largest market for polymeric composite materials.

Industry Trends

There are both negative and positive trends in the industry. The drops in defense spending and commercial aerospace have had a major negative impact on the industry. The 1993 study by the Strategic Analysis Division of the Commerce Department found that nearly 40 percent of the firms in this business reported operating losses in 1991.[4] Overall employment in the industry dropped nearly 20 percent between 1990 and 1993. Research and development (R&D) employment in 1993 was down nearly 40 percent from its peak in 1990, indicating a dramatic decrease in R&D investments in the private sector. Consolidation, divestment, and layoffs of skilled production workers and technologists have become quite common.

[4] *Critical Technology Assessment of the U.S. Advanced Composites Industry,* op. cit., footnote **51.**

TABLE 9: Firms Involved in the Polymeric Composites Industry in Early 1994

Item	Company
Resin	American Cyanamid, Amoco, BASF, B.P. Chemicals, Ciba-Geigy, Dow, Epolin, Fiber-Resin Corp., Hercules, Hexel, ICI/Fiberite, Masterbond, McCann, Minnesota Mining and Manufacturing, Poly-Freeze, Polyrene Development, PTM&W, Shell, S.P. Systems, Textron
Fiber	
Suppliers	Allied Signal, Amoco, AKZO, Ashland, DuPont, Great Lakes Carbon, Hercules, Mitsubishi Rayon, Owens Corning, PPG, Textron Specialty Materials, Toho Rayon, Toray, Zoltek
Weavers	Advanced Textiles, Atlantic Richfield, BGF, Burnham Products, Clark Schwebel, Dexter, Fabric Development, Fiber Materials, Highland Industries, J.B. Martin, J.P. Stevens, Ketema, Miliken, Mutual Industries, North American Textiles, Precision Fabrics Group, Techniweave, Textile Composites, Textile Technologies, Textron, Woven Structures, Zoltek
Composite equipment	Airtech International, AVS, Bondline Products, Cincinnati Milicron, Dow Corning, Grim, Icon Industries, Ingersoll, Liquid Controls, North American Textiles, Precision Fabrics Group, Richmond Aircraft Products, RIM Systems, Schnee-Morehead, Thermal Equipment, United McGill, Wacker Silicone
Prepreggers	American Cyanamid, BASF, B.P. Chemicals, Ciba-Geigy, Fiber Cote, Fiber Materials, Fiber Resin, Hexel, ICI/Fiberite, McCann, Minnesota Mining and Manufacturing, Newport Adhesives, Quantum, S.P. Systems, YLA
Major parts manufactures/end users/systems integrators	
Defense	ABB, Aerojet, Alcoa-CSD, Bell Helicopter, Boeing, B.P. Chemicals, Brunswick, General Dynamics, Grumman, Hercules, Kaman, Lockheed, LTV, Martin Marietta, McDonnell Douglas, Morton Thiokol, Northrop, Rockwell, Rohr, Sikorsky, Teledyne
Commercial	Boeing, Chrysler, Composite Horizons, Dunlop, DuPont, Ford, General Motors, Hercules, Hexel, Prince, Wilson Sporting Goods

SOURCE: Office of Technology Assessment 1994, based on information from H. Reinert and P. Hauwiller, *Horizontal Assessment of the Organic Composites Industrial Base,* WLTR928044 (Beavercreek, OH; Universal Technology Corp., July 19, 1992), Office of Technology Assessment, "The Advanced Composites Industry, " *Holding the Edge: Maintaining the Defense Technology Base, vol. 2:*appendixes, 1990, and other sources.

On the other hand, according to the Composites Institute, the weight of U.S. shipments of composites in 1993 was 5.2 percent higher than it was in 1992.[5] In addition, four markets that represent 72 percent of the composites industry by market share (transportation, construction, electrical-electronic, and marine) were all forecasting faster growth rates than the general economy.

The major concern of those worried about the health of the industry is the aerospace-aircraft-military sector, where shipments decreased 19.5 percent in 1993. This downward trend is cause for alarm because this segment of the market generally represents the leading edge in technology development in polymeric composites. In the past, developments in aerospace/military have tended to filter down to commercial uses in other segments of the economy, and have provided technological and economic stimulation in those segments. As a result, this sector is viewed as a "leading indicator" of the polymeric composites industry overall.

[5] Society of plastics Industry, Inc., *Composites Institute Semi-Annual Statistical Report* (New York, NY: Society of plastics Industry, Inc.), August 1992.

BOX 5: Efforts by Consortia To Support Composites Technology

Consortia are emerging as a powerful force in the composites industry as a result of government policy initiatives, such as cooperative R&D agreements, that encourage pre-competitive development activities and that tend to enhance civilian-military integration. The typical consortium consists of groups of companies, including suppliers, fabricators, and end users, that band together to develop pre-competitive technology that can be used by all members. Funding is either a combination of federal funding and member funding or strictly member funding. Several consortia have been formed to address pre-competitive issues related to composites technology. Most of the industry representatives interviewed by OTA consider consortia essential if the U.S. industry is to survive and compete in the global marketplace. Because of the rapidly changing pace of the technology, no one company can afford the R&D investments required to address all the related multidisciplinary issues. Also, consortia are a cost-effective means for companies to address pre-competitive technology issues of interest to the entire community. The fact that many in industry have come to the conclusion that pre-competitive technology cooperation is possible reflects a major shift in attitude toward R&D investment strategy; for many years, companies believed that all related technology information was competitive in nature.

A wide spectrum of technology issues ranging from basic research to materials database development to manufacturing technology development are addressed in consortia.

Composite Materials Characterization, Inc., for example, is composed of Dow Chemical, Lockheed, General Electric, Grumman, LTV, Rohr, and Sikorsky. These members are primarily resin suppliers, fabricators, and end users of composite products. The purpose of this consortium is to establish standards for test methods, processes, evaluation criteria, and materials selection. The consortium also tests new composite materials to establish a consistent independent database of mechanical properties for promising materials. The database is not intended to be a detailed design database for design allowable; rather, it is intended for screening and general comparison of emerging materials. The participating companies fund this effort with no federal help, and the annual investment is about $500,000 to $700,000. However, the data are available only to consortium members.

The Automotive Composites Consortium consists of the “big three” automotive manufacturers — Ford, General Motors, and Chrysler. The purpose of this consortium is to establish joint research programs to demonstrate the advantages of structural polymeric composites for automotive applications and to develop pre-competitive technology necessary for implementation. The consortium is currently working on a demonstration program on rapid resin-transfer molding of structural parts, such as the front end of the Ford Escort. Very ambitious goals have been set for the program, including manufacturing the parts in 5 minutes or less using structural reaction injection molding (SRI M). These manufacturing times are necessary for an economically viable production process for the volumes common in automotive production.

The Center for Composite Materials at the University of Delaware operates a U.S. Army Research Office/University Research Program that concentrates on the manufacturing science of composites from a research perspective. The Center also offers several educational products, including a Design Encyclopedia, an interactive videodisk course on the Experimental Mechanics of Composite Materials, and a video series entitled “Introduction to Composites. ” Each year, it sponsors a workshop about composites for members and a symposium for the public.

The National Center for Manufacturing Science (NCMS) in Ann Arbor, Michigan, is a broad-based manufacturing consortium that addresses many types of manufacturing technologies and issues relating to manufacturing. Only a very small portion of its work is devoted to composites.

(continued on next page)

BOX 5: Efforts by Consortia To Support Composites Technology (Cont'd.)

The Composites Automation Consortium of Burbank, California, consists of Dow Chemical, Charles Stark Draper Laboratories, Foster Miller, Hexcel Corp., Ingersoll Milling Machine, Lockheed Corp., and several others. This consortium is developing automated manufacturing assembly and joining systems to produce composite structures. Its focus is not to develop machines for one assembly or joining technique but to develop machines that are inherently flexible enough to handle a variety of joining and fiber-placement processes. Automated fiber placement and joining had been identified as a critical technology for manufacturing polymeric composite structures in a cost-effective way.

The Great Lakes Composites Consortium, Inc., of Kenosha, Wisconsin, is probably the most broad-based consortium in the United States that concentrates solely on composites manufacturing. This consortium operates the U.S. Navy's Center of Excellence for Composites Manufacturing Technology and consists of over 60 members from all regions of the United States. The principal members are Bell Helicopter-Textron, Inc., Grumman Corp., Lockheed Corp., McDonnell-Douglas Corp., Northrop Corp., and Rockwell International Corp. Other members represent automotive suppliers, machine-tool builders, electrical-control manufacturers, shipbuilders, hand-tool manufacturers, and research institutes and universities. The consortium sponsors applied technology development and technology transfer programs at member facilities. One unique feature of this consortium is the Composites Technology Center in Kenosha, which is a modern composites manufacturing and teaching facility that allows members to transfer technology using the concept of "shared manufacturing. " The consortium's major initiatives include materials and process development, affordable tooling development, net-shape fabrication, fit-up and assembly technology, large structural repair, and environmental-compliance activities.

SOURCE: Office of Technology Assessment, 1995.

Although the number of commercial users of composite materials is growing, demand for defense products is declining and mirrors the decline in the defense budget.

An examination of public and private R&D investments in the advanced-composites industry between 1989 and 1993 reveals another interesting trend. In 1989, when the general perception was that demand for these materials would increase, private investment was a much greater part of the total investment in the industry than was public investment. Confronted with more difficult business conditions in the early 1990s, however, the private sector reduced its R&D spending and the government's share of the investment risk increased.

Designers and manufacturers are reportedly becoming more sophisticated in their technical capabilities, but there are relatively few technical experts in composite design and analysis. Most of these experts have obtained their education through years of on-the-job experience and/or graduate school courses. In general, undergraduate schools do not emphasize composites in formal degree programs. One reason often given for this is that composites technology is truly a multidisciplinary field, and many universities find it difficult to develop effective undergraduate interdisciplinary programs. To design and use composites effectively, technical experts need to understand the basics of chemistry, physics, materials science, mechanical engineering, manufacturing engineering, and must be computer literate. Many in the industry believe that the lack of a formal curriculum in composite materials technology at the undergraduate level has inhibited the widespread use of composites in industrial applications. Industry is also concerned about the lack of basic math and science skills for its composites labor force.

Manufacturers interviewed for this study generally reported a need to improve the manufacturing technology of polymeric composites. For many sophisticated aerospace applications, manufacturing output is low and costs are high. Traditional processes are cumbersome and uneven in quality. The federal government has provided a significant amount of funding for manufacturing-technology development under a variety of programs, which according to some industry observers, have yielded good results for defense applications.[6] Examples of manufacturing-technology programs with both defense and commercial applications include developing resin-transfer molding, injection molding, automated fiber placement, and tooling. (See box 5.)

Material suppliers and small fabricators have been severely hurt by the downturn in business. Some have filed for protection under the bankruptcy laws, others have been put up for sale by their parent organizations. S.P. Systems has been put up for sale by its Italian parent, Montecatini, as have the composites operations of B.P. Chemicals. Alcoa attempted to divest itself of its composites operations but took them off the market when no suitable buyer could be found. The same thing happened to Fiberite, whose parent company is British-based Imperial Chemical Industries (ICI). Industry insiders say that the parent organizations often paid too much for the companies and were subsequently unable to recoup their investments. Continued consolidation and downsizing is expected.

CIVIL-MILITARY INTEGRATION

OTA interviewed several representative firms to assess the current level of integration and factors that favor or constrain integration. The firms chosen, all of which have had significant experience with the government and civilian sectors of the market, were a large, diversified chemical company that started as a material supplier and forward-integrated into parts manufacturing; a small, very capable fabricator that recently diversified out of the military sector entirely into the commercial aerospace sector; a small company that provides the commercial and military marine industries with composite structures and R&D; and a large, diversified commercial and military aerospace company whose development efforts are considered pioneering in the composites field. OTA conducted standardized, indepth interviews with key executives of these firms. In addition to these interviews, less formal interviews were conducted with other material suppliers, designers, manufacturers, and users of polymeric composite materials to expand the database and gather as wide a variety of opinions as possible. Because of competition among firms and the reluctance of some individuals to be quoted directly, some descriptions of specific applications, customers, market share, and specific strategies are not given. Rather, information is presented as general observation.

The firms represent diverse business activities. Their product mix varies from a high of 30/70 civilian/military, to a 50/50 civilian/military, to nearly all civilian (aerospace and nonaerospace), and finally to 100 percent civilian. Their products range from basic polymeric composite raw materials to large fabricated structures, and almost everything in between, including medical x-ray tables, bicycle wheels, aircraft structural parts, recreational boat parts, corrosion-resistant electrical housings, and infrastructure parts, such as small bridges, piers, and poles.

Factors Favoring Integration

Several technical, market, and policy factors favor integration.

Technical Factors

Technical factors favoring civil-military integration in the polymeric composites industry include common design and software, similar manufacturing processes, common inspection technology, and common materials.

[6] Interviews conducted for this assessment.

Common design and software

The increasingly sophisticated products of both the civilian and military markets require firms to update and enhance their design, analysis, and materials-selection processes. Firms now have at their disposal a wide range of design, modeling, and analysis software.[7] This software allows the designer to conceptualize products, often with three-dimensional details, and translates material properties into quantitative material requirements and spatial arrangements to meet product specifications. Much of the impetus for developing modeling capabilities stemmed from military requirements that demanded detailed design and analysis of products, and from the need to substantiate the mechanical and environmental performance of products before anyone would buy them.

The federal government is sponsoring several design technology R&D efforts. An example is the concurrent engineering and manufacturing systems development at the Design and Manufacturing Institute of the Stevens Institute of Technology in Hoboken, New Jersey. This effort, which has been funded by the Army Research Office and the U.S. Navy's MANTECH program, seeks to develop sophisticated software that incorporates artificial intelligence in the form of expert-system rules in the design, analysis, and manufacturing process and attempts to integrate them into one package. The goal is to reduce significantly the time it takes to go from conceptualizing the product to delivering it to the customer. Indeed, now that the know-how to manufacture high-quality, low-defect products is widespread, time to market is the key issue in global competitiveness.

Similar manufacturing processes

End-use-product structural and environmental requirements greatly influence, and in many instances dictate, the choice of the manufacturing process. Many common manufacturing-process technologies, however, can be used to make products for both the defense and commercial markets. For example, injection molding of short-fiber composites is used to produce electronic enclosures for commercial computers or military electronics, and autoclave curing technology, coupled with continuous fiber-reinforced raw materials, is used to produce wing skins for commercial jetliners and military fighter aircraft.

Not all manufacturing-process technologies, however, can be adapted to produce civilian and military products in cost-effective ways. For instance, manufacturing technologies required to produce low-observable structures for military applications have been rather expensive because of the unique nature of the product's requirements. Several firms in conjunction with DOD are pursuing the development of lower-cost manufacturing processes for *stealth* structures.

Common inspection technology

Nondestructive testing techniques developed primarily to assess military applications product quality are applicable in both markets. Information derived from *inspection* investigations helps to provide a database and the knowledge needed to improve and optimize existing manufacturing processes. However, commercial products, especially nonaerospace commercial products, rarely have the same high level of formal inspection re-

[7] One reasonably priced software package called Auto-Cad (manufactured by Auto-Desk, Inc.) runs on personal computers, features three-dimensional modeling, and sells for a few thousand dollars. Another design package named Pro-Engineer (manufactured by Parametric Technology Corporation) features three-dimensional modeling and parametric dimensioning, which uses mathematical equations to describe and automatically recalculate the relationship among part attributes, such as length, width, and height, when changes are made. This type of software package costs about $10,000. SDRC, Inc., manufactures IDEAS, a parametric-based three-dimensional modeling system that includes finite element modeling capabilities for stress and thermal modeling and fluid dynamics. This system is in the $10,000 to $20,000 price range. A much more sophisticated system, ICAD, is being marketed by ICAD, Inc. ICAD incorporates artificial intelligence in the form of knowledge-based rules to assist the designer in creating sophisticated parts. This type of system is in the $100,000 price range.

quirements as do military or commercial aerospace products.

Common materials

Another technical factor favoring civilian-military integration in the polymeric composites industry is the ability to use common materials, especially in the aerospace sector. Both commercial and defense aerospace demands that structures be made from materials deemed to be *qualified* in various mechanical-property evaluations and manufactured in a *precisely controlled* process. In the case of some commercial applications outside the aerospace market, however, the *aerospace way*, as it has been termed, may actually inhibit integration because of the cost of precisely controlling the process.

Market Factors

The major market factors that favor civil-military integration in the polymeric composites industry are the reduced defense market and the current approaches to quality assurance and customer satisfaction.

Reduced defense market

The reduced demand for military aerospace products has already been noted. Commercial aircraft producers are also experiencing a downturn in demand for new aircraft. Many airlines have either not exercised production options or have canceled existing production options. The reduction is forcing material suppliers and manufacturers, as well as end users, to look to new markets if they are to survive and grow. The civilian nonaerospace market (composed of bridges, railcars, light poles, prostheses, highway dividers, structural enhancements to existing structures, and sporting goods and other recreational products) is the logical place to look for new product applications. Many firms are doing so, but with mixed results.

Bridge components such as pins, hangers, and cables are thought to be huge potential markets for the industry. Some have suggested that the federal government, through the Federal Highway Administration, could increase the funding for demonstration projects already under way, sponsor additional projects, and accelerate the rate at which technology is demonstrated and applied. The Technology Reinvestment Project awarded a multimillion-dollar contract to the Advanced Technology Transfer Consortium to develop and deploy many of the technologies needed to exploit the use of composites in the infrastructure, especially in vehicular and pedestrian bridge-building and bridge-repair technologies.

The development of new, nondefense composites markets could allow firms to stabilize their business base, thus facilitating military-civilian integration. As was noted earlier, the transportation, marine, construction, and electrical-electronics markets were expected to grow faster than the general economy in 1993, making them attractive possibilities. There is, however, a question about how cost-effective the transition from military and civilian aerospace applications to nonaerospace commercial applications will be. Such transitions often require significant changes in a firm's culture and its business practices. (See *Factors Inhibiting Integration*, below.)

Approaches to quality and customer satisfaction

The trend toward *lean production* will also enhance civilian-military integration in the composites industry. This strategy is not the same as traditional divestment and consolidation; rather, it refers to redesigning the business to provide existing customers and markets with high-quality products in a timely fashion. This concept has been extended to new-product development, forcing firms to integrate their development activities and to transfer technology between previously separate customer bases.

In the past, the predominant view in both the military and commercial composites sectors was that quality was *inspected in* the product. Each item was inspected separately. This practice led to a very large and cumbersome quality-control system that added significant cost to products. Over the past decade, the military and commercial companies have moved to implement a different philosophy of quality, reducing reliance on detailed examinations and increasing the reliance on detection and elimination of process problems. Changes in federal regulations and paperwork requirements are needed to promote this approach at DOD. The DOD changes in the application of military specifications and standards address some of these issues.

The adoption of a modern philosophy of quality strongly affects a firm's approach to operations in general and to manufacturing operations specifically. The development of high-quality, flexible manufacturing processes is an outgrowth of these improvements and should help firms serve both the civilian and military markets.

Policy Factors

Finally, several recent policies appear to favor civilian-military integration efforts in the composites industry. The DOD attempt to adopt the total quality management (TQM) philosophy is one step. Adopting a TQM approach promotes integration efforts because it encourages defense firms to move toward "lean production" and develop closer cooperation among suppliers and customers. Further, if the government truly adopts this philosophy, defense-procurement activities should be conducted more like those in the private sector and firms seeking to serve both markets would not have to support two different operational systems (e.g., defense and commercial accounting and quality control). However, the fact that one company interviewed for this study recently spun off a sister company as a means to separate its government and commercial composite business activities is evidence that the objectives of this policy have not yet been achieved.

ARPA's Technology Reinvestment Project (TRP) includes several composite projects. Industry representatives interviewed generally believed that the TRP can have a significant positive impact on integration in this industry. Some argued that the TRP is emphasizing dual-use technologies that apply equally well to military and civilian uses. The development of product applications for both markets could lead to an overall expansion in the use of composite products. This expansion would tend not only to lower overall costs for existing and new products but would also create spinoff applications. Further, firms stated that TRP funding, which is cost-shared by the private sector, represents investments in the technology that could not otherwise be made by the industry. (See box 6.)

Factors Inhibiting Integration

Technical Factors

Several technical differences between markets inhibit civil-military integration, including the length of the design process, product requirements, and the material-properties database and testing methods.

Length of the design process

In the military market and in the civilian aerospace market, customer requirements tend to be developed by large, complex organizations over relatively long periods. In contrast, firms providing commercial, nonaerospace applications of composites are required to respond to relatively rapid market changes and the design phase is compressed. Complexity is also a factor in the length of the design process. Aerospace products perform functions that are often more complex and potentially more dangerous than are those of other commercial products. Problems can arise when one organization attempts to serve both markets simultaneously because organizations often have difficulty "shifting gears" to meet customer needs.

Product requirements

Civilian and military applications usually have very different product requirements, especially for nonaerospace applications. To serve a market with diverse product requirements, an organization needs diverse design and manufacturing skills. However, because of the nature of military products, specialists tend to concentrate in rather narrow technical areas. This specialization can become a barrier to addressing the wide range of technical issues arising in the commercial nonaerospace market.

As a result of differing product requirements, the manufacturing technologies and procedures needed to satisfy many commercial applications are quite different from the ones that are suitable for military applications. Even when these skills can be developed within an organization, the cost of doing so can be very high. In addition, diverse manufacturing methods often require the use of different types of equipment, which can require large amounts of capital investment.

Material-properties database and testing methods

The development of acceptable material properties and testing standards represents a significant investment. Often, the data needed to serve one market are vastly different from those needed for another market. Testing standards required to certify or produce "believable" results can cost millions of dollars. Many firms simply cannot afford this investment.

Industry members and federal users of composite materials are attempting to develop standards for testing and a common database for the mechanical and environmental performance of composite materials. Much of this work is funded by DOD and defense firms, which contribute the time and travel expenses of their technical experts in the field. The development and acceptance of standard testing methods and a commonly accepted design database would help lower the cost of using composites.

Market Factors

Certain product or market characteristics inhibit civilian-military integration, including production volume and size and procurement practices.

Production volume and size

Typical military and commercial aerospace products are usually large and are produced in relatively low volumes. Because aerospace manufacturing equipment and processes are geared to large, low-volume products, these firms find it difficult to address civilian markets that are composed of small, very high-volume products. One potential exception is the use of composite structures in infrastructure applications, such as bridges, which are large structures produced in relatively low volumes.

Procurement practices

Almost every industry participant interviewed by OTA cited government procurement practice as one of the leading factors inhibiting civilian-military integration. Government procurement regulations are viewed as too complex, often contradictory, and difficult to interpret. Because of the nature and complexity of the regulations, significant costs are incurred.

Some observers have argued that large organizations sometimes have difficulty quantifying the effects of the regulations on product costs because these organizations employ so many people who are working both on the government procurement process and on civilian markets. Although most of these organizations segregate costs very precisely according to government accounting regulations, there is still inefficiency and some level of error in the process.

One small company that serves the military and civilian markets reported that if a commercial product has a cost of 1.0, the nearly identical government product would cost between 1.6 and 2.0. Three factors generally account for this differential: quality-assurance and documentation costs, security costs, and contract administration costs. Quality assurance and documentation is estimated to be responsible for approximately 50 percent of the increase; security, 30 percent; and contract administration, 20 percent.

Policy Factors

Government policies were identified as perhaps the most complicated factors inhibiting civil-military integration in the polymeric composites industry. They encompass a wide range of often competing social, economic, and business policies, including policies to limit profits, subsidize foreign competitors, require domestic investment, set taxes, protect intellectual property, establish export controls, and defer cost-sharing requirements.

BOX 6: Recent Federal Efforts To Support Composites Technology

The Federal government has sponsored a considerable amount of composites R&D and has made significant attempts to coordinate these activities across the various federal agencies. The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), established in 1976 to address science and technology policy issues affecting multiple federal agencies, included the Committee on Industry and Technology (CIT). The CIT has promulgated the Advance Materials and Processing Plan (AMPP) designed to improve the manufacture and performance of advanced materials, to increase productivity, and to bolster economic growth. A CIT Working Group on Materials (COMAT) was established to coordinate CIT's activities.

Federal funding for R&D in advanced materials was $2.1 billion in FY 1993 with a planned $2.1 billion in FY 1994. Federal investment for composites, including ceramic and metal matrix composites, in FY 1993 was $225,3 million with a projected $199,7 million in FY 1994, The decrease in FY 1994 reflected DOD budget cuts. Such figures exclude classified R&D activities funded under specific DOD systems-related programs. The funding for such activities is said to be considerable.

All the military services and ARPA invest in composites technologies. DOD programs range from basic R&D through exploratory and advanced development to manufacturing technology development. The Services tend to support programs that directly affect their missions: the Army supports programs involving the use of composites in helicopters and ground fighting vehicles; the Air Force supports activities related to aircraft structures, missiles, and satellites; and the Navy supports activities related to submarines, surface ships, and aircraft. ARPA tends to concentrate its efforts in higher-risk, higher-payoff areas than do the Services.

NASA has invested most of its efforts in two composites-related activities: the Advanced Composites Technology (ACT) program and the High Speed Civil Transport (HSCT) program. ACT concentrates primarily on applications for transport aircraft. It is aimed at improving structural performance, particularly damage tolerance, while reducing processing and fabrication costs. Stated goals include

Many people believe that reform of the procurement process and related regulations is the single most important task to be accomplished in enhancing civilian-military integration. Many of those interviewed pointed out that current procurement regulations are poorly thought out and are often inconsistent. They observed that current practices stem from an attempt to control a small minority of firms that have taken advantage of the system in the past and that the majority of honest firms are being penalized. The procurement process is said to actually inhibit the adoption of modem quality and manufacturing practices because current regulations are too complex, stipulate the exact process to be followed by contractors, discourage close product-supplier partnerships that might be very efficient and cost-effective, and tend to perpetuate inefficient manufacturing and engineering practices. Moreover, the paperwork associated with government contracts is thought to be excessive. Many businesses make the case that they simply could not compete in the global commercial economy if they were required to generate the paperwork associated with government contracts.

Limiting "profit," or earnings as a fixed percentage above costs, reportedly inhibits integration. Industry (especially the carbon-fiber manufacturers) believes that the capital-intensive nature of the polymeric composites business was not adequately addressed when the allowable profits were determined. Typically, $2 to $4 of invested capital is required to generate $1 of sales revenue in this technology. Given the guidelines now in effect, coupled with the downturn in DOD business volumes, the industry as a whole generates poor returns on invested capital.

BOX 6: Recent Federal Efforts To Support Composites Technology (Cont'd.)

cutting acquisition costs by 20 to 25 percent and reducing structural weights by 30 to 50 percent for resized aircraft, Automated manufacturing techniques, such as filament winding, pultrusion, resin transfer molding, and automated tape-to-fiber placements, are being explored as ways to improve quality and cut manufacturing costs. Emphasis is being placed on automated textile processes needed to fabricate near net-shaped structural elements, which have significantly improved damage tolerance with respect to conventional structures, Over $100 million was invested before 1994. About $25 million has been committed until 1997, when investments are projected to be in the $45 million to $65 million range until the program is completed in 2002.

Investments in HSCT are directed primarily toward development of composite materials. Projected requirements for these materials include a 60,000-hour service life at about 300 to 350 OF The long service-life requirement represents the major challenge for polymeric matrix composites in this application,

The Department of Energy (DOE) has supported composites technology primarily in or through its classification of "materials characterization, synthesis and processing. " A recent initiative is aimed at developing lightweight composite materials that can be used in passenger automobiles and later recycled. Candidate components include chassis, frames, body parts, and panels.

The Department of Commerce's National Institute of Standards and Technology (NIST) has sponsored significant efforts in polymeric matrix composites. The two main areas of interest are improving the speed, reliability, and cost-effectiveness of fabrication and developing a better understanding and predictive capability for long-term performance. Specific technical initiatives include the development of mold-filling models useful for resin-transfer molding and cooperation with the Automotive Composites Consortium to demonstrate front-end structures and cross members. Another technical effort Involves implementing in situ process monitoring and control for the resin transfer-molding process.

SOURCE" Office of Technology Assessment, 1995.

Firms also complained about foreign-government subsidies. American firms report difficulty competing in the bidding process with companies that are heavily subsidized by their own governments. Moreover, firms argued that foreign companies are able to form joint ventures with little concern for antitrust laws. Many of those interviewed think that regulations related to vertically integrated industrial consortia could be simplified and in some cases relaxed to allow U.S. firms additional competitive advantages. In the Department of Commerce study cited earlier, individual respondents generally expressed a fear of U.S. antitrust regulations, even though a majority admitted that they had not adequately examined the technical details of the regulations and could not say whether they were really a barrier to working together.

One legislative mandate (Public Law 100-202, Statute 1329-77, Section 8088, and the related DFARS 225.7013-2 and DFARS 252.225.7022) requires domestic investment in facilities as a prerequisite for participation in future government programs. This requirement created an unprofitable situation in the carbon-fiber industry by increasing capacity much faster than demand. Several companies have reported that after they made the investments, the market for carbon fibers in these DOD applications did not materialize, and they were unable to recoup their investments.

Some of those interviewed argued that current tax policies inhibit investments in the advanced-composites business. The specific concern was the limit on a firm's abilities to depreciate obsolescent equipment (thus decreasing income taxes) in a technology that changes very rapidly. Historically, accelerated depreciation has allowed firms to reduce taxes and increase cash flow. These increased cash flows can be used to finance further investments. In terms of available investment capital, it can be argued that firms that attempt to serve the civilian and military markets require more capital because the equipment and manufacturing-process requirements needed to serve both markets might be quite diverse.

The protection of intellectual property is a concern for firms conducting military business. Many of the firms believe U.S. intellectual property is subject to unauthorized transfer to foreign entities as a result of participation in offset programs. Although protection against unauthorized transfer is in place, some of those interviewed said they were nervous that such transfers may happen inadvertently.

On the other hand, others interviewed raised concerns about export controls. Some argued that export controls imposed by the United States have arbitrarily limited the participation of many U.S. companies in foreign markets where the application of polymeric composites in civilian markets is widespread. Some argue that many European countries are more advanced in their use of polymeric matrix composites and that restrictions on U.S. firms and U.S. technology place arbitrary limits on their ability to compete in these markets. Industry insiders also point out that technology transfer from Europe to the United States would be a plus.

Finally, some industry observers expressed their belief that the TRP cost-sharing requirements are detrimental to integration. The idea of deferring cost-sharing requirements until a particular project generates enough profit may have merit, especially in an industry such as polymeric composites, where nearly half the companies reported operating losses as a result of their dependence on defense business. Deferring cost-sharing may be especially advantageous for small firms that have very few resources to commit to ideas and whose access to investment capital, especially R&D capital, is quite limited.

Implications of Enhanced Integration

For the Defense Sector

The reduction in defense spending has had a major impact on those firms who have done defense work. Some companies have left the business entirely, and one major company is in bankruptcy. Thousands of high-skilled jobs have already been lost, and thousands more will be lost if firms do not find additional markets. Enhanced civil-military integration might help stabilize this situation and ensure that essential skills and capabilities are available to serve the national interest.

Integration might also reduce costs of raw materials and manufactured goods, especially if policies and procedures are adopted that allow commercially accepted products to be used for military applications. This argument is essentially the common volume-price argument—that is, as demand for a product increases, manufacturers can use economies of scale to reduce costs, thereby reducing prices for the end user. Some in government argue that using commercial products for military applications will often not work because many military applications have unique requirements. Arguably, there is merit to the notion of "peculiar and extreme use" for certain specific applications; however, other observers have argued that military requirements are sometimes generated from a list of "nice-to-have" attributes rather than mission-essential characteristics.

Civilian products are often engineered and developed more rapidly than typical military products. A more integrated base might include closer cooperation between defense-oriented firms and other firms skilled in rapid design and product prototyping.

For the Civilian Sector

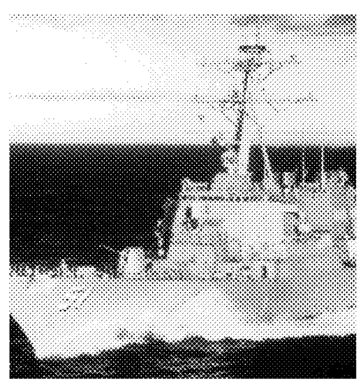
Those interviewed also thought that enhanced integration might benefit the civilian sector. It was pointed out that a significant amount of specialized engineering and manufacturing technology that has been developed for defense applications can be used in commercial applications. Examples include specialized information on electromagnetic shielding and on structures that require electrical continuity. This technology transfer could result in new products and markets in the civilian sector, perhaps in the computer industry, thereby stabilizing and creating additional employment. Care would still have to be taken with respect to any security implications of this technology transfer.

Another area of potential interest is the considerable amount of specialized performance data generated for defense applications that could be used as a basis for new-product development in the civilian sector. For example, the specialized electrical, vibrational-damping, and acoustical data generated for composites could be used in unique electronic or sonic-electronic applications for the information superhighway. In addition, several firms have said that the defense emphasis on a rigorous approach to quality has helped them to improve their own quality, but they have found that the paperwork associated with the defense approach is unnecessary.

Case Study 3: Shipbuilding

The importance of an American shipbuilding industry has long been the subject of debate. A strong U.S. shipbuilding industry is considered an essential national attribute by many observers. The United States is, after all, a maritime nation, is one of the world's largest trading nations, and has the world's largest single national economy. Many of the nation's goods are shipped by sea. Further, the world's oceans are critical to U.S. military security. Indeed, every significant U.S. military engagement in the 20th century has included ocean transportation of U.S. military forces. The oceans that provide barriers to foreign threats also make deployment of American forces abroad more difficult. But while the United States has developed and deployed the largest and most technically advanced naval forces to guard its approaches and to project U.S. military power; in the post-World War II period, foreign-owned and foreign-built ships have provided most of the nation's ocean transportation.[1]

The U.S. shipbuilding industry has been in decline since the mid-19th century, when except for wartime production, it peaked. Over the years, the U.S. government has enacted many laws designed to retain shipbuilding capabilities. For example, laws passed in the late 19th and early 20th centuries granted a monopoly to U.S. shipyards to build ships for trade between U.S. ports. A 1936 law authorized a direct subsidy to shipyards building vessels for U.S. foreign trade, and U.S. naval construction, repair, and overhaul work has largely been reserved for domestic yards. Nonetheless, many argue that there is less long-term government



[1] Some of these ships have U.S. owners but foreign registry, largely to reduce costs associated with U.S. labor and safety laws

support for shipbuilding than for competing transportation technologies such as aviation.

Concern about the health of the entire shipbuilding base grew, however, as fierce global competition and a worldwide slump in shipbuilding reduced American commercial large-ship construction to zero. This situation was compounded by the reevaluation of naval requirements and the subsequent reduction in naval shipbuilding as a result of the end of the Cold War. By the end of the 1980s, the Bush Administration had concluded that "Navy shipwork alone will not sustain the U.S. Shipbuilding Industrial Base."[2]

Expected reductions in naval forces make it even more difficult for Navy work alone to maintain a viable U.S. shipbuilding industry. Critics argue that a strategy focused solely on Navy shipbuilding can neither provide the Navy with affordable ships, nor provide the basis for rapid expansion of naval construction if such an expansion is needed in the future.[3]

Two principal alternatives have been suggested to preserve a Navy shipbuilding capability. One is to shrink to a small shipbuilding base dedicated to military shipbuilding. A second alternative is to reestablish the United States as a globally competitive commercial shipbuilder and to use the renewed commercial capability, which would reside in an integrated base, to help meet future U.S. Navy needs. The Shipbuilders' Council of America for example, has stated that: "The only way a reconstitutable shipbuilding base can survive in the United States is for U.S. yards to build commercial ships."[4] During the course of OTA's civil-military integration study, the potential for an integrated shipbuilding base was examined.

In the face of the moribund U.S. commercial shipbuilding program for large ships, however, reestablishing a commercial base is indeed a challenge. In 1993, the United States, the world's largest trading nation, ranked a distant 27th in merchant shipbuilding, with two-tenths of 1 percent of the world's gross tonnage on order and only one commercial ship under construction.[5] During the course of the CMI assessment, a significant government effort aimed at enhancing U.S. commercial shipbuilding was initiated. This effort is discussed later.

This case study considers the potential for integrating the defense shipbuilding base with a reestablished commercial base. The study briefly outlines the current structure and condition of the U.S. shipbuilding base. It discusses the national security shipbuilding base that might be needed in the future and considers some market trends. It examines alternatives for reestablishing a commercial element of the base. Finally it considers factors that inhibit integration and factors that favor integration in shipbuilding.

STRUCTURE AND CONDITION OF U.S. SHIPBUILDING BASE

The shipbuilding industry includes shipyards that build, repair, and overhaul ships; component producers that develop and build critical ship parts; research organizations that explore new marine technologies; and design firms. The industry has an extensive public sector component composed of shipyards, research laboratories, supporting naval industrial centers, and the Navy's ship-acquisition organization. This public sector portion

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[2] U.S. Department of Defense, *Report on the Effects of Navy Shipbuilding and Repair on U.S. Public and Private Shipyards and the Supporting Industrial Base*, January 1990.

[3] A 1992 report by the General Accounting Office, for example, noted that the costs for submarines and other ships being built by the two submarine shipbuilders would probably increase because of the amortization of overhead costs over a smaller production base; a smaller but more senior, and therefore more highly paid, workforce; and higher vendor costs. U.S. General Accounting Office, GAO/NSIAO-93-32-BR (Washington, DC: U.S. Government Printing Office, 1992).

[4] Shipbuilders Council of America presentation to Presidential Transition Team, Washington, DC., Dec. 14, 1992.

[5] U.S. Department of Commerce, *U.S. Industrial Outlook 1994: Shipbuilding and Repair* (Washington, DC: U.S. Government Printing Office, January 1994), p. 21-1. Japan led the world with 31 percent, South Korea with about 20 percent, and China with about 5 percent.

of the base is important to any strategy for integrating the commercial and defense bases. It currently does much of the repair and overhaul work and has a profound impact on military construction.

The shipbuilding base is geographically dispersed and is a major source of employment. According to Department of Labor statistics, over 109,000 people were employed in shipbuilding and repair alone in 1993 (down from 123,000 in 1992). Employment generated in the lower, or supporting, tiers is also probably significant. For example, OTA estimates of spending patterns based on Bureau of Economic Analysis input-output analysis data indicated that in calendar year 1992, defense shipbuilding purchased almost $7 billion in goods and services at the first tier (i.e., government prime contracts to firms classified under the Standard Industrial Classification under SIC 3731—shipbuilding and repairing). This spending, in turn, induced demand of almost $3 billion at the second tier (major components), over $1 billion at the third tier (subcomponents), and about $600 million at the lower tiers (materials).[6]

Research and Development

Nondefense shipbuilding research and development (R&D) in the United States was extremely limited during the 1980s (probably averaging less than $100 million per year).[7]

Shipbuilding R&D has included the National Shipbuilding Research Program (NSRP), a cooperative program between government and industry. NSRP aims to develop and implement improved shipbuilding and repair processes. The program was funded by the Maritime Administration (MARAD) at a rate of about $2 million a year between 1972 and 1985. The Navy, mostly through its MANTECH budget, provided about $2 million a year from 1982 to 1985 and between $500,000 and $1.75 million a year from 1987 through 1992. The shipyards absorbed the indirect costs and were responsible for implementation costs.

Companies also invest their own funds in R&D projects. In the recent past such spending may have been more common among so-called second tier shipyards than large shipyards. For example, the Trinity Marine Group in Gulfport, Mississippi, developed and built a vessel made of composite Kevlar that has been sold to Mexico and is being shown in the Middle East.

The low level of R&D spending is partly attributable to the industry's assessment of market prospects. A 1985 OTA report on maritime R&D, for example, surveyed U.S. ship operators and shipyards and found that expected market demand was the single most important factor in determining company R&D investments.[8] The report concluded that the low demand for U.S.-built ships during the 1980s had "forced the shipbuilding industry to be extremely conservative in devoting funds to R&D."[9] Such low levels of R&D investment have, in turn, limited American competitiveness in shipbuilding because companies that do not develop better ways to build ships or other desirable products cannot hope to compete for future sales.

Observers argue that there are few university or college programs supporting the maritime industry. Only a few American universities have pro-

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[6] These estimates are based on the latest available U.S. Department of Commerce, Bureau of Economic Analysis tables: "1987 Annual I-O Tables," (unpublished), and Bureau of the Census CY 1992 spending by the federal government for national defense.

[7] In comparison, the automotive industry reportedly spends about $12 billion each year on R&D. While this figure includes much development work for new model cars, it also includes longer term research on propulsion, structures, materials and other items. Automotive Trade Association, McLean, VA (personal communication).

[8] U.S. Congress, Office of Technology Assessment, *R&D in the Maritime Industry: A Supplement to an Assessment of Maritime Trade and Technology*, OTA-BP-O-35 (Washington, DC: U.S. Government Printing Office, May 1985).

[9] Ibid., p. 6.

grams in naval architecture and naval engineering, including the Massachusetts Institute of Technology (MIT) in Cambridge, the Stevens Institute of Technology in Hoboken, New Jersey, Webb Institute of Naval Architecture and the University of Michigan at Ann Arbor. The Japanese, in contrast, appear to have a robust network of research support for their maritime industry. For example, Japan's Ship Research Institute supports research on new types of ships and addresses such topics as fuel-saving marine engines. Japan also has a Marine Technical College for vocational training and an Institute for Sea Training for on-board training for students from universities and colleges.

The outlook for increased U.S. shipbuilding R&D has brightened recently as the commercial market possibilities have improved. Several firms have reported investments in new manufacturing technologies and are studying new ship designs. Furthermore, the improving commercial market has coincided with government initiatives with heavy R&D components. The Clinton Administration's shipbuilding initiative includes the Advanced Research Projects Agency (ARPA) managed MARITECH Program aimed at developing and applying advanced technology to improve the competitiveness of the U.S. shipbuilding industry.[10]

Design

The design element of the shipbuilding base resides in both shipyards and in separate marine design firms. These separate firms often work closely with a shipyard, or with the Naval Sea Systems Command (NAVSEA) to develop new ship designs. Once a Navy design is selected, it is passed on to production yards, which do the final design.

Because no builder or prospective owner or operator has shown an interest, however, design houses have produced few new commercial designs in recent years. The industry has been forced to survive largely on Navy work and the ability to provide services other than designing ships.

Production

American shipbuilding establishments are usually classified into four basic categories: major shipyards engaged in the construction and repair of ships, major ship-repair and dry-dock facilities, smaller shipyards that service inland waterway and coastal commerce, and topside-repair facilities. In the past, the benchmark for tracking the U.S. shipbuilding industry was the active shipbuilding base (ASB), defined by both shipyard capability and business criteria. Due to the reduction in construction of new ships, especially of those 1,000 gross tons and over, the ASB has been replaced by a measure based primarily on capability. This new benchmark is the U.S. major shipbuilding base (MSB), defined as privately owned yards that are open and have at least one shipbuilding position—either an inclined way, a side-launching platform, or a building basin capable of accommodating vessels 122 meters or more in length. With few exceptions, these shipbuilding facilities are also major repair facilities with dry-docking capability. Under the new definition, there were 19 major shipbuilding facilities in the United States on October 1, 1993 (versus 14 shipyards in the former ASB).[11]

Several hundred medium- and small-sized, or second-tier, U.S. shipyards primarily support the inland waterway and coastal commerce business. These shipyards produce tugboats, ferries, fishing vessels, barges, small government-owned ves-

[10] *Strengthening America's Shipyards: A Plan for Competing in the International Market*, The White House, Oct. 1, 1993, p. 7.

[11] U.S. Department of Commerce, op. cit., footnote 5, pp. 21-1 and 21-2. MSB shipyards employ about 73 percent of all employees in the sector. The remaining 27 percent is distributed across the approximately 550 other establishments classified under SIC 3731 (shipbuilding and repairing). Not included are the nine government-owned shipyards (some now scheduled for closing) which do not engage in new construction, but do overhaul and repair of Navy and Coast Guard ships.

TABLE 10: Major Industry Sectors Supporting Shipbuilding

Fabricated plate work (boiler shops)
Condensers
Diesel engines
Steam turbines
Propellers
Reduction gears
Large shafting equipment
Electrical power equipment
Power distribution switchboards
Air circuit brakers
Gas turbines
Heating and ventilation
Periscopes
Combat systems
Electronics
Heavy handling equipment (Cranes)

SOURCE: Office of Technology Assessment, 1995,

sels, and oil-drilling equipment. Some are currently engaged in large riverboat projects as a result of legislation that allows gambling on inland waterways. These yards have generally maintained a better commercial business base over the past decade than have the large yards. Many are considered internationally competitive having built fishing trawlers, patrol craft, and other vessels for export.

Several major component sectors, each an industry in its own right, support shipbuilding (table 10). These sectors, in turn, draw on a host of subcomponent producers and material suppliers. For example, the Naval Sea Systems Command reported in 1990 that the construction of the *Arleigh Burke* class of guided-missile destroyers (DDG-51) involved over 500 primary equipment subcontractors and thousands of subcontractors in the lower tiers.[12] The supplier base has been consolidating as a result of reduced Navy spending and little commercial work. Many firms have reportedly either left the industry or have devoted most of their work to supporting military shipbuilding. A 1991 survey of U.S. marine machinery suppliers found that only 81 percent of those surveyed were at the time of the survey supporting the marine industry and that 71 percent of those supporting the marine industry were directly involved in U.S. Navy shipbuilding. Many of the firms reported that they were working at only 40 to 70 percent of full capacity.[13]

Component producers have also been hurt by the increasing use of imports by the U.S. shipyards. The U.S. Marine Machinery Association, for example, has estimated that over 70 percent (in terms of value) of components used by U.S. shipyards in repairing or building commercial ships are imported. Industry sources cite the reduction of the supplier base as one reason for higher construction and repair costs and longer ship-construction time in the U.S. shipbuilding industry.

Some of the sectors shown in table 10 support both commercial and military shipbuilding, while others, particularly combat systems and electronics, principally support the military. Some participants from component producers in the OTA shipbuilding workshops reported that they were integrated in production and could survive without government business in the future. Indeed, they argued that the current government acquisition laws and regulations encouraged many component producers to quit accepting government business, further reducing the level of CMI. The Federal Acquisition Streamlining Act of 1994, combined with changes in the use of military specifications and standards, is expected to have a positive effect on allowing firms to continue to accept both defense and commercial business.

Maintenance and Repair

Maintenance and ship conversion work is an important element of the industry. Navy maintenance and repair is split between the public and

[12] OTA, *Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base,* op. cit., footnote 1, p. 81.

[13] Ivars Gutmanis, *Analysis of the Civil-Military Integration Feasibility for Selected U.S. Industry Sectors* (Washington, DC, Hobe Corp.) August 1993, p. 32.

private sectors, with work either allocated directly to public yards or awarded to private yards under competitive bid. In 1993, Navy work was performed at eight naval shipyards, two Navy-owned ship-repair facilities, and 36 privately owned shipyards. Some repairs are also done overseas. The overwhelming amount of Navy ship repair goes to public yards.[14] Under the Navy competition program, most submarine repairs have gone to the public sector and most surface-ship repair to the private sector.[15]

Industry Trends

The large U.S. shipyards are highly dependent on U.S. government business, and military construction is falling. According to the Department of Commerce, 65 military ships greater than 1,000 light displacement tons (ldt) were on order, or under construction, as of October 1993 in 12 privately owned shipyards.[16] (See table 11.) In 1993, the Navy ordered the first of several sealift ships. Five commercial container ships were converted to meet military requirements. Eleven new sealift ships were included in the FY 1994-99 shipbuilding program. Many viewed these ships as a potential means to help shipyards make the transition to more commercial work, but the initial contract awards were controversial, with some critics arguing that the decisions paid inadequate attention to preservation of the shipbuilding industrial base.[17]

Commercial possibilities for U.S. shipbuilders remain mixed. On the one hand, the market for large commercial ships is improving and U.S. shipyards such as Newport News Shipyard have secured contracts for commercial ships from foreign owners. On the other hand, Korean shipyards have announced major expansions in shipyard capacity to meet the anticipated market demand.

Second-tier shipyards are reportedly in better shape, although they, too, have had to contend with a downturn in business because expected increases in demand for vessels to carry grain and coal failed to materialize. Nevertheless, the Commerce Department reports that Gulf Coast shipyards "continue to invest in and expand their facilities and equipment used in ship repair and conversion work."[18] Firms such as Trinity Marine Group, for example, have reported that they are applying new manufacturing technologies such as plasma arc cutting to gain higher precision in parts manufacturing, single-side welding of plate, and automated blast and paint facilities, to improve productivity and reduce the labor input.[19]

Another important trend that emerged in the early 1990s was the increased U.S. government interest in improving U.S. shipyards commercial competitiveness. The Clinton Administration's interest in strengthening U.S. shipbuilding was preceded by interest from Congress. The National defense Authorization Act for Fiscal Year 1993 (Public Law 102-484) included a number of shipbuilding initiatives including the requirement that sealift ships built under the fast sealift program be designed and constructed to commercial specifications. The law directed the President to develop a plan to ensure that domestic shipyards could compete effectively in the international marketplace.

The following year, the National Shipbuilding and Shipyard Conversion Act of 1993 included:

[14] U.S. Department of Commerce, op. cit., footnote 5, p. 21-4. The FY 1994 budget requested about 14 percent of the ship repair funds be allocated to competition.

[15] Ibid.

[16] Ibid., pp. 21-2 and 21-3.

[17] R. Holzer, "Major U.S. Shipyards Question Navy Awards," *Defense News*, Sept. 20-26, 1993, p. 6.

[18] U.S. Department of Commerce, op. cit., footnote 5, pp. 21-2 and 21-3.

[19] H.B. Walpert, Senior Vice President, Trinity Marine Group, "Vessel Technology: U.S. Shipyard Perspective," speech to the International Conference on the Maritime System of the Americas, Mar. 25, 1993.

TABLE 11: Military Ships on Order or Under Construction as of October 1, 1993

Type	Number
Fast combat-support ship (AOE)	4
Guided-missile cruiser (CG)	1
Aircraft carrier (nuclear-powered) (CVN)	2
Guided-missile destroyer (DDG)	23
Amphibious assault ship (multipurpose) (LHD)	3
Dock-landing ship (LSD)	3
Mine-countermeasures ship (MCM)	2
Attack submarine (nuclear-powered) (SSN-21)	2
Attack submarine (nuclear-powered) (SSN-688)	9
Ballistic-missile submarine (nuclear-powered) (SSBN)	4
Oceanographic research ship	1
Fast sealift	2
Ice breaker (WAGB)	1
Ocean surveillance ship (T-AGOS-23)	1
Ocean survey ship (T-AGS-60)	3
Fleet Oiler (T-AO)	4
Total	65

SOURCE: U.S. Department of Commerce, *U.S. Industrial Outlook 7994*, table 1, p 21-2.

1. a financial incentives program to provide loan guarantees to initiate commercial ship construction, encourage shipyard modernization, and support increased productivity;
2. a technology development program (subsequently carried out by ARPA in its MARITECH Program) to improve the technology base for advanced shipbuilding and encourage innovative commercial ship design and production processes and technologies;
3. enhanced DOD support for the Navy's Affordability Through Commonality Program to foster the use of common modules for military and commercial ships; and
4. enhanced support for those portions of the Navy's Manufacturing Technology and Technology Base Program that are associated with shipbuilding and ship repair technologies.[20]

The Clinton Administration's shipbuilding plan addressed many of the Congressional objectives through a combination of international negotiations, the MARITECH program, acquisition reform, loan guarantees, and international marketing support.

These government initiatives could potentially have significant impact on CMI. In 1995, the MARITECH program claimed some success from its near-term technology development projects in helping firms win commercial contracts.[21]

Market Forecast

Workshop participants and others interviewed during this case study stressed the importance of the commercial market to shipyard survival, and the need for U.S. shipbuilders to understand and address market needs in order to succeed in reentering commercial shipbuilding. Some shipyards espoused a market *niche* strategy aimed at capturing a part of the market that includes specialty ships, such as cruise ships, survey ships, one-of-a-kind ships, or few-of-a-kind ships. Other builders reportedly plan to apply advanced technologies to directly attack the global competition (e.g., the Japanese and Koreans) in high-volume sectors such as large tankers.

As noted earlier, however, the prospects for a renewed demand for large commercial ships remains a matter of debate. More than 14,000 ships from the global commercial fleet will probably

[20] National Shipbuilding and Shipyard Conversion Act of 1993, 10 U.S. Code 2501.

[21] Specifically listed were Newport News Shipbuilding's construction of a 40,000 deadweight ton (DWT) product carrier, Todd Shipyards' success in winning a contract for Washington State ferriers, and Alabama Shipyard's Inc. letter of intent to build from bulk cargo ships for Tritea Maritme Ltd. of Piraeus Greece. See MARITECH Program Fact Sheet.

TABLE 12: Estimate of Level of Work for a 400- and 300-Ship Navy

Ship category	Fleet size	Service life	Average new ships per year	Building yards	Overhaul/repair projects per year	Overhaul/repair docks needed
Aircraft Carriers	1 2/1 0	40	0.3/0.25	1/1	1 .5/1	3/2
Submarines	55/45	30	1.8/1 .5	1 to 2/1	8/7	9/8
Surface combatants	1 30/100	30	4.3/3.3	2/1 to 2	18/1 4	20/1 6
Amphibious/replenishment ships	128/95	30	4.3/3.2	2 to 3/1 to 2	18/14	20/1 6
Mine warfare/support ships	75/50	30	2.5/1 .7	1/1	11/8	12/9
Total	400/300		13.2/1 O	9 to 7/7 to 5	56.5/44	64/51

SOURCE: Office of Technology Assessment, 1995.

need to be replaced by the turn of the century. Almost 2,000 additional new ships are expected to be required to meet expanded needs. But despite the many forecasts of a commercial shipbuilding boom in the 1990s, the worldwide number of large merchant ships on order, or under construction in 1993, declined. Still, new construction is expected to develop to provide the double-hull oil tankers to comply with the Oil Pollution Act which became law in 1990. These tankers are scheduled to be phased in between 1995 and 2005, but might not be built in U.S. yards. Further, changes in environmental regulations could have an impact on the speed with which these ships are introduced. U.S. production ultimately depends on what percentage of the global market the United States is able to capture.

Other potential commercial work includes oil drilling rigs, marine structures, and large land structures demanding extensive welding or using shipbuilding techniques.

Although Navy shipbuilding, conversion, and repair activities are expected to continue to decrease, Navy work will still dominate the U.S. shipbuilding and ship-repair industry in the near term. A principal national security concern is how to preserve the capability to build nuclear submarines and aircraft carriers. But while these programs represent important defense capabilities, they appear to have limited direct CMI effects, with most CMI potential being in supporting industries such as electronics.

Other Navy programs are more directly applicable. The Navy sealift program, for example, was viewed by many of those interviewed as an opportunity to assist the transition to commercial shipbuilding business. There has been considerable debate, however, over the extent to which CMI can be achieved given the current design requirements of the sealift ships. Participants at OTA's shipbuilding workshops disagreed over whether the planned ships were too militarily unique.

The size of the Navy fleet is currently projected to fall from over 500 in 1993, to between 300 and 400 ships under the DOD's *Bottom-Up Review*. Table 12 gives an estimate of the level of work and number of shipbuilding and overhaul facilities that might support a Navy of 300 to 400 ships.

Given reasonable assumptions about service life, new Navy construction for a force of this size might range from 10 to 13 ships a year. This new construction might be supplemented with the overhaul and repair of 44 to 67 vessels, but overhaul and repair work is also decreasing as the Navy moves away from its past practice of allowing 35 percent of a ship's service life to be spent out of commission in major repair and overhaul, and toward the commercial industry's figure of about 5 percent.

Participants in OTA's shipbuilding workshops concluded that three building yards might be the minimum necessary to meet anticipated Navy shipbuilding needs for a force this size. Partici-

TABLE 13: Defense Objectives of Integrating Civilian and Military Shipbuilding

Design, develop, build, and support effective naval forces
Preserve a skill base in design, engineering, and production
Maintain key facilities
Lower the costs of naval vessels
Enhance the transfer of critical technologies

SOURCE. Off Ice of Technology Assessment, 1995.

TABLE 14: Civilian Objectives of Integrating Civilian and Military Shipbuilding

Ensure profitability
Preserve a skill base in design, engineering, and production
Maintain key facilities
Lower the costs of commercial vessels
Enhance the transfer of critical technologies

SOURCE: Off Ice of Technology Assessment, 1995.

pants argued, however, that five to six yards were preferred. Building yards and overhaul and repair docks are important not only to provide normal peacetime support but also to handle unforeseen peacetime accidents or combat damage that might disable a vessel. A future shipbuilding defense base might include the following types and numbers of building yards:

- one carrier yard
- one submarine yard
- two surface-combatant yards
- two auxiliary yards

Some of these yards could, of course, build more than one type of ship.

CIVIL-MILITARY INTEGRATION

Some CMI currently exists, particularly in the subtiers, but integration at the shipyard level is limited. Increasing CMI at all levels is made more challenging by the lack of commercial competitiveness in building large ships.

Industry and government personnel participating in the two OTA shipbuilding workshops argued that civil-military integration of the shipbuilding base demanded a clear statement of the objectives to be achieved by such integration. Five defense objectives (see table 13) were identified. The highest-priority defense objective is to preserve the capability to design, develop, build, and support the vessels needed to perform the Navy's basic missions: sea control and sea denial in war, forward presence and support of political interests in peacetime.

Workshop participants also identified five civilian objectives of integrating shipbuilding (see table 14) and noted that commercial success in building ships demands that the operations be profitable. Participants observed that the mix of skills for commercial production might differ from those needed in the defense base. For example, the skills needed for modular construction of commercial vessels might be very different from those needed for defense, with the commercial base having less demand for highly skilled electricians and electronics personnel and more demand for basic welders and assembly personnel.

Shipbuilding facilities appear to have considerable defense and commercial overlap. Although defense might demand some unique facilities (e.g., nuclear), many of the costly, fixed shipbuilding facilities can be used for military or civilian work.

Workshop participants argued that technology transfer is as important to the commercial sector as it is to defense. Certain technologies, such as the technology to produce large composite structures, may be needed in both civilian and defense work. Armaments technologies, however, have few commercial uses.

Although many of the broad defense and civilian objectives overlap, the difference between the first priority of each list underscores the fundamental difference that makes CMI difficult. Government goals stress combat performance and oversight of public funds. Commercial goals, of necessity, stress profitability, which is key to staying in business. While the differences between such objectives might be reduced, they are unlikely to be eliminated.

Factors Favoring and Inhibiting Integration

There are a number of technical, market, and policy factors favoring increased integration in the shipbuilding sector.

Technical

Although there are many acknowledged differences between defense and commercial hull designs, propulsion systems, and weapons systems on board, government and industry personnel argued that there are also many commonalities in components and that technological developments in design and manufacturing processes—if exploited—might enhance integration within the shipbuilding sector. The possibility of such integration has increased with the new DOD policy toward the use of military specifications and standards.

Both the commercial and defense sectors face many common environmental and safety problems. Research efforts in these areas, as well as in design and manufacturing processes, might be expected to provide useful information to both the commercial and defense sectors. In July 1994 the Deputy Director for Defense Research and Engineering for Laboratory Management reported on a DOD effort to determine what research and technologies might be sourced from non-DOD laboratories and which ones might be expected to remain in the more militarily unique Service laboratory environment. Increased out-sourcing potential for naval systems included: habitability and outfitting, shock, propulsion machinery, and electrical power systems.[22] In order to exploit technical developments, the Non-Government Panel studying the issue recommended that Navy laboratories establish strong collaborative programs with industry and university partners.[23]

The MARITECH Program aims to use a wide variety of technologies that appear to have application to both commercial and defense needs. These include exploiting developing technologies:

- in simulation and modeling, virtual prototyping, and advanced materials to enhance integrated product development;
- in simulation and modeling, prototyping, and communications to enhance integration in design;
- in flexible automation/robotics, real-time physical measurement, agile manufacturing and advanced methods in cutting, welding, and pasting to enhance integrated construction; and
- in communications and advanced repair to enhance integration in follow-on support.[24]

Navy studies on Affordability through Commonality (ATC) have examined concepts for modular construction, equipment standardization, and process simplification. In many cases these processes and the equipment might be confined to using standardized militarily unique items. Indeed, past standardization programs have sometimes isolated the military from commercial developments when the standardization has been to specifications not used in the commercial sector. Component producers interviewed by OTA argued, however, that standardizing to commercial specifications in areas where they appear appropriate (e.g., many of the different pumps and valves that go on ships), is feasible and can promote savings.

Civil-military integration at the shipyard level is aimed at maintaining a skilled workforce, shipyard facilities that can accommodate large naval

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[22] *The Laboratory Infrastructure Capabilities Study: Non-Government Panel Meetings June/July 1994.* Summary available through DOD Laboratory System World Wide Web Services: LabLINK Home Page: Projects.

[23] Ibid.

[24] Robert Schaffran, “MARITECH,” Presentation at the ARPA Seventeenth Systems & Technology Symposium, Oct. 25-27, 1994, San Francisco, CA.

vessels, and at improving U.S. shipbuilding technology. Workshop participants concluded that much of the hull work can be automated. Computer aided design and computer aided manufacturing (CAD/CAM), for example, can drive a battery of robots in welding. Much of the rest of the ship can be built in specialized factories.

Workshop participants noted that foreign technology is important and that U.S. firms may gain access to it through partnerships with international firms (such as those developed in the electronics industry) or through direct license agreements.

At the sector level, technological opportunities for integration are enhanced by the availability of public sector facilities for private sector use. This appears to make most sense when the facility investments are too costly for the private sector to make individually. For example, the David Taylor Naval Ship Research and Development Center in Carderock, Maryland, has one of the largest maritime model basins in the world. Research topics at the Center include hull-form structures, propulsion, silencing, maneuvering and control, auxiliary machinery, environmental effects, pollution abatement, logistics, computer techniques, and software for analysis and design—most of which have some commercial application. The enabling legislation for the Center specifies that experiments can be conducted for private shipbuilders if the builders defray the cost of the experiment.[25] The authority, however, has reportedly seldom been used, except for examining some hull designs.

Other possibilities exist in facilities such as the Navy Surface Warfare Center's Crane Division of Crane, Indiana, which conducts R&D on a variety of systems, including microwave devices, acoustic sensors batteries, and microelectronic technology. While these efforts are directed at fleet support, some might be exploited to enhance commercial capabilities.

National laboratories represent additional government resources available for use in shipbuilding. The use of supercomputers at Sandia National Laboratories to solve planning problems in design and manufacturing is an example of sector level integration. Both the Sandia National Laboratories and Oak Ridge National Laboratory currently have supported shipbuilding activities. Sandia, for example, has a Cooperative Research and Development Agreement (CRADA) with one of the shipyards in advanced welding techniques, and Oak Ridge has ongoing cooperative work in manufacturing.

Exploiting commonality in process technology (e.g., design, manufacturing, testing) appears fairly straightforward. The use of commercial components on combatants, however, raises questions about the durability of products manufactured under commercial standards. Critical questions about shock resistance, for example, must be addressed. Many electronic components are currently meeting such requirements through ruggedization, a process by which commercial items are placed in a rugged container that can resist the shocks and stresses of combat. In common with findings in other critical combat areas, those interviewed generally agreed that design, manufacturing processes, and components represent the greatest opportunities for integration.

Market Factors

The U.S. military and commercial shipbuilding markets have almost been mutually exclusive at the shipbuilding level. Yet many OTA workshop participants argued that this need not be the case. Workshop participants and others interviewed during the assessment stated that ship components and subcomponents are the most likely items to be purchased, but major end items might also be bought commercially. The Navy, for example, used an off-the-shelf merchant tanker, modified

[25] OTA, *R&D in the Maritime Industry: A Supplement to an Assessment of Maritime Trade and Technology,* op. cit., footnote 8, p. 35.

with defense features, to provide underway replenishment to fleet combatants in 1972.

The Navy's T-AGOS program was run "commercially" from 1981 until 1986. The commercial philosophy followed in that case reportedly allowed the program to reduce Navy oversight significantly.

More recently, the United Kingdom contracted for construction of a helicopter carrier based on a commercial, rather than a military, hull design. By modifying a commercial design rather than using a militarily unique one, the United Kingdom expects to save over $76.5 million.[26]

The French have also used a more commercial approach to meet some of their needs. An earlier OTA study reported that the French Navy, in developing a new class of frigates for routine patrol missions, decided against sophisticated and expensive warships to perform these missions.

A commercial shipyard, Chantiers de l'Atlantique (owned by the Alcatel-Alsthom GEC Group), that specializes in the design and construction of passenger liners, received the contract. In lieu of military specifications, the French Navy permitted Chantiers de l'Atlantique to use somewhat less rigorous "safety of life at sea" norms conceived for merchant-marine and passenger ships. The patrol frigates are equipped with the same weapons systems as are standard frigates, but lack a computerized battle-management system capable of integrating them into a naval task force. Because of these economies, the patrol frigates were developed and built at one-third the cost of frigates built to military specifications. The limited defensive capabilities of the patrol frigates could, however, prove problematic if they confront comprehensive threats.[27]

More market commonality may be achieved in naval transport ships, but there were mixed views on whether this will occur. As noted earlier, some participants in OTA's shipbuilding workshops expressed concern that the ships then in the Navy's sealift program had little commercial overlap, while DOD participants argued that the ships were "the least military-specified ship ever" and that the specifications that did exist were mostly performance specifications.

One argument made by those concerned about CMI was that the design's performance specification forced noncommercial solutions, and that if support for a commercially viable ship had been a consideration, a different design would have emerged. It was the opinion of some participants that the DOD could have met 90 percent of the lift requirement at 50 percent of the cost and had a commercially viable ship. Concerns were focused on the requirements for off-loading and the hazardous cargo requirements. Regardless of their views on current designs, workshop participants generally supported the idea of moving toward a more commercial vessel for most Navy purchases.

Policy Factors

The recent government shipbuilding initiatives aim not only at developing technology but also at applying that technology to demonstration vessels with the objective of reestablishing the U.S. shipbuilding industry as a self-sufficient, internationally competitive industry.[28] The MARITECH program, outlined earlier, is designed to develop and apply advanced technology to improve the competitiveness of the U.S. shipbuilding industry. According to Dr. Larry Lynn, Director of

[26] P. Felstead, "VSEL Wins Contract To Build U.K. Helo Carrier," *Janes Defense Weekly*, May 22, 1993, p. 10.

[27] U.S. Congress, Office of Technology Assessment, *Lessons in Restructuring Defense Industry: The French Experience*, OTA-PB-ISC-96 (Washington, DC: U.S. Government Printing Office, June 1992), p. 26.

[28] National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, Nov. 30, 1993, Sec. 1352. 10 USC 2501.

ARPA, "MARITECH will ensure that a domestic shipbuilding infrastructure, capable of building competitive ships, is available to procure affordable Navy ships at such time that new construction tonnage is needed."[29]

As a part of its plan for strengthening America's shipyards, the Clinton Administration has also pursued efforts to eliminate foreign shipbuilding subsidies through the Organization for Economic Cooperation and Development, provided guarantees through the Department of Transportation for ship construction, and extended loan programs to cover ships built for export.

Workshop participants raised and discussed several other near-term strategies, including building and leasing commercial ships in place of the Ready Reserve Fleet and purchasing a fleet of vehicle carriers that would be on a standby arrangement under government contract for use in an emergency. (See box 7.)

Factors Inhibiting Integration

Several factors have inhibited integration in the shipbuilding sector. The major factor has been the almost total lack of commercial shipbuilding. The dearth of commercial shipbuilding is partly a function of the technical, market, and policy factors noted below.

Technical

As discussed earlier, naval combatants have very specific tasks to perform that often have little or no overlap with commercial activities. They must be capable of withstanding damage that would not be expected in a commercial vessel. Shock tests, and special fire-fighting equipment are often essential. Because of the potential for sustaining combat damage, many observers question the capability of the new French patrol frigates to operate in a high-intensity combat environment.

Since they incorporate many technologies that are different from those used in large commercial vessels, the construction of combatants often requires different skills than do commercial ships (e.g., electronics integration and weapons systems installation). Much of the value added in combat vessels is associated with these complex electronics and weapons systems. CMI here is more likely to occur at the electronic component level. Thus, while process technology may potentially be easily integrated, the special needs of combat vessels will create some technical limits to product integration. The existence of many militarily-unique systems must be acknowledged in considering a realistic CMI strategy in this sector.

The lack of competitiveness of the American shipbuilding industry has been exacerbated by the general absence of investment in new process technology in the industry. Although smaller yards report investments, representatives from the major yards participating in the OTA workshops estimated that large U.S. shipyards are as much as 10 years behind in technology. The result is that production time per ship is two to three times as long in U.S. yards as it is in the best foreign yards. The MARITECH Program is aimed at introducing new technologies, but the workshop concensus was that outdated yards will require substantial new investment to become commercially competitive.

New technological developments in the United States are aimed at both reducing the number of workers needed to build a ship and the time needed to complete a ship. Although American wages have declined to the degree that they are slightly lower than Japan's and much lower than those in Western Europe, they remained high compared to South Korean wages or those of the People's Republic of China. Further, almost all major foreign yards can reportedly build ships faster and with fewer people than can U.S. yards. For example,

[29] Statement by Larry Lynn, Acting Director, Advanced Research Projects Agency, before the House Appropriations Committee, Subcommittee on National Security, Mar. 23, 1995.

BOX 7: Other Suggestions for Preserving a Naval Construction Base

Workshop participants generally agreed that the falling rate of Navy construction, combined with the lack of a commercial market for large ships, necessitated drastic action to reestablish a domestic shipbuilding industry. A number of alternatives were discussed in addition to integrating the commercial and defense bases. These included: ceasing to transfer ships to other nations as the Navy decommissions them because this practice eliminates potential customers; building ships directly for the export market (including diesel submarines); starting a major building program for Coast Guard ships.

Participants suggested that there should be greater support for foreign military sales. Such sales may be controversial, however, because they can potentially create threats to U.S. forces. On the other hand, they can sustain important high-level skills in the absence of commercial work. Some participants discounted the possibility of future threats to U.S. forces.

Participants also proposed changing the duration of the charter of MSC ships. Longer charters could certainly be used to facilitate sealift acquisition. Participants indicated that tankers, as well as vehicle carriers, might be built for a five-year charter. They pointed out that the production of double-hulled tankers, coupled with a focused sealift construction program built around longer charters, might create a commercially viable program.

Finally, workshop participants suggested that the Nation needs to develop incentives that support the shipbuilding industry. The Norwegians, for example, use tax policy (i.e., high depreciation rates for ships) to sustain a very modern fleet. Liberia and Bahrain are both tax-free environments. U.S. tax policy, on the other hand, was viewed as punitive to the shipbuilding industry.

SOURCE: Office of Technology Assessment, 1995.

the Japanese are estimated to have cut the percentage of labor cost in the cost of a ship from about 40 percent in 1987-88 to 20 to 25 percent in 1991.[30] A ship operator noted that the international ship market is highly dependent on the lowest price. Technology aimed at productivity improvements is essential.

Participants at OTA's shipbuilding workshops expressed concerns about the ability of shipbuilding firms to gain access to necessary financing to make technology investments. They estimated that U.S. yards would require new technology and facilities—thought to cost between $100 million and $200 million per yard—to compete effectively. Component producers complained that small firms could not get access to such financing, and they called for government guarantees. Others argued, however, that financing was available for good investments and that government loans were therefore unimportant.

Market

A number of market factors inhibit integration. One of the greatest is the uncertainty in the market for large ships. Despite the expectation of increased demand, expansion has been slow. A further problem is fierce international competition. Several Korean shipyards, for example, have announced major capacity expansions to meet the expected increased market demand. Japanese and European yards can also be expected to be competitive.

Owners, operators, and government workshop participants noted that U.S. shipyards have been very poor at marketing. Although shipyards com-

[30] *Drewry World Shipbuilding, The Next Ten Years:Can the Challenge Be Met?* (Drewry Shipping consultants, Ltd., London: April 1992) , p. 26.

plain about a lack of orders, some workshop participants argued that American shipyards lack a commitment to marketing and often fail to visit firms interested in buying new ships. Foreign builders, on the other hand, are said to visit regularly.

Market subsidies were hotly debated at the workshop. Many workshop participants argued against direct, long-term subsidies, stating their belief that federal subsidies have hurt the base by isolating it from competition.[31] A 1983 OTA report hinted at this, noting that:

> Over the past two decades the United States has only built major merchant ships when Federal subsidies were used to pay a large portion of the cost or when laws, such as the Merchant Marine Act of 1920 (Jones Act), required that the ship be built in a U.S. yard.[32]

Instead, participants generally supported a program in which shipyards would receive initial transition funding to help them convert to commercial shipbuilding. Such a program would also include a commitment on the part of the government to encourage shipbuilding through incentives.

Some workshop participants advanced a different market approach. They suggested that smaller, cheaper ships might be better suited to the new defense environment and take advantage of technology developments to retain combat capability. For example, smaller fighting ships might be built (at $250 million a copy) with an acceptable compromise in performance by capitalizing on space-based (or airborne) command-control links whose costs would be met through joint service support. Expensive, large radars and associated equipment could then be removed in favor of off-board sensors. A modular design would allow additional "tuning" of ships for particular needs in various locations around the world.[33] A small ship might also be more likely to develop an export market.

Policy Factors

Government acquisition laws and regulations that have effectively separated much of the defense and commercial bases have had a negative effect on the shipbuilding industry too. As in other sectors, special rules have driven up costs. For example, although Navy and commercial hull welding for surface ships might be similar, the costs are far higher for Navy work because of the additional testing required and the more stringent labor requirements to certify those tests. It was reported that certified welders were paid $16 an hour for Navy work and $10 an hour for commercial work. As a result, a yard doing both Navy and commercial work reportedly either had to have two labor forces with different training requirements and pay scales, or use the more highly skilled workers and pay the higher wages for commercial work as well.

Government cost-accounting and inventory requirements that differ from commercial practices have also reduced commercial competitiveness and ultimately inhibited integration. Workshop participants noted that commercial and Navy ships were once built side-by-side and that such construction was helpful; now, partly because of government acquisition rules, this does not, and cannot, occur. Integrating production processes in the shipyards will continue to be difficult if current acquisition laws are not changed. Shipyards argue that the paperwork associated with govern-

[31] The subsidies included a construction-differential subsidy (CDS) under the Merchant Marine Act of 1936. The CDS provided for the government to pay a shipyard, contracting with an American foreign-trade ship operator, the difference between the higher American cost and the lower foreign production cost. The Merchant Marine Act of 1970 anticipated the building of 300 ships under CDS over a 10-year period.

[32] U.S. Congress, Office of Technology Assessment, *An Assessment of Maritime Trade and Technology*, OTA-O-220 (Washington, DC: U.S. Government Printing Office, October 1983), p. 85.

[33] A. Skolnick, "Sea Power, Peacekeeping, Defense Conversion and Budgets: Can They Be Balanced?" *Naval Engineers Journal*, September 1993.

ment regulations drives up the cost of commercial products.

Finally, military specifications and standards have separated shipbuilding in much the same way they have affected other defense sectors. Extensive discussions about the impact of military specifications and standards took place in both the OTA shipbuilding workshops and during interviews. Some of the component producers predicted that continuing the same level of Navy specifications and standards would drive many component producers out of the government market. Although some specifications and standards are viewed as valid, many are thought to be inappropriate. The effects of Secretary of Defense Perry's changes in the use of military specifications and standards are not yet clear, but are considered to be helpful.[34]

Many of those involved in the workshops argued that in the past, decisions to modify the use of military specifications and standards often did not filter down to those charged with writing and implementing the specifications and standards. As a result, little seemed to change despite decisions to proceed with specification *reform*.

U.S. Coast Guard safety standards for ships built and/or requested in the United States (including the use of nonflammable materials and different boilers) were cited as inhibitors by some workshop participants because of their impact on the price of U.S.-built ships. The cost of a boiler that meets U.S. Coast Guard standards, for example, was said to be twice that of one that did not meet those standards.

The actual cost impact of U.S. Coast Guard standards on new commercial construction, however, is disputed. The Coast Guard maintains that the actual cost of compliance is far below the 15 percent figure often cited by shipbuilders. The Coast Guard uses a 1973 report by the American Commission on Shipbuilding that cites a 3 to 5 percent additional "cost of a U.S. flag vessel for compliance with the technical requirements of the Coast Guard, American Bureau of Shipping (ABS), and the U.S. Public Health Service."[35]

Further, the Coast Guard argues that even in the absence of Coast Guard regulations, U.S. shipyards are not competitive and that the absence of foreign flag shipbuilding in the United States must be attributed to factors such as the long delivery schedules and corresponding high delivery costs at U.S. yards, rather than any *added* cost of compliance with Coast Guard regulations.[36] In support, several in industry noted that "what we need is *globalization of standards*" to level the production field and improve safety.

Implications of Increased Integration

Increased integration is thought by many to be essential for the preservation of a domestic shipbuilding base that can provide affordable ships for the Navy. Without increased non-defense work it will be difficult to preserve more than a very few building yards. Greater use of common components and greater use of common design and manufacturing technologies appear useful for both the defense and commercial sectors. It is in these areas that the greatest potential for CMI may exist.

[34] Secretary of Defense William J. Perry, *Memorandum for Secretaries of the Military Departments, Subject: Specifications & Standards: A New Way of Doing Business*, June 29, 1994.

[35] *White Paper: Cost of U.S. Coast Guard Regulations to U.S. Shipbuilders and the Initiative with the Shipbuilders' Council of America To Reduce These Costs*, Sept. 6,1991 (updated December 1992), p. 2.

[36] Ibid., p. 8.

Appendix A Workshops

A

Workshop on Shipbuilding, June 23, 1993

Jack Nunn, *Chair*
International Security and Space Program

John Bissell
Director of Industrial Planning Branch
Industrial Planning Division
Naval Sea Systems Command

John J. Carr
Executive Vice President
IMO Industries, Inc.

Robert Draim
Executive Officer
Naval Sea Systems Command

Ron McAlear
Vice President, Advanced Program
Avondale Shipyard

James A. Palmer
Vice President
Aircraft Carrier Construction
Newport News Shipbuilding

David Reece
Executive Director
Naval Surface Warfare Center
Crane Division

Paul M. Robinson, Captain, USN
Director, Supportability, Maintenance and Modernization Division
The Pentagon

George Sawyer
Executive Vice President
J.H. Lehman

Robert Schaffran
Program Manager
PRC/Maritime Systems Technology Office

Fred Seibold
R&D Program Manager
Maritime Administration

Alfred Skolnick
System Science Corp.

Peter Tarpgaard
Professor
Naval War College

Harvey Walpert
Senior Vice President, Administration
Trinity Marine Group

John Welch
Vice President
Program Management/ Development
General Dynamics Electric Boat Division

William Wert
General Manager
G.E. Navy and Small Steam Turbine Department

Workshop on Shipbuilding, August 19, 1993

Jack Nunn, *Chair*
International Security and Space Program

Steven G. Buttner
Vice President Strategic Planning
Bath Iron Works

J. William Charrier
President and CEO
American Automar, Inc.

David P. Donohue, RADM, USN
(Retired)
The Jonathan Corp.

Robert Draim
Executive Officer
Naval Sea Systems Command

Tom Ellis
Manager
Micro Electronics Department
Naval Surface Warfare Center

John H. Ferrara
President
Maersk Lines, Ltd.

George R. Fister
Vice President, Government Programs
Shipbuilders Council of America

James B. Greene, RADM, USN
Deputy Chief of Naval Operations Logistics
The Pentagon

Paul Hagstrom, Captain, USCG
Chief of Naval Engineering Division
U.S. Coast Guard Headquarters

Gerry Lamb
Director of Washington Operations
Bath Iron Works

Paul Martineau
Executive Director
Ingalls Shipbuilding—Washington Office

Robert J. Scott
Vice President
Gibbs & Cox, Inc.

Alfred Skolnick
System Science Corp.

Guner Woehling
Vice President & General Manager
Henschel, Inc.