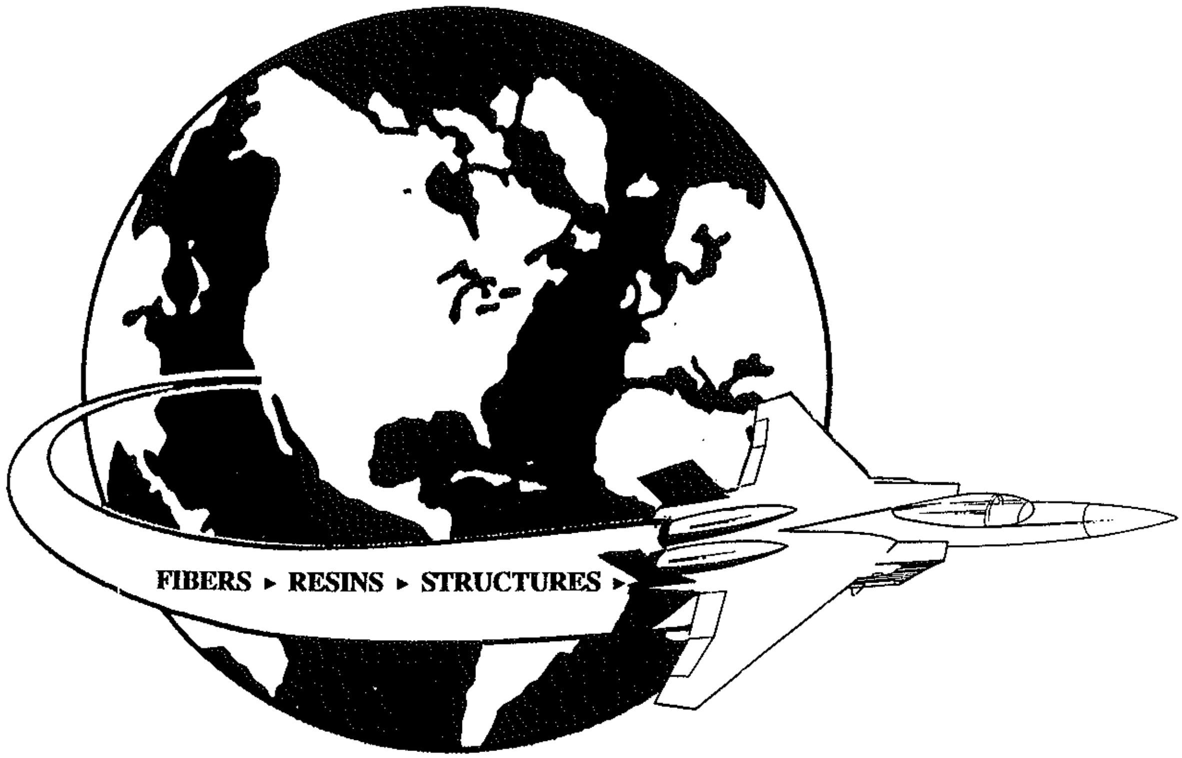
CRITICAL TECHNOLOGY ASSESSMENT OF THE U.S. ADVANCED COMPOSITES INDUSTRY



U.S. DEPARTMENT OF COMMERCE
BUREAU OF EXPORT ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

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Critical Technology Assessment of the U.S. Advanced Composites Industry

Prepared by

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Overview

It is estimated that the 1991 U.S. market for advanced composites was $2.6 billion, out of a total world market of $4.7 billion. The U.S. industry is driven by defense/aerospace applications, the largest U.S. end-user market of advanced composites, while foreign advanced composite industries are more focused on commercial applications. Reductions and cancellations in recent years in defense spending, particularly in military aircraft applications such as the Air Force's Advanced Tactical Fighter, the B-2 bomber, the Army's LH light helicopter, and the Navy's A-12 airplane, have resulted in the downsizing of the U.S. industry, declining profits, employment, and private research and development (R&D) expenditures. Recent years have also shown an increased government share of the industry's total R&D (according to our sample), indicating a growing dependency on federal dollars during a time of defense reductions. The implications for the U.S. industry are negative, as the industry is less financially capable of converting to commercial applications, where the U.S. industry has historically lagged, without sustained U.S. Government assistance.

Background

- The National Defense Authorization Acts of 1991 and 1993 require the Departments of Commerce and Defense to prepare assessments for the Senate and House Armed Services Committees on the financial and production status of industries supporting technologies critical to current and next generation defense systems.

- The primary objective of these assessments is to provide government policymakers and industry with comprehensive information and analysis of the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets.

- Advanced composites were one of six such technologies chosen for initial analysis by a consensus of the Department of Commerce (Bureau of Export Administration), Department of Defense, and the White House Office of Science and Technology Policy. The other assessments cover Advanced Ceramics, Artificial Intelligence, Flexible Computer Integrated Manufacturing, Optoelectronics, and Superconductivity. While the Department of Defense has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy.

Scope

- Advanced composites are generally defined as a family of lightweight structural materials with reinforcing fibers such as carbon, aramid, or high-strength fiberglass that are

embedded in a matrix material. Advanced composites are generally distinguished from other reinforced materials by the use of these continuous high-stiffness strength fibers.

- A comprehensive questionnaire was used by the Department of Commerce to collect data from a wide range of companies in the U.S. advanced composites industry: **material suppliers; fabricators**; and **prime contractors.**

- Associations and consortia were asked to participate and provided support in survey design and field testing, technical advice, and in establishing company contacts. The Suppliers of Advanced Composite Materials Association (SACMA) was particularly instrumental in this advanced composites assessment.

- An extensive product code list was formulated to collect data from this broad spectrum of companies. It was subdivided into two groupings, one for the actual advanced materials and the other for applications of these materials.

- The materials covered include **fibers, resins, prepregs, metal matrix composites, ceramic matrix composites, and carbon/carbon composites.**

- Applications include **military aircraft, other non-aircraft military items, commercial aircraft, sports and recreation, automotive, industrial, non-defense space structures (other than ablatives), mass transit, civil engineering/construction, and an "all other" category.**

Industry Overview

- The U.S. Bureau of Mines estimated that the 1991 U.S. market for advanced composites (excluding advanced ceramics) was $2.6 billion, which comprised 54 percent of the world market of $4.7 billion.

- Study participants reported total sales by their advanced composite divisions as $1.1 billion during this same time period, representing almost half of U.S. consumption. This comparison is not definitive, however, as total sales of certain advanced ceramics, specifically, ceramic matrix composites, are included in this study's data, which may not be included in the Bureau of Mines data. In addition, many of the value-added advanced composite structures, which comprise a portion of the total market, may not have been reported as such, indicating an understatement by our study participants. Foreign sales in the United States were also not definitively captured.

- A total of 66 companies participated in this data collection effort, with information provided on 73 individual company operating units. These units serve as the sample analyzed for purposes of this assessment. This sample is strongest in its coverage of the

U.S. advanced composite fibers industry. Information collected on imports was limited to those foreign producers who have actual sales offices in the United States.

- Respondents further defined the 73 operating units into 99 manufacturing plants located in thirty-one U.S. states and seven foreign countries. The majority of these plants, 89 of the 99, are located domestically.

- Sixteen of the 66 respondent companies are foreign-owned: 6 by British firms; 4 by Japanese firms; 2 each by Dutch and Swiss firms; and 1 each by a French and a German firm.

Implications for Economic and National Security

- **The data collected on the U.S. industry, ranging from financial statistics, employment, shipments, capacity utilization, to research and development expenditures, highlights the negative impact of defense reductions on this U.S. industry.** This injurious effect, combined with foreign industries' lead in commercial advanced composite applications, has dire implications for the future competitiveness and survivability of the U.S. industry.

- The vast majority of information provided by companies who are users of advanced composites materials pertained primarily to defense uses. Almost all respondents, whether producer or user of advanced composites, reported supplying various domestic weapon systems: 34 different military aircraft systems were identified; 24 missile and rocket systems; and 16 other various military and space systems. This is in contrast to foreign advanced composite industries, particularly those in Asia (primarily Japan), where commercial uses are more predominant than defense.

Economic/Corporate Financial Data

- The surveyed firms reported that domestic plants are on average 17 years old; foreign plants are on average 8. Over half the domestic facilities went on-line since 1980, indicating a high level of continued investment by this industry.

- Capacity utilization rates for the advanced composites industry are low in comparison to the U.S. average for manufacturing facilities. The average rate for all reporting facilities in 1992 was 59 percent. In all, 50 percent of these facilities (19 of 38) were operating at 50 percent or less capacity.

- Financial information was collected on both a corporate basis and, when possible, on a division basis. Many companies in the advanced composites industry are operating units of much larger, diversified corporations.

- o On a corporate basis the financial performance of participant companies varied between 1987 and 1991, with aggregate sales volumes (including advanced composites) increasing from $56 billion in 1987 to $93 billion in 1991. Profit margins declined during the same period, dropping from 7.3 percent of sales in 1987 to 4.5 percent in 1991. Roughly one-third of the reporting companies experienced net corporate losses in each year during the five year review period.

- o The division data reflects the changing nature of the advanced composites business, where economic pressures on all businesses have resulted in new financial pressures on each operating unit of larger organizations.

- o Division level sales grew 73 percent over the review period, yet net losses grew from $2.2 million in 1987 to $27.4 million in 1991. This reflects extreme competition and the high costs of doing business in advanced composites. Profit/loss margins reflect these losses. [More detailed financial information is included in the material suppliers, fabricators, and prime contractor summaries below.]

- o Based on this financial data, corporations are now generally less capable of financially underwriting specific operating units in the long term, resulting in these units having to financially support themselves more than in the past. The consolidation in this industry (e.g., Rhône-Poulenc's sale of its advanced composites operation in Kentucky to Ciba-Geigy or BASF's shut-down of its South Carolina facility for want of a buyer) reflects this inability by large corporations to maintain non- or less-profitable units.

Employment

- o Overall industry employment declined 17.3 percent between 1989 and 1993.

- o Manufacturers comprised the vast majority of employees reported, ranging from 89.9 percent of total employment in 1989 to 91.7 percent in 1993. Manufacturers' total employment declined 16.7 percent between 1989 and 1993, with the downsizing beginning in ernest in 1990.

- o Research and development (R&D) facilities comprised the second largest group of employees reported, accounting for 9.1 percent of total employment reported in 1989 and declining to 5.3 percent in 1993. The number of R&D employees declined each year, with a net change between 1989 and 1993 of -53.9 percent. This reduction is attributed to the contraction of the industry due to reductions in the aerospace market, which is the predominant reason for the decline in profits. Companies cannot afford R&D at the same level as before the aerospace downturn.

- o Employment by sales/non-manufacturing firms was the smallest category of employees, but was the only category to experience an increase in employment. During the review

period employment climbed 253.4 percent. The growth is attributed to increased market share by foreign companies with sales operations in the United States.

- o Availability of a skilled workforce was of major concern to survey participants. Many entry-level employees have low skills, requiring significant company investment in basic training, as well as technical training needed for advanced composites work. Lack of skilled workers, both in basic fundamentals such as math and reading and technical expertise, serves as an impediment to the vitality of this and probably other U.S. industries.

Shipments of Materials and Intermediate Products

- o Total reported shipments of all **fibers** increased 29.7 percent between 1989 and 1993. During this same period, defense shipments as a portion of total shipments declined from 35.3 percent to 28.1 percent. This can be attributed directly to reduction in defense spending. Exports grew from 9.6 percent to 14.0 percent. Carbon fiber comprised the bulk of these reported fiber shipments.

- o The increase in fiber shipments is attributed in part to an increase in exports and to the trend of sports and recreational product manufacturers' expanding use of fiber (carbon fiber). The price necessary to compete in this application, however, is substantially less than defense/aerospace carbon fiber, resulting in fiber producers barely breaking even, if at all. The same holds true for the growth in prepreg shipments as discussed below.

- o The remaining fiber categories experienced a 24 percent decline in shipments between 1989 and 1993. Defense shipments fell drastically, dropping 59 percent in dollar terms and from 51.5 percent to 27.5 percent of total shipments. These products have been severely hit by defense cutbacks. Exports of these other fibers grew, both in dollars (18 percent) and as a percent of total shipments (from 16.4 percent in 1989 to 25.5 percent in 1993).

- o Total shipments of **resins** rose nearly 35 percent between 1989 and 1993. Defense shipments dropped 13.6 percent over the period. More significant is the drop in defense's share of all resin shipments, which fell from 28.4 percent in 1989 to 18.3 percent in 1993. Exports fluctuated, with a net result of a 4.5 percent increase overall. The majority of data submitted in the resins category pertained to epoxies.

- o Total **prepreg** shipments showed steadier growth throughout the review period than did either fibers or resins. Shipments grew 13.3 percent between 1989 and 1993. Prepreg shipments for defense fell, both in dollars and as a percent of total shipments. Defense applications accounted for 49.4 percent of total shipments in 1989, dropping to 36.3 percent in 1993. The value of defense shipments fell by 16.8 percent during the same

period. Prepreg exports boomed, growing 42.3 percent between 1989 and 1993, and going from 4.6 percent of total shipments to 19 percent.

o Shipment information for non-polymer matrix composites, **metal matrix composites, ceramic matrix composites**, and **carbon/carbon composites**, were found to be almost entirely defense driven, more than any other product reviewed. Non-polymer based composites comprise less than 10 percent of all advanced composites, but hold unique abilities unavailable from polymer matrix composites. Defense shipments of non-PMCs declined 31 percent between 1989 and 1993, dropping from 100 percent of total shipments to 78.4 percent. There were no exports reported during the review period. **As the development of these newer composite areas is driven overwhelmingly by the Defense Department, defense spending cutbacks could inhibit U.S. industry participation in these areas.**

Total Research and Development Expenditures

o Many companies reported that their reduced overall sales correlate to reduced profits and reduced funds available for R&D. **Increased competition in a smaller worldwide defense market, combined with declining U.S. defense spending, will further impair financially-troubled companies' ability to expend funds for new research. In the long term this could result in next generation technologies being developed offshore by foreign firms who are not as dependent on defense spending and defense markets.**

o Total reported research and development (R&D) expenditures grew 58 percent during the review period. During this same period there was a drastic change in the sources of R&D funding. In 1989 private funds (i.e., industry) accounted for nearly 80 percent of all reported R&D; by 1993 private funds made up less than half of R&D spending.

o Through the five-year review period, private R&D funds were fairly constant in dollar terms, declining slightly over five percent between 1989 and 1993. In-house sources comprised the majority of these private funds, but the dominance of this source lessened somewhat, dropping from 77 percent of total private R&D funds in 1989 to 65.2 percent in 1993. The role of domestic customers grew in importance, from 19.9 percent in 1989 to 33.8 percent in 1993. The other private sources remained fairly constant and were not significant.

o In contrast, public funding skyrocketed between 1989 and 1993, particularly in the first two years. Funds from public sources grew by nearly 300 percent. The Department of Defense (DOD) consistently accounted for the majority of the funding, while non-defense government entities never provided more than 19 percent of total public support. Within DOD the Air Force was initially the largest financier of advanced composites R&D; by the end of the review period, the Advanced Research Projects Agency (ARPA) had assumed the dominant role.

Material Suppliers Sector: Economic Analysis

- o In 1992 the average capacity utilization rate for material suppliers was 58.9 percent. The largest producers who comprise the bulk of U.S. production have the lowest utilization rates, a negative indicator for the industry.

- o Between 1987 and 1991 total corporate sales for material suppliers increased 62 percent, while net income fluctuated. Corporate profit margins exhibited a decline, dropping by almost half from 9.5 percent in 1987 to 5.1 percent in 1991. The number of individual companies reporting net losses increased each year, ranging from 12.5 percent of respondents in 1987 to 31 percent in 1991. **In spite of the increase in dollar value of sales, profits have declined.**

- o The financial performance of these companies' advanced composites divisions was much worse. While total divisional sales increased ($328 million in 1987 to $563 million in 1991), net incomes plummeted from about $12 million in 1987 to a loss of $28.5 million in 1991. These divisions' aggregated profit margins dropped from 3.6 percent in 1987 to -5.1 percent in 1991.

- o The percentage of companies experiencing net losses grew from 20 percent of divisions in 1987 to almost half in 1991.

- o R&D expenditures by material suppliers increased by almost 41 percent during the review period of 1989 to 1993. In 1989 private funds accounted for 98.1 percent of these expenditures; this percentage dropped further in each subsequent year. By 1993 private sources accounted for less than half the R&D expenditures. This sharp decline reflects the poor financial health of material suppliers' advanced composites businesses.

- o The decline in the U.S. industry's ability to internally fund research for new materials impairs the ability of the industry to compete internationally in next generation developments.

Fabricators Sector: Economic Analysis

- o Moving from material suppliers to fabricators and then prime contractors, the nature of these different firms changes, as fabricators and prime contractors are more diversified and thus less dedicated to the advanced composites sector. For this reason it was difficult for these companies to segregate their advanced composites business for reporting purposes.

- o Fabricators had an average capacity utilization rate of 58.6 percent in 1992, about the same as material suppliers. Over half the reporting plants were operating at 50 percent

or less capacity. Unlike the material suppliers, fabricators with the largest shipment volumes also had the highest capacity utilization rates. This is attributed to their diversified operations, of which their advanced composites business is only a portion.

- Corporate sales for fabricators grew between 1987 and 1991, from $31.1 billion to $53.2 billion. Net income peaked in 1989, and then declined. Profit margins reflected this trend, peaking at 8.8 percent in 1989 and dropping to 4.1 percent in 1991.

- The number of companies reporting corporate losses during the review period was fairly constant at about 38 percent of responding firms.

- At the division level, gross sales grew during the five-year period, from $303 million in 1987 to $531 million in 1991. In only one year, however, was a net profit reported. In 1987 the loss was 4.6 percent; fabricators recovered in 1991, the only profitable year, with a profit margin of 0.2 percent. The number and percentage of companies experiencing net losses declined during the five-year period, with 71 percent of divisions reporting losses in 1987 and 33 percent of those reporting in 1991.

- Fabricators' R&D expenditures rose 37 percent between 1989 and 1993. Private funds comprised 68.8 percent of these total expenditures in 1989, and declined as a percentage of the total each year. In 1993 private funds accounted for 58.9 percent of fabricators' R&D expenditures.

Prime Contractors Sector: Economic Analysis

- In 1992 prime contractors had on average the highest capacity utilization rate, 72.7 percent. None of these companies, however, are major advanced composite producers, and are dependent on their upstream suppliers, both fabricators and material suppliers.

- Aggregated corporate sales increased each year during the five-year period, from $1.7 billion to $2.4 billion. Net incomes also increased each year, from $55.1 million to $92.9 million. The profit margins fluctuated from 3.2 percent in 1987 to 3.8 percent in 1991. None of the reporting companies reported a net loss.

- None of the reporting prime contractors have operating divisions which specialize predominantly in advanced composites, so no such information was provided.

- R&D expenditures by prime contractors grew significantly between 1989 and 1993, up 224 percent, although in actual dollars these expenditures were much lower than those by material suppliers and fabricators. In 1989 private funds accounted for roughly half these expenditures. As was seen with both material suppliers and fabricators, this percentage declined each year. In 1993 private funds accounted for only 23.2 percent of R&D expenditures.

Cooperative Agreements

- o Industry participants reported 81 significant cooperative agreements, both domestic and foreign. The trend toward joint efforts, particularly in consortia, has been growing in recent years, especially since the principal U.S. advanced composite end-market, the defense/aerospace industry, continues to decline. The companies reported that they are engaged in joint efforts as a necessity for financial survival.

- o Examples of consortia include Great Lakes Composites Consortium, an industry/Navy cooperative development effort, the Advanced Composite Technology Transfer Consortium, an academia/industry group studying infrastructure applications, and the Northrop Development Team, a group of 18 California companies who are developing mass transit applications.

- o The National Aerospace Plane (NASP) program, developing an airplane that can fly into space, is an example of a joint industry/government program. The NASP program to date has cost approximately $2.5 billion, of which the U.S. Government has invested $1.8 billion. Industry has estimated that commerical application of composite developments alone will provide at a minimum about $7.5 billion in new sales during a twenty year period, generating 75,000 new jobs and a four-fold return on taxpayers' investment.

- o Of the 81 major cooperative agreements reported, 31 are with foreign firms. While there has been significant interrelationships between U.S. and foreign companies in this industry since the 1960s, our study participants reported recent licensing agreements that indicate that technology tends to be flowing out of the United States, rather than into the United States. The Japanese were cited most frequently in foreign agreements.

Sourcing and Dependencies

- o Industry survey respondents reported a number of sole and single source producers and suppliers for defense items. Rather than citing this as a potential bottleneck to production, the companies attributed this in part to DOD's costly qualification process, which tends to create single and sole sources. Respondents also cited the proprietary material formulation used by companies which results in many advanced composite materials being sole sourced, although other materials may have similar properties and be qualified to the same specification. In sum, few items or products serve as impediments due to sole or single source problems.

- o Companies also reported imports of key manufacturing equipment, components, parts, and materials needed for their advanced composite operations. The most frequently cited source was the United Kingdom, followed by Japan and then Germany. In most cases

the use of foreign sources is attributed to the DOD qualification system, costs, and lack of awareness, among other factors.

Impact of Defense Cuts/Defense Conversion

o The study participants were asked of the impact of defense cuts on their advanced composite business as a whole. Most companies indicated that their sales have declined, along with comparable drops in employment and in expertise. Technological developments in the industry, historically driven by military programs, were also reported to feel the adverse affects of reduced defense spending.

o The reductions and cancellations of major defense programs and the slow-down in commerical aircraft build rates have thus adversely impacted the U.S. advanced composites industry. Sales to defense/aerospace customers were the most profitable for advanced composite suppliers. While some of the volume lost has been recovered, the prices required to compete with both foreign sources and conventional materials in these market segments force advanced composites suppliers to often sell at a loss in these areas. As a result the financial health of U.S. advanced composites suppliers continues to erode.

o The vast majority of study participants indicated that they were unaware of any Federal, state, or local government defense conversion programs to assist advanced composite suppliers.

o Awareness of conversion programs is changing, however. In March 1993 President Clinton announced an initiative to distribute the $1.4 billion appropriated by the Congress in 1992 plus an additional $300 million. About $500 million is available this fiscal year through the Technology Reinvestment Program (TRP), an interagency project which already has identified advanced composites as technology focus areas.

o The respondents who were familiar with the TRP indicated the importance of funding advanced composites programs. These programs could utilize the dual use potential of these materials to address many of the nation's transportation and infrastructure needs while providing the military with the technology advantages it needs. The areas most often mentioned which would require Federal assistance to demonstrate the benefits of and catalyze the market acceptance/expansion of advanced composites include bridge contruction/repair, automobile bodies/fuel tanks, and commercial aircraft engines/primary structures.

o The Department of Commerce National Institute of Standards and Technology (NIST) Advanced Technology Program (ATP) was also mentioned as an opportunity to facilitate market acceptance/expansion of advanced composites. However, no companies were

aware of any existing or pending NIST/ATP programs which focus on advanced composites.

- o Study participants made a number of suggestions of how the Federal Government could provide conversion assistance. These included recommendations for new Federal funding programs to demonstrate the benefits of advanced composites to new users, continued funding for existing programs, education and training assistance, and tax incentives for reinvestment to develop non-military applications.

- o Most responding companies reported (in 1992) that DOD has made no effort to use commercially viable advanced composites. When asked in what ways DOD could assist in promoting such dual use composites, companies provided a wide range of comments, including funding requests, development of dual-use demonstration programs, expansion of transition programs like the NASP, and the creation of a central technology development office which would coordinate defense and commercial technology activities.

Competitors

- o There were 129 different companies reported as principal domestic competitors. Eighteen of these companies, roughly 14 percent, are foreign-owned. Half of the ten most frequently mentioned companies are also foreign-owned. Hercules of Magna, Utah, most the most frequently mentioned company by survey respondents.

- o Companies also provided information on who they consider to be their major foreign competitors. There were 64 different companies reported from 19 different countries. Only three of these companies are U.S.-owned firms. Toray Industries of Japan was the most frequently mentioned firm. Three of the ten most frequently mentioned foreign firms also appear in the list of top ten domestic companies.

- o It is evident from the responses that company respondents, whether material supplier, fabricator, or prime contractor, assessed the competitiveness area from a materials perspective, given the reporting of Hercules and Toray as the most frequently cited competitors. The industry is driven by the materials, as seen from these responses.

Conclusions

- o The combination of the defense cutbacks and the financial and competitive pressures on large corporations is having a negative impact on the size and vitality of the U.S. advanced composites industry, an industry deemed by DOD as critical to the performance of current and next generation weapon systems.

- The high costs associated with commercializing advanced composites, coupled with the downturn in the aerospace market, have resulted in consolidation within the industry, especially among producers (rather than users) of advanced composite materials.

- The industry has made continuous financial investment in plants and equipment, especially in the last thirteen years. Based on the fact that the domestic industry's greatest single market, the defense industry, is faced with a dramatic downturn which began with the end of the Cold War, it is apparent from the investment perspective alone that the defense downturn has dire financial implications for the advanced composites industry.

- Material suppliers appear to be in the most precarious position: the largest companies have the lowest capacity usage, in fact, half of all responding material suppliers are at 50 percent or less capacity; corporate profits cut in half; these companies are collectively operating their advanced composites business at a loss; internal R&D funding is no longer affordable, diminishing chances of converting to commercial markets; increased competition from offshore competitors already well entrenched in commercial markets; future government (i.e., defense) funding is uncertain.

- The entire production process, beginning with material suppliers, is unlike the supply chain in many industries, because the process is determined from the outstart by the specifications required by the ultimate end user. The decline of the U.S. advanced composite materials industry thus infects downstream users, both fabricators and prime contractors. Prime contractors are also in a precarious position because of reduced orders from DOD. The problem for them is thus cyclical, as it hurts them from above, their customer, and from below, their suppliers.

- The Federal Government can help preserve the U.S. advanced composites industrial base. One of the best ways would be to assist U.S. advanced composite suppliers in speeding the adoption of these materials into non-defense/aerospace applications like infrastructure, automotive, and expanded use in commercial aircraft. The existing TRP and ATP programs could serve as vehicles to accomplish this objective.

CRITICAL TECHNOLOGY ASSESSMENT
OF THE U.S. ADVANCED COMPOSITES INDUSTRY

I. BACKGROUND

This critical technology assessment of the U.S. advanced composites industry was initiated under Section 825 of the Defense Authorization Act for Fiscal Year 1991. This section of the law required the Secretary of Defense (acting through the Under Secretary for Acquisition) and the Secretary of Commerce (acting through the Under Secretary for Export Administration) to submit annual reports to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of industries supporting technologies deemed by the Department of Defense (DOD) as critical to the performance of current and next generation weapon systems. The National Defense Authorization Act of Fiscal Year 1993, Section 4215, further expands the scope and requirement for technology and defense industrial base capability assessments.

The primary objective of these assessments is to provide industry executives and government policymakers with comprehensive information and analysis on the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets. While DOD has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy. Not surprisingly, almost all of the DOD critical technologies are also found on the Department of Commerce's 1990 list of Emerging Technologies and the White House Office of the Science and Technology Policy's 1991 list of National Critical Technologies.

Six of the DOD critical technologies[1] were selected for review and submission to the Congress during FY 1992-1993. Advanced Composites is one of the six chosen; the other assessments cover Advanced Ceramics, Artificial Intelligence, Flexible Computer Integrated Manufacturing, Optoelectronics, and Superconductivity.

The Department of Commerce's Office of Industrial Resource Administration (OIRA), Strategic Analysis Division, is the office within the Bureau of Export Administration that is responsible for conducting these critical technology assessments. For each technology OIRA created an advisory team whose members were drawn from the Department of Commerce's Technology Administration (including the National Institute of Standards and Technology - NIST) and International Trade Administration, and the Department of Defense's Office of the Secretary of Defense (OSD) Production Resources Support Office (PRSO). Assistance was also provided by the Advanced Research Project Agency, the U.S. Air Force, the U.S. Navy, and the White House Office of Science and Technology Policy (OSTP).

OIRA also sought out private sector associations, consortia, and businesses which specialize in the six critical technologies selected for review. Associations and consortia participating provided support in the area of industry survey design and field testing, technical advice, mailing lists, on-site visits, and in establishing company contacts. The Suppliers of Advanced Composite Materials Association (SACMA) was particularly instrumental in this advanced composites assessment. Assistance was also provided by such organizations as the Advanced Composite Technology Transfer Consortium, Advanced Composites Magazine, Amoco Performance Products, the Great Lakes Composites Consortium (GLCC), Hercules Composite Products Group, Lawrence Associates, Inc., and Proposal Resources, Inc.

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[1] The DOD list includes: air-breathing propulsion; composite materials; machine intelligence & robotics; passive sensors; photonics; semiconductor materials & microelectronic circuits; sensitive radars; superconductivity; biotechnology materials & processes; computational fluid dynamics; data fusion; high energy density materials; hypervelocity projectiles; parallel computer architectures; pulsed power; signal processing; signature control; simulation & modeling; software producibility; and weapon system environment.

In accordance with the requirements of the FY 91 and FY 93 National Defense Authorization Acts, the following factors were addressed in each of the critical technology assessments:

A. *The financial ability of U.S. industries supporting these critical technologies:*

1) to conduct research and development relating to critical defense technologies;

2) to apply those technologies to the production of goods and services;

3) to maintain a viable production base in critical areas of defense production and technology in the wake of reductions or terminations in defense procurement; and

4) to expand the defense production base in national security emergencies.

5) to maintain a viable defense production base in each critical area in which terminations of major Department of Defense procurements are planned; and

6) to engage in any other activities determined by the Secretary to be critical to national security.

B. *Additional analysis was undertaken on such factors as:*

1) trends in profitability, investment, research and development, and debt burden of businesses involved in research on, development of, and application of critical defense technologies;

2) international competitiveness and market trends;

3) consequences of mergers, acquisitions and takeovers of such businesses;

4) effects of dependence on foreign or foreign-owned suppliers;

5) results of Defense spending for critical technologies in the current fiscal year, as well as the likely future levels;

6) efforts of Defense to expand the use of commercial technology and equipment; and

7) the need and efforts of industry in the area of defense conversion.

With industry and interagency assistance, OIRA devised a comprehensive questionnaire to collect information to respond to the assessment factors listed above. The questionnaire was field tested

with regard to availability of data, technical accuracy, clarity of instructions, disclosure and reporting format. As part of this effort, OIRA co-sponsored a Critical Technologies Workshop with NIST on February 6, 1992, to gather and incorporate industry input into our draft survey instruments and assessment outlines for each of the six studies. Approximately 500 experts from academia, industry, and government attended the workshop with many providing comments on our six draft survey forms. Approximately 80 representatives were present at the afternoon session devoted to the advanced composites assessment.

OIRA disseminated the six different questionnaires to U.S. industry, selected U.S. Government laboratories, and universities under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 12656.

To enhance Commerce's effort to assess the industry's international competitiveness and the effects of dependence on foreign or foreign-owned suppliers, BXA's Office of Foreign Availability (OFA) conducted a separate review of the efforts of leading foreign companies, governments, and research institutions in the six technologies. To conduct this review OFA contacted industry specialists in leading domestic and foreign firms, as well as in government agencies and universities. Department of Commerce foreign commercial officers in U.S. embassies and consulates in Europe and Asia also collected and forwarded information to OFA to supplement the data collected from industry. The OFA review is available from the National Technical Information Service (NTIS) by calling 703-487-4650 and requesting PB 93-183168LIB.

II. STUDY METHODOLOGY

OIRA's questionnaire served as the primary source of data for this assessment. The survey cover page and the table of contents are attached as *Appendix 1*.[2] The questionnaire was designed to collect information from a wide range of companies in the industry's supply chain. Three broadly defined links, or categories of companies, in this chain served as the basis of our study: **material suppliers; fabricators; and prime contractors**. The collection of information from such a diverse yet related set of companies provided the unique ability to study the industry from two different perspectives, those of both the suppliers and the users of advanced composite materials.

To collect information from such a broad spectrum of company types, an extensive product list was formulated and provided as part of the questionnaire. Participants were asked to classify their work in the advanced composites field using this coded product list, and to report all data on a product code basis, as appropriate. This product code list is attached as *Appendix 2*.

This listing is subdivided into two groupings, one for the actual advanced materials and the other for applications of these materials. The materials section covers categories for **fibers, resins, prepregs, metal matrix composites, ceramic matrix composites, and carbon/carbon composites.** These specific categories are defined and discussed in Part III.

The applications section covers end-use applications in **military aircraft, other non-aircraft military items, commercial aircraft, sports and recreation, automotive, industrial, non-defense space structures (other than ablatives), mass transit, civil engineering/construction, and an "all other" category**. These categories are also discussed in Part III.

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[2] A copy of the questionnaire has not been attached, due to the length of the document. A copy may be obtained, however, by calling the telephone number listed on the title page of this report.

III. PRODUCT COVERAGE AND APPLICATIONS

A. Product Coverage Definitions

Advanced composites are generally defined as a family of lightweight structural materials with reinforcing fibers such as carbon, aramid, or high-strength fiberglass that are embedded in a matrix material. While there are many types of composites, advanced composites are generally distinguished from other reinforced materials by the use of these continuous high-stiffness and -strength fibers.[3] The matrix material used is often a polymer, hence the name polymer matrix composites (PMCs). These are most familiar and prevalent composite materials in current use, but other metallic, ceramic, and carbon-based composite materials are also used. The driving force behind the use of such materials is the high structural performance and the low weight, which together contribute to increased efficiency.[4] These materials are used primarily in military and some civilian aircraft, military hardware, sports equipment, and some automotive applications.

Given the broad spectrum of materials and end uses, it is difficult to estimate the size of the U.S. advanced composites market. In May 1993 the U.S. Bureau of Mines estimated that the 1991 U.S. market for advanced composites (polymer matrix composites, plus metal matrix and carbon/carbon composites) was $2.6 billion, which comprised 54 percent of the 1991 world market of $4.7 billion.[5] These estimates do not include advanced ceramics. For purposes of this assessment, we did collect information on advanced ceramic matrix composites. We excluded all other advanced ceramics, which include ceramic powders, coatings, and monoliths. These products are covered in a separate critical technology assessment on the U.S. advanced ceramics industry.

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[3] Rogers, Curt. Advanced Composite Materials: The Air Force's Role in Technology Development. Santa Monica, CA: RAND Corporation. 1991. p. 1.

[4] Aerospace Industries Association of America, Inc. A Detailed Technology Roadmap for Composite Materials. Washington, D.C. May 1989. p. 7.

[5] McDonough, William J., and Robert D. Brown, Jr., Bureau of Mines. Advanced Materials Annual Report 1991. Washington, D.C.: U.S. Department of the Interior. May 1993. pp. 9, 17, 21.

The advanced composite industry's origins are often debated. Some contend that its lineage traces back to the applied research conducted at the Materials and Structures Laboratory of Wright-Patterson Air Force Base in Dayton, Ohio, in 1943, as part of the American war effort. The industry is also an outgrowth of the reinforced plastics industry of the 1940s. The origin's debate stems from the varied beginnings of many of the important components of today's industry. The history of carbon fiber is one example, as this vital fiber can be traced back to the U.S. invention of carbon fiber light bulb filaments in 1879[6], although it was not until the 1960s that carbon fibers became commercially available.

Fibers such as carbon and others which are produced by material suppliers serve as the first generation within the advanced composite supply chain. To move to the next step, or generation, the fibers are combined with resins to create a structure. This is done by injection or resin transfer molding, wet filament winding, or combining with the resin to form a prepreg[7] sheet. The prepreg is the most common product form in the advanced composites/aerospace industry. Both the fiber and resin producers draw their raw materials from a common supplier base, the petrochemical industry. An advanced composites fabricator processes the prepreg to a desired shape, which then undergoes the curing process. It is at this point that the composite materials are transformed into highly durable goods to be used in specific applications, the third generation of the chain.

An overview of the structure of the advanced composite industry is provided as *Graph 1*.

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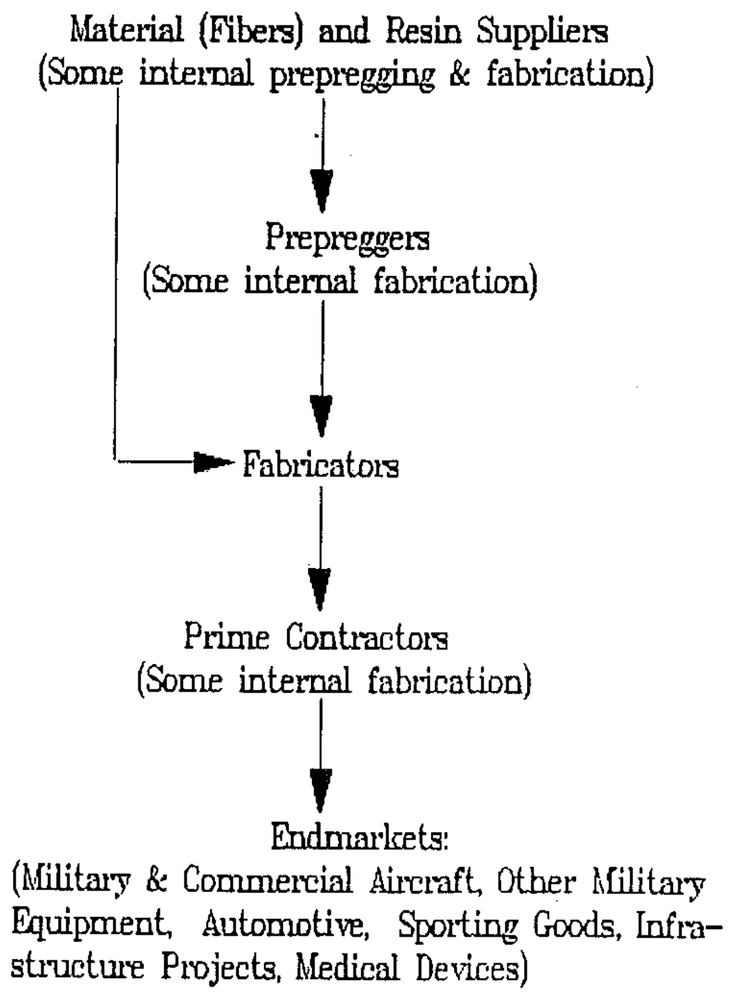
[6] Bennett, William F., Amoco Performance Products. Fiber Reinforcements Carbon Fiber. Federal Sector Briefing to the Suppliers of Advanced Composite Materials Association. February 2, 1989. p. 15.

[7] The term "prepreg" is taken from the process of making a fiber product by preimpregnating a fiber with resin before manufacturing into a component shape.

Graph 1:
Structure of the Advanced Composites Industry



1. <u>Fibers</u>

While *Graph 1* is an oversimplified representation of the industry, the information collected with the use of the questionnaire's product code listing was much more extensive. The first category on this listing was that for fibers. As can be seen from *Table 1*, OIRA collected information on seven categories of fibers.

Table 1: Fiber Categories			
1.	Carbon Fibers		
2.	Ceramic Fibers		
	A.	Silicon Carbide/Silicon Aluminum Fibers (Non-Oxide)	
		1.	Organic Precursor
		2.	CVD onto Carbon Fiber
		3.	Sintered Silicon Carbide
	B.	Oxide Fibers	
	C.	E-Glass Fibers	
	D.	Whiskers	
	E.	Particulates	
3.	Polymer/Organic Fibers		
4.	Metallic Fibers		
5.	Aramid Fibers		
6.	Glass Fibers		
7.	Boron Fibers		

Source: OIRA Questionnaire

Among these seven types of fibers, **carbon fiber** is the most widely used in advanced composites. As recently as 1989, carbon fibers (primarily carbon/graphite[8] fibers) represented almost 60 percent of all advanced composite fiber usage.[9] Usage of carbon fibers in advanced composites applications can be traced back to 1965, when the U.S. Air Force began funding Union Carbide to develop carbon fiber technology. This followed carbon fiber development efforts in the United Kingdom. This early funding was considerably less than early Federal efforts in boron fiber development, and while carbon fiber technology lagged that of boron, by around 1968 it became clear that carbon fiber had significant advantages. In fact, by the mid-1970s boron was largely replaced by carbon/graphite fibers, with boron being used only in special design cases.[10]

Carbon fibers are further distinguished by precursor and raw material from which they are made, specifically, **polyacrylonitrile (PAN), pitch, or rayon**. Of these three types, PAN-based fibers are the dominant reinforcement in use, either in the form of a filament, tape, or tow[11]. PAN-based carbon fibers account for more than 95 percent of the carbon fibers currently being used as structural materials.[12] Japan accounts for 40 percent of the world's PAN fiber production, followed by the United States with 30 percent. Other regions such as Asia and Europe account for the balance.

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[8] Graphite fiber is carbon fiber which has undergone heat treatment above 2,000°C, a process called graphitization.

[9] Weatherall, James, and Carl Eckert. "Advanced Polymer Composites Overview and Outlook." U.S. Bureau of Mines Information Circular 1990: Advanced Materials Outlook and Information Requirements. Washington, D.C. 1990. p. 30.

[10] Curt Rogers, p. 27.

[11] A filament is an individual fiber of indefinite length used in tows, yarn, or roving. A tow is an untwisted bundle of continuous filaments, typically man-made from carbon, aramid, or glass fibers.

[12] "Advanced Composite Materials, Challenge Toward 21st Century." Nikkei New Materials. Tokyo, Japan. July 13, 1992. pp.84-95 [translated from Japanese].

Pitch is the residual material of some coal and petroleum products which is used as a base material for the manufacture of some carbon fibers and as a matrix precursor for carbon/carbon composites. Pitch-based fibers, while important, are typically employed for those applications which do not require high performance properties or have critical end uses. Pitch fibers typically have high stiffness but low strength. They also have some unique thermal/heat transfer characteristics which make them attractive for special applications in such areas as satellite and brake applications. Use of rayon-based carbon fibers is relatively low, and it is often not considered to be an "advanced composite" material, although this material has been deemed critical to several ablative applications for rocket systems. The greatest use of advanced composites made from carbon fibers tends to be for aerospace applications, while sports and recreation uses are a growing area.

Aramid fibers (named for their chemical name, aromatic polyamide) are the second most widely used fibers for advanced composites, accounting for about 25 percent of total use.[13] They are a synthetic organic fiber produced in the United States by E. I. DuPont de Nemours, which markets three types under the registered trademark name Kevlar (Kevlar, Kevlar 29, and Kevlar 49; Kevlar 49 is structural fiber). Aramid fiber is inferior to carbon in tensile strength, but it does have a lower density and lighter weight than other reinforcements. Its specific strength is the same as that of carbon fiber, while it is superior in chemical resistance.[14] Aramid fibers do have superior toughness and lighter weight than glass and have replaced glass in several secondary structures. DuPont's Kevlar is also known for ballistic resistance characteristics.

Aramid fibers are classified into two groups, para aramid and meta aramid fibers. The para group is dominant, with one of its principal uses as rubber tire reinforcement (although not an advanced composite use). Other non-advanced composites applications include some cement reinforcement uses, heat-resistant and pressure-tight hoses, bulletproof vests, and gloves.

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[13] Weatherall. p. 2.

[14] "Advanced Composite Materials, Challenge Toward 21st Century," p. 86.

Aramid fibers are also used in automobile parts such as brake linings and clutch facings, which were once made using asbestos fibers but are no longer, due to health reasons. Advanced composites uses for structural composites include aircraft parts, helmets, and sports equipment.

High-strength **fiberglass fibers** are also used in advanced composites, and account for most of the remaining usage of advanced fibers (following carbon and aramid). This classification included S-glass ("structural glass"), which was produced in the United States by Owens-Corning, which developed this fiber in 1968 to wind missile casings. Owens-Corning's production, however, halted in 1981. In the mid-1980s Owens-Corning introduced S-2 glass, which is a commercial version of S-glass. The new S-2 has wider production tolerances, is stronger and stiffer than conventional E-glass fiberglass, and is applicable to broader uses. Its applications currently include cargo liners, commercial aircraft floors, helicopter blades, and recreation uses (mainly sailboards and wind-surfers).[15] These high-strength fibers are relatively heavy and tend to be the least expensive of the three fibers discussed thus far. Fiberglass fibers were the basis of the first modern, but not yet advanced, composite material to be used in secondary structures in the 1940s. It was because fiberglass was not stiff enough for primary aircraft structures that research into new fiber materials was begun in the late 1940s.[16]

A number of other fibers are used in advanced composites, many of which are still in the developmental stages. These other fibers account for about two percent of fiber usage in advanced composites.[17] While the usage of these fibers is still small, several are critical in some applications. **Ceramic fibers** are one such classification. A ceramic material is a rigid, often brittle material made from clay and other inorganic, nonmetallic substances and fabricated into articles by sintering, which is cold molding followed by fusion of the part at a high

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[15] "Continuous Glass and Boron Reinforcing Fibers: Both Offer High Compressive Strength But Low-Cost Glass Will Find More Applications." High-Tech MATERIALS Alert. Volume 5, Number 6. June 1988. p. 5.

[16] Curt Rogers, p. 11.

[17] Weatherall. p. 30.

temperature.[18] As was seen in the fibers table earlier, there are a number of ceramic fiber subcategories. Silicon carbide and alumina fibers are used as important reinforcements for metal matrix composites because of their high strength and modulus, their density, and their relatively low cost. The same holds true for ceramic matrix composites except for alumina fibers, which react with ceramics and cannot be used as a reinforcement. Silicon carbide reinforcements can be used in fiber form, but also as whiskers or particulates. Whiskers are short single crystal fibers or filaments, usually made from ceramic materials, while particulates are particles, either metallic or non-metallic, which with one or more components form a material that is suspended in the matrix as a reinforcement.[19]

Sintering is one approach to forming complex shapes with silicon carbide in mass production quantities at acceptable costs. It is a cheaper alternative to the more traditional hot pressing approach. Silicon carbide, however, like many other nonoxide ceramics, is difficult to sinter because of its covalent bonding. This can be remedied in some cases by added small quantities of both boron and carbon.[20]

It should be mentioned at this point that we included E-glass within the ceramic fiber subcategories of our questionnaire, although many in industry contend that it does not qualify as an "advanced composite". It should not be inferred from its inclusion, however, that we are attempting to resolve this industry debate. Technically, **E-glass** is "electrical glass", which is the borosilicate glass principally used for the glass fibers in conventional reinforced plastics.[21] For purposes of our assessment, we did attempt to collect data on this product category but little information was submitted.

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[18] Great Lakes Composites Consortium. Composites Glossary, p. 10.

[19] Composites Glossary, pp. 33, 54.

[20] Mutsuddy, B. C., Michigan Technological University. "Prospects and Problems with Ceramic Injection Molding." Key Engineering Materials. Volumes 56-57. Zürich, Switzerland: Trans Tech Publications. 1991. p. 300.

[21] Composites Glossary, p. 18.

Boron fiber is another fiber type that, while still small in use, is important for certain applications. It usually has a tungsten-filament core with boron vapor deposited onto it to give it strength and stiffness. This fiber is more dense than carbon and is more expensive.[22] Research sponsored by the U.S. Air Force in the late 1950s helped to identify boron fiber as a promising material for use in combat airframes; for this reason it is considered to be a component of the first "advanced" composites.[23] Its limited use is attributed to its very high cost, and its use is thus still limited primarily to high-performance military aircraft. As recently as late 1991, a boron/epoxy composite developed by Textron Specialty Materials was used to repair and structurally reinforce the United States' entire fleet of B-1 strategic bombers. Other aircraft reinforced with this particular material include the Air Force's F-5 and F-16 jets, the B-52 bomber, the C-130 and C-141 cargo planes, and the Navy's P-3 Orion.[24] Textron has begun efforts to convince commercial airlines to use the material for repairs on jetliners. Its boron-based composites are also used to a limited extent in some golf clubs, fly-casting rods, skis, and tennis rackets. Most of this fabrication is done in Japan with imported Textron fiber.

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[22] Composites Glossary, p. 8.

[23] Curt Rogers, p. vi.

[24] Von Hassell, Agostino. "Boron/Epoxy Composite Helps Fix B-1 Bombers; U.S. Air Force Using Boron/Epoxy Composite Manufactured by Textron Specialty Materials Inc. to Repair Cracks in Aircraft." Plastics World. Volume 49, Number 11. October 1991. p. 29.

2. Resins

Table 2: Resin Categories	
1.	Epoxy
2.	Bismaleimide
3.	Polyimide
4.	Thermoplastic
5.	Vinylester
6.	Polyester
7.	Cyanate Esters

Source: OIRA Questionnaire

The next step in the production process is the combining of fibers and resin in order to create a structure. The resins that are used in this process are classified into two primary categories, thermosets and thermoplastics; both are plastic materials but each have some unique capabilities. A thermoset is a polymer that reacts irreversibly to form a hard structure. Once it is reacted, the polymer will not soften or flow when heat and pressure are applied. Because of its irreversibility, thermosets may only be processed once. A thermoplastic is a polymer which softens and flows when heat and pressure are applied. The process is thus reversible, which allows thermoplastics to be reprocessed. The matrix resin used, whether thermosetting or thermoplastic, is determined by the application, and it is usually the matrix that limits the thermal and environmental performance of the composites.

Depending on the end-use requirements, the resins used most often in matrices are thermosetting, as thermosets are at present more easily processed than thermoplastics. More than 95 percent of thermoset-based composites are either epoxy or polyester resins. **Epoxy resins** are in fact the most common matrix resin used in the advanced composites industry. These and the other classes of resins used for advanced composite production are listed in *Table 2* above. Epoxy resins are used with a wide range of reinforcements, have good chemical

resistance, are widely available in various forms, and have good electrical-insulation properties. Thermoset **polyester resins** are typically used in glass fiber-reinforced formulations and have been used for over forty years for a variety of industrial, marine, and consumer goods, including fiberglass boats, fishing rods, and automobile body panels.

Polyimides are another type of highly heat-resistant resins used as a binder or adhesive. **Bismaleimide ("BMI")** is a type of polyimide that cures by an addition rather than a condensation reaction, thus avoiding problems with volatile formation. BMI resins are intermediate in temperature capability between epoxy and polyimide. They are used at temperatures in the range of 350 to 450°F. Polyimide resins have an even higher heat tolerance level in the 550 to 600°F range; their difference from epoxy and BMI resins is that they may be either thermoset or thermoplastic. BMI and polyimide resins are not as widely used as epoxy resins, however, as they are still undergoing processing advances and property improvements.[25] The U.S. Air Force has a polyimide, AFR 700, which can be used at temperatures up to 700°F.

Vinyl esters are another class of thermosetting resins which contain esters of acrylic and/or methacrylic acids, of which many are made from epoxy resin. These are cured by copolymerization with other vinyl monomers. These are typically used in non-aerospace applications, such as recreational.

Throughout the 1980s there was an increased effort (primarily by the U.S. Air Force) to develop **thermoplastics** for advanced composite matrices; however, their usage has been limited in comparison to thermosets and are still in the developmental stages in many respects. Thermoplastics composites are currently used on the F-117A, the SSN-21 Seawolf submarine, and are planned for limited use on the F-22.

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[25] McDermott, Joe. "The Structure of the Advanced Composites Industry." Advanced Composites Magazine. p. 9.

3. Prepregs

Table 3: Prepreg Categories		
1.	Carbon Fiber/Resin	
2.	Glass/Resin	
3.	Aramid/Resin	
4.	Boron/Resin	
5.	Hybrids:	
	A.	GR/G/Resin
	B.	GR/K/Resin
	C.	Other
6.	Ablatives	

Source: OIRA Questionnaire

As discussed earlier, the prepreg manufacturer serves as an intermediate customer of the material supplier. The manufacturer combines a given reinforcement with resins, forming a prepreg which is stored under controlled conditions. *Table 3* above provides the various reinforcement and resin combinations with which a prepregger works. Survey information was collected by these different classifications. Once the prepreg is complete, a fabricator shapes it and completes the curing process. In this sense the prepregger is a middleman between the material supplier and the fabricator, although the prepregger could be considered a type of fabricator as well. The fabricator, in turn, completes the processing of the advanced composite part or item based on its end use. The entire production process, beginning with the fiber producers, is unlike the supply chain in many industries, because the process is determined from the outstart by the specifications required by the ultimate end user. This will be discussed in more detail when reviewing the various advanced composite applications.

4. Metal Matrix Composites

Table 4: Metal Matrix Composite Categories	
1.	Silicon Carbide/Aluminum
2.	Silicon Carbide/Titanium
3.	Intermetallics Titanium/Aluminum

Source: OIRA Questionnaire

Much of the discussion thus far has been fairly generic, as it applies not only to polymer matrix composites but to other types as well. These other types of advanced composites, whether metallic, ceramic, or carbon-based, have specialized matrix properties tailored for applications for which PMCs are not suited. The technology for metal matrix composites (MMCs) is not as advanced as that for polymer-based composites, but it is a growing area. MMCs can be used at higher temperatures than PMCs. They have been developed for aerospace applications, such as General Electric Aircraft Engines' development of the first titanium MMC engine nozzle exhaust links to be used on a fighter aircraft, the F-16. The National Aerospace Plane program has developed silicon carbide/titanium MMCs which hold potential for varied aerospace applications. The primary application for MMCs to date, however, has been automotive.

The Japanese and Europeans are studying MMCs, primarily for automotive applications.[26] Silicon carbide/aluminum MMCs are the most promising for automotive applications. These MMCs are reinforced with particulates of either silicon carbide or alumina, and have been effective in the place of certain steel and cast iron parts, with a weight savings in excess of 50 percent. All three U.S. automobile producers are testing MMC parts but have not begun using them in commercial production. Japanese automobile producers have been more aggressive in

[26] "U.S. Composites Competitiveness Threatened, AIA Warns." Aerospace Daily. Volume 151, Number 8. July 14, 1989.

this regard; Honda is producing a car with MMC cylinder liners and Toyota is producing one with MMC reinforced pistons. While it is currently more expensive to use these parts, the Japanese companies are gaining more experience in using these materials.[27]

5. Ceramic Matrix Composites

Table 5: Ceramic Matrix Composites Categories	
1.	Nonoxide
2.	Oxide
3.	Glass

Source: OIRA Questionnaire

Like MMCs, ceramic matrix composites (CMCs) can be used at higher temperatures than PMCs. Application of CMCs is expected to grow at an annual rate of 21 percent through this year and at 17 percent until the end of the century for cutting tool inserts, wear parts, aerospace and military use, and particularly space shuttle tiles. Applications for engine components, hypersonic radomes, military armor, aerospace applications, and energy related uses are in the research and development stages.[28] CMCs are expensive to manufacture, in part because Japan and Europe are the main sources of ceramic powders. CMCs continue to be the object of a large international technical effort, and the United States still maintains a lead in their development. CMCs are an improvement over monolithic ceramics, as they offer improved

[27] Lundy, David. "Metal Matrix Composites May Be Key to More Efficient Automobiles." Industry, Trade, and Technology Review. May 1993. pp. 1, 3.

[28] Spriggs, R. M., Center for Advanced Ceramic Technology, Alfred University. "Applications and Prospective Markets for Advanced Technical Ceramics." Key Engineering Materials. Volumes 56-57. Zürich, Switzerland: Trans Tech Publications. 1991. p. 9.

fracture toughness. The main drawback in the use of CMCs, however, is still unpredictable fracture. Solving this problem is instrumental in current development efforts.

As mentioned earlier in this section, all other advanced ceramics, which include ceramic powders, coatings, and monoliths, were excluded from our data collection. These products are covered in a separate critical technology assessment on the U.S. advanced ceramics industry.

6. Carbon/Carbon Composites

Table 6: Carbon/Carbon Composites	
1.	Liquid Infiltration
2.	CVD/CVI

Source: OIRA Questionnaire

Carbon/carbon composites consist of carbon or graphite fibers in a carbon or graphite matrix. They have a unique property in that they maintain their strength at much higher temperatures than CMCs. They may even become stronger and stiffer as the temperature increases. This makes carbon/carbon composites the only material that can be used in some advanced jet and rocket engine applications. They have been used on rocket engine nozzles, nose cones, and jet landing wheel brakes since the 1960s.[29] Because of their unique high-temperature properties, research on carbon/carbon composites is receiving significant government funding in France, Japan, and Russia.

Chemical vapor deposition (CVD) and chemical vapor infiltration (CVI) techniques provide uniform coatings of tailored compositions, including multiple layers of different composition.

[29] Spriggs, p. 9.

Coatings are used on C/Cs for oxidation resistance at elevated temperatures. Currently, the CVI technique has demonstrated the greatest commercial success to form complex shape C/Cs.[30]

The protection of a re-entry vehicle of a space shuttle has led to the development of silica based tiles as heat shield material. Space insulation material covers the whole of the shuttle orbitor to protect it from burning up when it re-enters the atmosphere. The most vulnerable parts are its nozzle, the leading edges of the wing, and the nose cap. These are sheathed with reinforced carbon/carbon composites.[31]

B. Applications

Table 7: Applications		
1.	Dept. of Defense - Aircraft	
2.	Dept. of Defense - Other	
3.	Commercial Aircraft	
4.	Sports/Recreation	
5.	Automotive	
6.	Industrial:	
	A.	Corrosion Resistant
	B.	Other
7.	Non-Defense Space Structures (Other than Ablatives)	
8.	Printed Wiring Board	
9.	Other Applications:	

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[30] Dutta, S., NASA-Lewis Research Center. "Key Issues in Si_3N_4 and SiC Matrix Composites for Automobile and Aerospace Applications." Key Engineering Materials. Volumes 56-57. Zürich, Switzerland: Trans Tech Publications. 1991. p. 104.

[31] Sarkar, B. K., Central Glass & Ceramic Research Institute, Calcutta, India. "Structural Ceramics for Launch Vehicles and Satellites." Key Engineering Materials. Volumes 56-57. Zürich, Switzerland: Trans Tech Publications. 1991. p. 144.

A.	Mass Transit
B.	Civil Engineering/Construction
C.	Other

Source: OIRA Questionnaire

1. Defense

To date the predominant application for advanced composites has been for military items, primarily aircraft and missiles. The U.S. Navy's fleet ballistic missile program has been dependent on advanced composites since its inception. The missile cases have used S-glass, DuPont's Kevlar, and most recently carbon fiber to extend the range.

Military aircraft have also been primary users of advanced composites. At first these materials were used in secondary structures such as control surface skins and fairings on aircraft like the F-16, the F-14, and the B-1B. During the 1980s aircraft like the F/A-18 C/D and the AV-8B expanded the use of advanced composites. The B-2A and A-12 relied on advanced composites to achieve both range/payload requirements and low observable characteristics. Future U.S. aircraft like the F-22 and F/A-18 EF will use between 20 and 25 percent advanced composite materials. Other future systems like the V-22 and RAH-66 helicopter will make even greater use of advanced composites. Tactical missiles and armored vehicles are planned to have greater use of advanced composites in the future.

In the mid- to late-1980s, the advanced composites community began gearing up to support impending production of the B-2A (132 aircraft), the A-12 (858 aircraft), the C-17 (210 aircraft), the Advanced Tactical Fighter (750 aircraft), the LH (2,096 aircraft), the V-22 (956 aircraft), as well as support continued production of the F/A-18 C/D, F-16 C/D, and Trident D-5 missiles. There were also several classified programs which were slated to use large quantities of advanced composite materials. The advanced composites community responded to this large market by investing heavily in plants, equipment, and personnel. In addition, at the

request of DOD, the Congress placed a clause in the FY 1988 Appropriations Bill (enacted as PL 10-202) which required domestic carbon fiber producers to build PAN raw material plants here in the United States. The cancellations and stretch-out of many of these weapon systems programs have resulted in a 78 percent reduction in the amount of carbon fiber required by DOD. These defense cutbacks, coupled with the overcapacity generated as a result, has placed severe financial burden on advanced composite suppliers.

Foreign application of advanced composites for military applications has lagged that of the United States. However, both the Europeans through the European Fighter program and the Japanese through the FS-X will make greater use of these materials in future systems.

It is clear that future U.S. weapon systems will require advanced composites to achieve the technological superiority required for the United States to maintain its military capabilities. As such, the DOD declaration that advanced composites are a critical technology is warranted, with concerns over the future viability of the U.S. advanced composites industrial base a factor which should not be ignored.

2. Commercial Aircraft

For advanced composites manufacturers the most obvious and financially alternative market to the defense market is commercial aircraft. Unfortunately, the use of advanced composites in commercial aircraft is relatively small in percentage compared with their military aircraft counterparts. The use of advanced composites on commercial aircraft is slowly increasing, but prime aircraft manufacturers no longer place advanced composites on airplanes unless there are significant benefits associated with their use. Advanced composites are increasingly being forced to be at cost parity with aluminum structures prior to being baselined for the aircraft. This is difficult, given current advanced composites structures fabrication technology.

The leading user of advanced composites for commercial aircraft is Airbus Industries. Indeed the Europeans, through Airbus, have pioneered the use of advanced composites for many applications, including one of the most impressive composite structures made to date, the A340

horizontal skin. Boeing's newest aircraft, the 777, will use more advanced composites than any previous Boeing model but still falls short relative to Airbus's application. In addition, the 777 will rely on carbon fiber from Japan's Toray Industries for most of its advanced composite applications, which further hurts the U.S. carbon fiber industry.

Commercial aircraft engine applications continue to increase. Most nacelle structures, blocker doors, cascades and thrust reversers are being designed using advanced composites. In addition, the GE-90 will be the first engine to utilize advanced composite fan blades. The Pratt & Whitney Advanced Ducted Prop (ADP) engine scheduled to be introduced later this decade will also increase the use of advanced composites in commercial aircraft engines. A Pratt & Whitney-lead team has submitted a TRP proposal which, if enacted, would drastically increase the usage of advanced composites for the ADP engine.

Smaller commercial aircraft also use advanced composites. The Beech Starship is made almost entirely of advanced composite materials. Once again, with the exception of the Starship, the Europeans seem to be ahead in the application of advanced composites to smaller commercial aircraft.

3. Non-Defense Space Structures

Non-defense space structures are also a focal point for use of advanced composites. Most, if not all, commercial satellites depend upon advanced composite materials for their light weight and dimensional stability. Carbon/carbon composites are an integral part of several Space Shuttle components. Japan's National Space Development Agency plans a carbon/carbon composite and ceramic tile construction for its proposed H-II Orbiting Plane (HOPE), a robotic shuttle intended to resupply the Japanese Experiment Module on the U.S. Space Station.[32]

[32] "Japan's Aerospace Industry Faces Turning Points in Military, Civilian Programs." Aerospace Daily. Volume 161, Number 51. March 13, 1992. p. 415.

4. Sports/Recreation Equipment

Sports and recreational equipment is the second-largest application for advanced composites, although the domestic industry infrastructure supporting this application is markedly different. There is little research and development money dedicated domestically for this application, in comparison to aerospace uses. As a result, the development and production of advanced composites for this market shifted to the Far East. The Japanese are using advanced composites for various items, ranging from golf clubs, fishing rods, and tennis rackets (which account for 90 percent), to bike frames and wind surfing boards.[33] Only now are a few sports applications being developed in the United States, while the production is mostly in Asia. The U.S. golf shaft industry is an example of rapidly growing area; although growth in this market segment has made up for some of the lost DOD volume, the price which the composite material must be sold to compete in this arena is drastically below that for defense/aerospace applications. As a result, most U.S. suppliers are forced to sell at little or no profit to compete with foreign suppliers and traditional materials.

5. Automotive

The automotive market is currently a small market for advanced composites. One of the driving forces for use of advanced composites is to reduce automobile weights, which is seen as necessary to meet the ever-tighter standards set by the Environmental Protection Agency for exhaust emissions and to offset rising fuel costs. The developmental costs, however, as well as the high investment level required for new production methods and tooling, are prohibitive.

In spite of these high costs, the U.S. automotive industry has begun limited use of some composite materials, dating back to the first application on Chevrolet's polyester/fiberglass Corvette. Racing cars contain more advanced composites than other U.S. vehicles, as the Indy Formula I cars now have carbon fiber composite bodies. General Motors has already demonstrated the ability to manufacture an entire vehicle frame and body from carbon fiber-

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[33] "Advanced Composite Materials, Challenge Toward 21st Century." Nikkei New Materials. Tokyo, Japan. July 13, 1992. p. 85 [translated from Japanese].

based composites. While this vehicle, called the Ultralite, has proven itself in weight and fuel savings, its costs are exorbitantly high. The cost of the carbon fiber material alone exceeds $13,000. As a result, the vehicle will not be introduced to the market until the costs for composite structural fibers can be brought down.[34] The industry is using some composite materials for automotive body parts, such as Chrysler's composite fender on its LH line of cars. Advanced composites have also been used in drive shafts. By using advanced composites, original equipment manufacturers have been able to eliminate a joint/bearing in the assembly, thus reducing both the cost and complexity of the drive shaft system.

Another potential market for advanced composites in the automotive arena are compressed natural gas (CNG) tanks. The industry views this application as both an excellent use of composite materials and a potential new lucrative market. There is concern, however, that the Federal Government may place restrictive regulations on advanced composite CNG tanks.

Mass use of advanced composites in the automotive industry will probably take place only once the advanced composites industry can produce for commodity applications, rather than government-related areas. This means that the volume demand must be very high while the cost must be fairly low. Finding a way to lower the costs, therefore, is the key to making the transition to such commodity uses.

6. Industrial

Advanced composites are used in a variety of industrial applications, such as piping, rollers, and corrosion-resistant flooring, and are also being considered in the energy/nuclear power field. Carbon fiber-based composites are being developed for low-cost fuel cells which have improved durability. Higher strength materials are also needed for uranium enrichment centrifugal separator rotating shells. The application of carbon/carbon composites in light water reactor uses is also being studied. The Japanese were the first to apply composite material

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[34] Crawford, Mark. "Costs, Processes Key to Advanced Materials in Autos." New Technology Week. December 7, 1992.

manufacturing technology to the development of radiation shielding materials that are expected to be effective in a wide range of facilities and equipment related to nuclear power.[35] Use of advanced composites in offshore oil platform applications is currently limited but has high payoff potential in terms of corrosion resistance, weight savings, fatigue resistance, and design flexibility.

7. Mass Transit

Research is also being conducted to use advanced composites for mass transit applications like railways. As with automobiles, the development of lightweight bodies is the driving force behind this research. Composites are expected to be used for railway bodies, streamlined front structures, and superconducting magnet heat insulation support materials. A California consortium led by Northrop has developed a lightweight bus which is shrouded with a composite skin. The new bus is a candidate for purchase by the Los Angeles Metropolitan Transit Authority program. Similar uses are being considered for marine and ship applications. This has been a primary focus in Japan, where advanced composites are being promoted for high-speed vessels to replace truck transportation of cargo.[36]

8. Infrastructure

The Europeans and particularly the Japanese have made extensive in-roads into the application of advanced composites in infrastructure projects. A recent evaluation of advanced composite applications by Japan, sponsored by the National Science Foundation, the Department of Energy, the U.S. Army, and the U.S. Air Force, concluded that the Japanese are years ahead of the United States in infrastructure applications; some of these applications which they have explored

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[35] Inoue, Masaki, Shigeo Nomura, and Sakae Shikakura; Power Reactor and Nuclear Fuel Development Corporation. "Radiation Shielding Composite Materials-Material Design, Manufacturing Process, Evaluation." Genshiryoku Kogyo. Tokyo, Japan. February 1992. pp. 60-64 [translated from Japanese].

[36] "Advanced Composite Materials, Challenge Toward 21st Century." Nikkei New Materials. Tokyo, Japan. July 13, 1992. p. 84 [translated from Japanese].

include curtain walls, reinforcing elements, pre-stressing/post-tensioning cables, columnar structures, chimneys, bridge decks, and cables.

As a result of previous efforts and years of research and demonstration in the infrastructure area, Japanese advanced composite suppliers are well ahead of their U.S. counterparts in developing unique material forms suitable for civil engineering applications.

The U.S. industry has also recognized, however, the potential for advanced materials in repairing and improving our country's sagging infrastructure and several efforts are underway to develop advanced composites for these applications. One such effort is being conducted by the Civil Engineering Research Foundation (CERF). CERF is currently developing a "roadmap" for introducing advanced composites for civil engineering applications.

Another activity geared toward applying advanced composites to bridge structures is being conducted by a consortium comprised of U.S. industry and the University of California-San Diego. This consortium, the Advanced Composites Technology Transfer (ACTT), is developing an advanced composite-intensive bridge to be built over Interstate 5 near La Jolla, California. The ACCT also hopes to apply their knowledge to bridge repair and seismic retrofits of civil structures. Several other U.S. advanced composite companies and universities are exploring the use of advanced composites for intrastructure.

While many U.S. advanced composite suppliers are optimistic that advanced composites will eventually gain wide acceptance and use in the civil engineering community, there is concern about the slow pace of their introduction and whether their companies will survive to reap the rewards. As such, this appears to be another area where the U.S. advanced composites community would welcome Federal Government assistance in speeding the acceptance/adoption process. Several companies reported that they hope to see advanced composite infrastructure programs funded under ARPA's Technology Reinvestment Program, which is discussed in greater detail later in this report. On October 22, 1993, President Clinton announced 41 award selections, which included $21 million for the ACTT bridge infrastructure project.

9. Medical

Medical uses of advanced composites are another growing market. Such applications include artificial muscles, artificial tooth roots, and some diagnostic equipment. Sabolich Prosthetics Research Center of Oklahoma City has already developed limbs made from composites and estimates that six of every ten prosthetics patients have artificial limbs that use composites.[37] The University of Illinois at Urbana-Champaign has made a new type of ceramic-based composite that can be used to produce bone replacements.

[37] Hicks, Jonathan P. "All About Composite Materials: Light and Tough, New Materials Head for Mass Marketing Stage." New York Times. Late Edition. March 25, 1990. Section 3, p. 14.

IV. STUDY COVERAGE

A. Company Participants

As indicated earlier, our primary data was collected by questionnaires completed by industry participants. A total of 66 companies participated in the data collection effort, with information provided on 73 individual company operating units. This difference results from several companies providing separate responses for separate sections within the same corporate structure. The 66 companies all have either domestic manufacturing or sales operations; companies with no U.S. operations or offices were not surveyed because Department of Commerce mandatory information collection authority does not extend beyond United States borders (including territories). Additionally, our collection authority is only applicable to operations physically located in the United States. This distinction is important to understand, as many of the responding companies have foreign operations which comprise an important segment of their operations, yet are not included in our analysis. However, we do discuss foreign companies and governments in the international section of this report.

Approximately 59 percent of the responding companies (39 of 66 companies) indicated that they were owned by some other corporate entity. Sixteen of these 39 are foreign-owned, as shown in *Table 8*. While the number of foreign-owned companies is probably too small to represent a trend, these ownership statistics reflect overall foreign investment figures for companies in the United States, as the British are the largest foreign investors here, followed by the Japanese.[38]

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[38] Ross, Emma. "Legislation on Foreign Investment in U.S. Introduced in the House." Investor's Daily. May 14, 1991.

Table 8: Nationality of Foreign-Owned Respondents	
Country	*Number of Respondents*
United Kingdom	6
Japan	4
Netherlands	2
Switzerland	2
France	1
Germany	1

Source: OIRA Survey Data

In our first step toward differentiating the types of firms surveyed, we asked each respondent to indicate the nature of its business. The most common response came from 59 companies who indicated that they are manufacturers. Another ten indicated that they are research organizations. Three companies stated that they are distributors, while another three said that they are resellers. One company reported that it is a holding company for a variety of businesses. Obviously the number of responses to this question is greater than the number of respondents; in some cases a company reported that it performs more than one function. For example, eight companies reported that they are both manufacturers and research organizations. One company is a manufacturer, a research organization, and a distributor. Another firm indicated that it performs research yet is also a distributor.

The ownership issue was revisited when reviewing these business classifications. Eleven of the 59 manufacturers are foreign-owned, which is 18.6 percent of this group total. Two of the ten research organizations are foreign-owned, as is one of the three distributors. All of the resellers and the one holding company are foreign-owned.

Once we were able to differentiate between various general types of businesses, we asked the respondents to classify themselves by their position in the advanced composites supply chain, generally, as a material supplier, fabricator, or prime contractor. The companies were asked to identify their primary activity, that is, to select the one of these three categories that best defines their business, and then secondly to identify each of the three categories in which they perform some function.

We received 64 responses to the primary activity question. Twenty companies reported that they are predominantly material suppliers. Of these four are foreign-owned. Thirty-six companies (of which seven are foreign-owned) classified themselves as fabricators. Only four of the 64 classified themselves as prime contractors. None of these firms is owned by foreign interests.

When asked to identify each activity area in which they have some function, the responses for companies involved in materials interestingly did not change. The number of companies indicating some form of fabrication did increase from 36 whose primary role is as a fabricator to 46. Of these nine are foreign-owned, dominated by the British with five of the nine. The number of prime contractors also increased from four to fourteen, with one British-owned company.

It should be mentioned that our assessment focuses on the producers and users of advanced composite materials. For this reason the survey did not include equipment suppliers, such as autoclave manufacturers, or manufacturers of filament winders or prepreg equipment.

B. Manufacturing Establishments

Those study participants who are engaged in some form of advanced composite manufacturing were asked to identify each of their manufacturing facilities, domestic or foreign. Using the product coding system, the companies also identified each product type being manufacturing at each facility.

Survey respondents further defined the 73 operating units into a total of 99 manufacturing plants located in thirty-one U.S. states and seven foreign countries. The majority of these plants, 89 of the 99, are located domestically. As mentioned earlier, information was submitted by establishment for 73 of the 89 domestic plants reported. The geographic distribution of these domestic plants is tabulated by state in *Table 8* below:

Table 9:
Ranking of States by Number of Manufacturing Plants

States	*Number of Plants*
California	25
Texas, Washington	7
Missouri, Tennessee	4
Delaware, Kansas, Massachusetts, Minnesota, Pennsylvania, Utah	3
Ohio, South Carolina, Virginia, Wisconsin	2
Others*	1
Total, All States	89

* Those 16 states with one reported plant each were Alabama, Colorado, Connecticut, Georgia, Idaho, Illinois, Iowa, Kentucky, Maine, Maryland, Michigan, New Jersey, New York, North Dakota, Oklahoma, and West Virginia.

Source: OIRA Survey Data

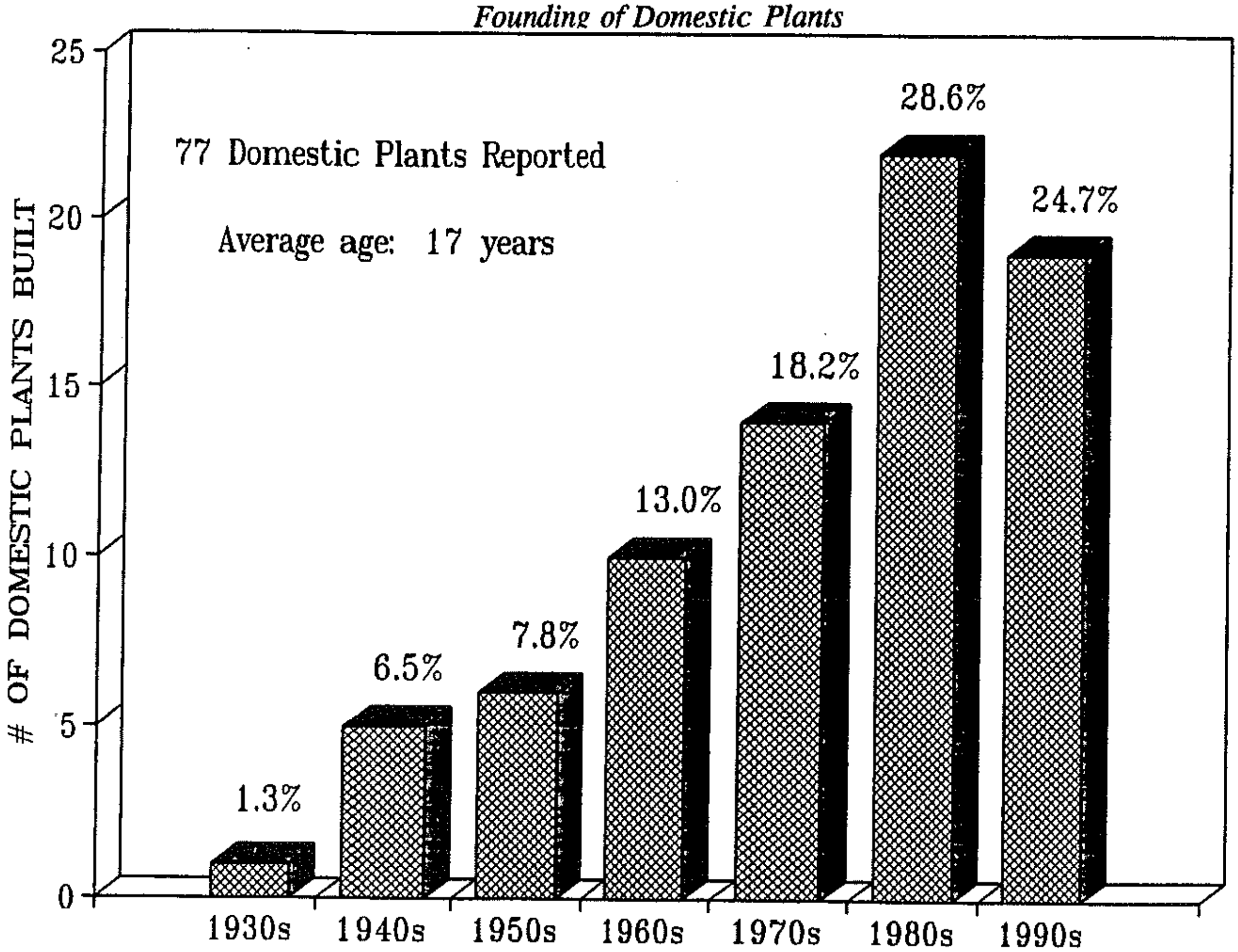
The remaining ten plants reported are located in seven different countries: three in the United Kingdom; two in Luxembourg; and one each in Austria, France, Germany, Japan, and Spain. The number of foreign plants reported is significantly understated, as respondents were not required to provide information on any facilities or operations not located on U.S. soil. Of the ten plants that were reported, six are foreign-owned firms and four are wholly owned or joint ventures by U.S. firms.

Most companies also provided the year of founding of each of their reported manufacturing facilities. Domestic plants are on average 17 years old; this is based on the founding dates of

77 of the reported 89 domestic plants. The reported foreign plants are on average eight years old, based on information reported on seven such facilities. Four of these seven are U.S.-owned or U.S. joint ventures.

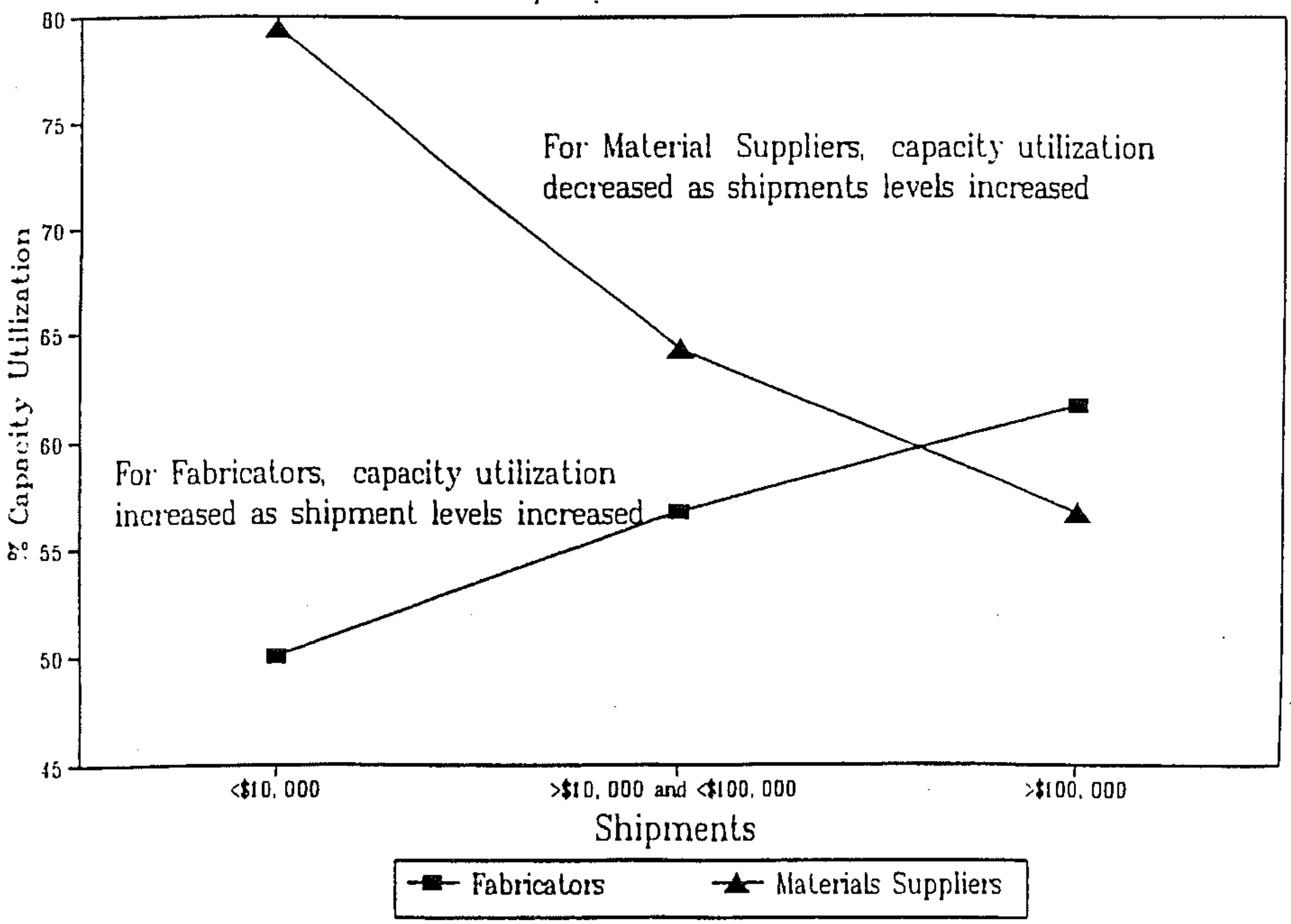
The oldest reported domestic facility was founded in 1933; the five newest plants were completed in 1992. The 1980s saw the largest number of new plants go online, accounting for almost 29 percent (22 of 77) of the plants reported. The first few years of the 1990s have seen a proportionately higher level of investment, with nineteen new plants beginning operation. As can be seen from *Graph 2* below, the advanced composite industry has continually increased its capital investment, particularly in the last thirteen years. As stated earlier, this was in anticipation of increased demand in support of DOD weapon systems. Based on the fact that the domestic industry's greatest single market, the defense aerospace industry, is faced with a dramatic downturn which began with the end of the Cold War, it is easy to understand from these plant investment statistics alone that the defense aerospace downturn has dire financial implications for the advanced composites industry.

Graph 2:
Founding of Domestic Plants



The product codes reported for each of the 99 manufacturing facilities provided a wealth of information on the specific operations of all respondents. In some instances, however, we found that companies reported more than what they actually produce. These respondents also included what they purchase to be used in their production process. This resulted in overstating the number of plants producing a given product or type of product. This occurred most frequently with the fiber categories.

Graph 3:
Capacity Utilization Rates



Source: OIRA Survey Data

The average capacity utilization rate varied by type of company. Prime contractors had on average the highest capacity utilization rate, 72.7 percent. Material suppliers had the next

highest at 58.9 percent, but almost half were operating at 50 percent or less. Additionally, **material suppliers' capacity utilization rates actually deceased as shipment levels increased, meaning that the largest producers who comprise the bulk of U.S. production have the lowest utilization, a negative indicator for the industry.** Fabricating plants had the lowest aggregated capacity utilization rate of 58.6 percent, slightly less than that for material suppliers. Over half the reporting plants were operating at 50 percent or less. Unlike the material suppliers, fabricators with the largest shipment volumes also had higher capacity utilization rates. This is attributed to their diversified product lines, of which their advanced composites business is only a portion. In all, 50 percent of the reported 38 plants were operating at 50 percent or less capacity.

C. Sales/Non-Manufacturing Operations

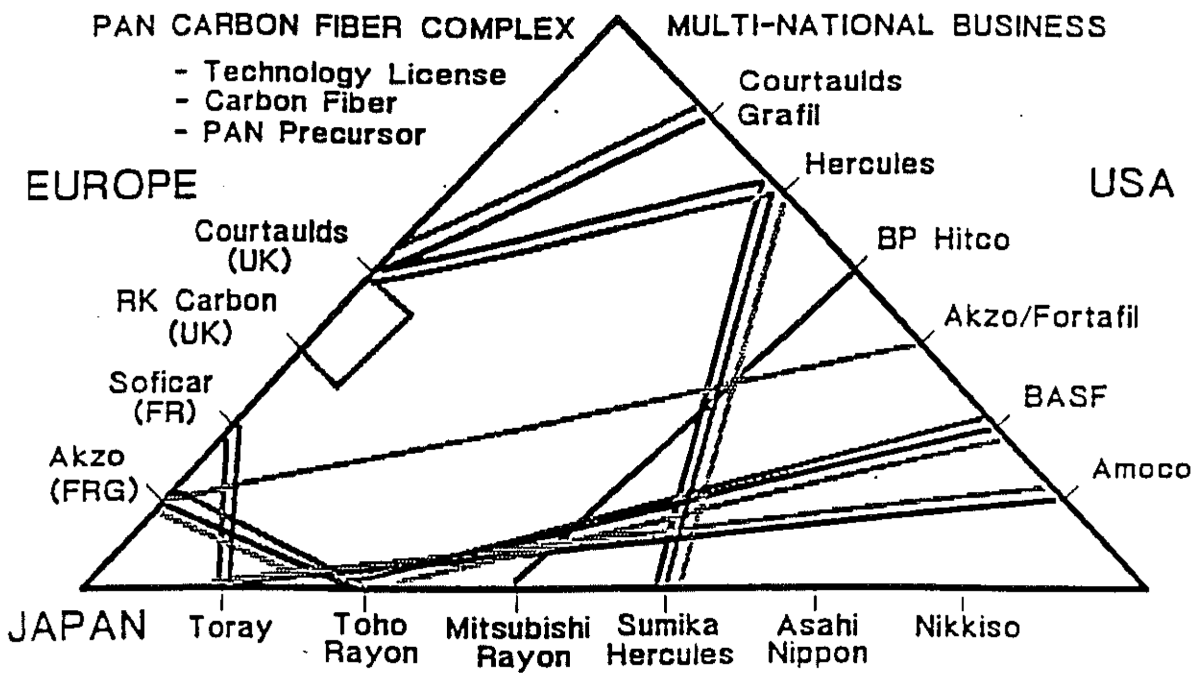
Study participants who do not domestically manufacture advanced composites or are solely sales organizations were asked questions similar to those posed to manufacturers about the specific product lines carried. Eight companies reported performing sales functions for a total of ten other companies. Most of these sales relationships (nine of ten) have been established since 1980. There are five with Japanese firms, two with other U.S. firms, and one each with firms in Luxembourg, the Netherlands, and the United Kingdom. Seven of the ten are between related parties. Five of these seven are with related foreign firms. The remaining three unrelated relationships are each with foreign firms. As with the manufacturing facilities, the products sold as a result of these agreements will be itemized as part of the shipments discussion.

D. Industry Cooperative Efforts

Tracing the cooperative activities of the advanced composites industry is extremely difficult, given the intricate network of agreements between the many various industry participants. As mentioned earlier, the advanced composites business is capital intensive, which is one reason why there are so many joint projects between companies that are otherwise competitors. The trend toward cooperative efforts, both here and abroad, has been growing in recent years, especially since the market has become tighter. Companies are engaging in joint efforts as a

necessity for survival. *Graph 4* below is an example of such cooperative efforts, showing the complex international network among companies in the PAN-based carbon fiber arena.

Graph 4:
Corporate PAN-Based Carbon Fiber Relationships, 1989



Source: Public Speech by William F. Bennett of Amoco Performance Products. "Fiber Reinforcements Carbon Fiber." Briefing to the Suppliers of Advanced Composite Materials Association (SACMA). February 2, 1989.

The consolidation in this industry is evident even from this 1989 diagram. Once the third largest U.S. supplier of carbon fiber, BASF has since exited the advanced composites business worldwide. Courtaulds sold its advanced composites business to Mitsubishi Rayon, who also purchased Grafil. Even Amoco has recently announced that it is exiting a portion of its advanced composites business line.[39]

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[39] Amoco Performance Products, Inc., Press Release. April 29, 1993.

Eighty-one cooperative agreements of different types were reported by industry participants. **This is by no means the cumulative total of all such agreements within the industry or even by our participants, but does represent the major projects in which our respondents participate.** Of these 81 agreements, 50 are between domestic companies and the remaining 31 are with foreign companies. The most common type of domestic agreement reported was joint development efforts. Fifteen such projects were reported, involving 23 companies, one laboratory, and one university. They range from general work on metal matrix composites and ceramic matrix composites, general process improvement and enhanced weaving methods, better tooling and fiber placement machines, to application-specific projects like a weapon-system specific armor design and a nestable fuel tank for an Air Force fighter.

Eight licensing agreements among various companies were also reported, involving eleven companies. As with the joint development projects, the agreements ranged from resin technology transfer to improved engine part testing capabilities. Two of these eight agreements were cross licenses. Three joint ventures were reported, two for advanced composite parts manufacturing and one for the production of PAN fiber.

Three distributorships between domestic companies were reported, two for sales of ceramic matrix composites and one for sales of composites for medical applications. Two sister U.S. companies of a foreign parent reported purchasing agreements for specific fibers; another respondent reported a strategic alliance with one of its suppliers.

U.S. Associations

Study participants identified a number of different domestic consortia which are involved in various stages of advanced composites research and development. The Suppliers of Advanced Composite Materials Association (SACMA) was established in 1984 with its membership representing the vast majority of advanced composite material producers in the United States, Europe, and Japan. Their focus is primarily polymer matrix composites, but many are involved in the growing fields of ceramic, metal, or carbon-based composites as well.

SACMA's principal mission is to support the growth of the U.S. advanced composite materials industry. It currently has fifteen regular members, down from 29 as recently as 1991. Its membership has maintained its international flavor, however, with eight of its fifteen members foreign-owned. The decrease in members reflects the contraction in this industry. The high costs associated with commercializing advanced composites, coupled with the downturn in the defense aerospace market, have resulted in some companies selling their advanced composite operations (such as Rhône-Poulenc's sale of its advanced composites operation in Louisville, Kentucky, to Ciba-Geigy) or shutting them down entirely (as in the case of BASF's three year old Rock Hill, South Carolina, facility, for which it was unable to find a buyer). In addition to its regular members, SACMA currently has eight associate members, who tend to be users rather than producers of advanced composite materials. A list of SACMA's membership, as well as the members of the other consortia discussed below, is attached as *Appendix 3*.

In 1990 the Great Lakes Composites Consortium was formed to manage the U.S. Navy's center of excellence for composites manufacturing technology. While this is its primary mission, the manufacturing processes that it develops are also intended for commercial uses and not exclusively for military applications. The group has six principal members, all aerospace prime contractors, but has a host of other members, classified as supporting members, associate members, and partners. It has a total membership of 81 and is drawn from many advanced composite material users and academia.

Domestic Business Agreements

Another reported consortium was formed in 1987, as a result of an Aerospace Industries Association initiative to promote industry research collaboration. This group of aerospace companies created Composite Materials Characterization, Inc., as a means to overcome customer barriers and implement new materials into aircraft.[40]

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[40] Phillips, Edward H. "Advanced Materials Success Will Rely on Joint Effort." Aviation Week and Space Technology. Volume 137, No. 4. July 24, 1992. p. 55.

In August 1988 the U.S. automotive industry formed a similar group under the auspices of its U.S. Council for Automotive Research (USCAR). The purpose of this consortium, called the U.S. Advanced Materials Program, is to conduct joint pre-competitive research on structural polymer composites.

Another research teaming effort was initiated on structural composite auto parts in 1992 involving Ford Motor Company and General Electric. A five-year $10.8 million joint research project is studying ways to manufacture structural composite parts for automobiles from thermoplastic polymers. Such structures will be extremely strong at about one-third of the weight of steel. NIST is providing some of the funding through its Advanced Technology Program. Ford is leading the group effort.

In 1992 the U.S. Department of Energy (DOE) also set up a new research consortium with the help of 42 companies. DOE is putting into place a ten year, $100 million program involving ten research teams from companies, national laboratories, and universities to develop continuous fiber ceramic composites. The results of this joint research effort will find applications ranging from heat exchangers to components in high-temperature gas turbine engines. Part of this effort will assist in reshaping the roles of national laboratories.

A group of 18 California-based companies led by the Northrop Corp. formed a development team in December 1992, when the Southern California Rapid Transit District selected the Northrop group for the first phase of a three-phase project to design and develop a lightweight, advanced technology bus. The purpose of the project is to develop the next-generation bus that also meets the California requirements for cleaner cars. The new bus uses a composite skin which reduces the weight of the vehicle by 1,200 pounds. This weight savings will enable the consortium to use a new type of clean propulsion system. Northrop is testing many of its

composite technologies, materials, and processes from its B-2 Stealth Bomber program for potential dual-use in the advanced bus.[41]

As mentioned earlier, another more recently formed consortium is the Advanced Composite Technology Transfer Consortium (ACTT), a group with ten industry and academic members who are working together to develop applications of advanced composites for civil sector applications. The use of advanced composites in such applications would reduce both construction costs and time, extend the life of the structure, reduce required maintenance, and reduce seismic problems. According to a White House report as part of a supplement to the President's Fiscal Year 1993 budget, the improvement of the performance and durability of the nation's roads and bridges by just one percent would result in a direct savings of as much as $30 billion.[42] The first project of the ACTT will be a full-scale traffic bridge in San Diego, California. The goal of this project is to demonstrate that advanced composite materials and technologies developed in the defense industry can be converted and applied to civil infrastructure problems cost-effectively. As was also mentioned earlier, the President announced funding of $21 million for the ACTT project through ARPA's TRP program.

Universities

Universities have long been involved in consortia in advanced composites, including such schools as Auburn University, Clemson University, the Massachusetts Institute of Technology, Michigan State University, and Penn State University, among others. One of the earliest continuing cooperative efforts was established by the University of Delaware, which is host to a consortium of industry and academia through its Center for Composite Materials. This Center conducts research efforts collaboratively with its members both as a means of assisting industry and

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[41] Reilly, Lucy. "Stealth Technology Used to Build Lightweight Buses." Washington Technology. Volume 8, Number 3. May 6, 1993. p. 30.

[42] Executive Office of the President, Office of Science and Technology Policy, FCCSET Committee on Industry and Technology. Advanced Materials and Processing: The Federal Program in Materials Science and Technology. Gaithersburg, MD: National Institute of Standards and Technology. 1993. p. 59.

training the next generation of composites specialists. In the last twenty years the University has provided the advanced composites industry with more than 250 graduates.[43]

Pennsylvania State University has a Center for Advanced Materials which was established in 1986 to perform research on advanced structural materials. A major objective of the Center is to facilitate the use of recent developments in advanced materials in high temperature technology for furnaces, heat exchangers, burners, and advanced engines. The Center has worked with a number of companies, Federal agencies, and laboratories for many projects. It currently has nine on-going projects for processing and properties of ceramics and composites.

In the fall of 1991 Michigan State University's Composite Materials and Structure Center became the host of a National Science Foundation/State of Michigan/Industry/University Cooperative Research Center on Low-Cost, High-Speed Polymer Composites Processing. As its title suggests, joint funding for the first four years is provided by the National Science Foundation, the State of Michigan, and MMPI. The goal of this new organization is to develop and deploy technology to reduce the cost of PMCs by reducing the costs of components, reduce the cost of processing by developing new high speed processing technologies, and reduce the time to implement new composite designs and processes.

Foreign Agreements

Company respondents reported that there were 31 agreements with foreign companies. The geographic distribution of these agreements is listed in *Table 10.*

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[43] McCullough, Dr. Roy L., Director. "Center Strategic Plan Identifies Opportunities in Current Trends." Composites Update. Winter/Spring 1993. Newark, Delaware: University of Delaware. p. 2.

Table 10: Geographic Distribution of Foreign Agreements	
Country	***Number of Agreements***
Japan	10
France	6
Spain	3
Canada, Italy, United Kingdom	2
Australia, Israel, the Netherlands, Russia, and South Korea	1
Europe*	1
TOTAL	31

* One company reported an agreement with an unspecified European company.

Source: OIRA Survey Data

All the foreign relationships reported were various types of business agreements, as listed in *Table 11* below.

Table 11: Types of Foreign Agreements
11 - Licensing U.S. technology abroad
1 - Cross-licensing technology
5 - Joint ventures
5 - Selling U.S. products abroad
4 - Selling foreign products in the U.S.
2 - Joint development projects
1 - Purchase agreement from parent abroad
1 - Subcontract production to sister abroad

Source: OIRA Survey Data

Significance of Cooperative Efforts

The significance of industry collaboration should not be lost in the maze of identifying who has agreements with whom and what each teaming project involves. The overriding purpose of such agreements is to share both costs and risks as a means of maintaining international competitiveness. Organizations such as the Aerospace Industries Association's National Center for Advanced Technologies (NCAT) are encouraging industry to pool research and share the results; otherwise, the U.S. will continue to lose its technological leadership and its aerospace business to companies in Europe and Japan, which are strongly supported by their governments.[44]

Historically the United States has excelled in collaborative development projects where there was a focus on solving a specific problem; often other innovations were derived during the course of such projects. The Manhattan Project in the 1940s is one such example, where research on the atom to develop the means to rapidly end World War II resulted in a new energy industry.

The sometimes controversial National Aerospace Plane (NASP) program is an excellent example of how solving a specific problem - - developing an airplane that can fly into space - - can have direct benefits not only for the advanced composites industry but also for the U.S. economy at large. Since 1985 the NASP program has merged funds from the Defense Department, NASA, and a five-company consortium[45] to develop such a spacecraft/airplane. The NASP program to date has cost approximately $2.5 billion, of which the U.S. Government has invested $1.8 billion and the industry contractor team $700 million.

To solve the myriad of technical problems associated with designing such a plane, technologies have already been developed that are being applied to other applications by American industry

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[44] Bond, David F., and Patricia A. Gilmartin. "Industry Collaboration Grows for Technology Development." Aviation Week and Space Technology. Volume 135, Number 11. September 16, 1991. p. 20.

[45] General Dynamics; McDonnell Douglas; Pratt & Whitney; Rocketdyne; and Rockwell.

with growing success. One such problem was to develop a skin material capable of meeting the most demanding thermal, stiffness, and lightness requirements yet required in an aerospace application. Timet, Inc., a NASP subcontractor based in Henderson, Nevada, has solved this problem with its development of a titanium-based metal matrix composite (TMC). Timet and its customers have projected several spin-off applications in the commercial market which exemplify the significance of pooled resources and task-specific efforts to U.S. competitiveness:

- Application of TMC Bolts for Offshore Oil Wells. Nickel steel bolts holding offshore drilling/pumping structures together under water are currently replaced every two years because of corrosion by salt water. Bolt corrosion tests indicate that TMC bolts will last for the lifetime of the structure. Timet projects their sales to the oil industry over the next twenty years will be over $2 billion for a million pounds of TMC bolts for use in approximately one hundred North Sea installations. The company projects that use of the bolts in the Gulf of Mexico, which hosts over 4,000 structures, could result in sales of $20 billion over twenty years. There are also significant estimated savings for the oil industry, based on the reduction in material and labor costs associated with the replacement of corroded nickel alloy bolts. Because each nickel alloy bolt must be replaced every two years, over a twenty year period a total of ten changes would be necessary. At $10 per pound for nickel alloy bolts, an estimated $10 billion will be saved in the North Sea on material alone when the TMC bolts are substituted. Additional savings in replacement labor total nearly $4 billion. These estimates do not include savings for structures in the Gulf of Mexico. In sum, the oil industry estimates that the same bolt will save approximately $14 billion over a twenty year period (based on North Sea oil structures only).

- TMC Oil Well Pipe Application. The new TMC is sixty times more resistant to corrosion than ordinary titanium alloys. This attribute has enabled the development of a new type of oil well pipe which is more corrosion resistant to sulfur at high temperatures and much lighter weight than currently used nickel alloy pipes. Because of the lighter weight of a TMC pipe, oil wells can be extended 33 percent deeper than with nickel alloy pipe due to the weight capacity limitations of the surface structure. Timet estimates sales of $3.5 billion of TMC oil well pipe over twenty years. Should the oil industry elect to extend drilling depths beyond their

current 20,000 foot depth limit to the 30,000 foot potential offered by the TMC pipe, the industry's twenty year sales estimates grow by over $5 billion. Savings to the oil industry based upon the longer life span of TMC pipe and the additional reserves accessible from the extra 10,000 feet of drilling depth attainable have not been estimated, but are potentially enormous.

- Boeing 777 Engine Application. The new TMC has been baselined into the new Boeing 777 airliner. The composite is capable of resisting Skydrol (aircraft hydraulic fluid) at high temperatures and lowers the weight of each of the 777's two engines by 850 pounds. Boeing projects operating and maintenance savings of between $2 million and $5 million per aircraft over a twenty year period based on the 1,750 pound per aircraft weight reduction. Depending on the number of aircraft Boeing is able to sell, savings to the airlines alone could approach $500 million over a twenty year period. Timet has not estimated its sales due to their insignificance relative to the savings numbers.

- Medical Applications. The new TMC has been found to be a viable candidate for many medical applications, based on its corrosion resistance and a coefficient of expansion very close to human bone. Timet expects to sell over 300,000 pounds per year of TMC for artificial hip implants over a twenty year period, generating sales of over $180 million. The company also expects to sell an additional $30 million in surgical tools made from TMC. The U.S. Department of Health and Human Services' Food and Drug Administration (FDA) is currently testing the material for these applications, although some companies, such as Biomet, have completed their evaluation and have decided to use the material pending FDA approval.

This one example of a new titanium-based metal matrix composite developed for the NASP program is projected by the companies involved to provide at a minimum about $7.2 billion in total sales during a twenty year period. These companies equate these dollars to approximately 75,000 new jobs that would not otherwise exist. There are other examples of advanced composite materials and processes which have been developed as part of the NASP program which have also found commercial applications. These applications drive total industry sales projections to over $20 billion over twenty years. The minimal Timet commercial estimates

alone represent a return on taxpayers' investment of four times what the U.S. Government has invested thus far in the NASP program. A conservative estimate of total advanced composite materials and processes commercial sales represents an 11-fold return on taxpayers' investment.

The trend toward cooperative efforts in recent years reflects their necessity for survival in a capital-intensive industry that faces ever tighter markets. The cooperative agreements and teams formed by the industry to pursue the TRP are another example of industry efforts aimed at leveraging scarce resources. Cooperative efforts involving government can be a boon to the taxpayer as well as to industry, strengthening and expanding the high-tech industrial base, which translates to high-paying, high-skilled jobs which, in turn, enhance the tax base. Government involvement, such as the recent TRP award to ACTT, serve as an example of such cooperative efforts.

V. FINANCIAL PERFORMANCE

Financial information was collected on both a corporate basis and, when possible, on a division basis. This information has been aggregated into the three general categories of companies, material suppliers, fabricators, and prime contractors. Many companies in the advanced composites industry are operating units of much large, diversified corporations. It is for this reason that corporate as well as divisional information was collected. **The data reflects the changing nature of the advanced composites business, where economic pressures on all businesses have resulted in new financial pressures on operating units of larger organizations. Corporations are now generally less capable of financially underwriting specific operating units in the long term, resulting in these units having to financially support themselves more than in the past.** The consolidation in the industry reflects this inability by large corporations to maintain non- or less-profitable units. The combination of the defense cutbacks and the financial pressures on large corporations is having a negative impact on the size and vitality of the U.S. advanced composites industry.

Corporate Overview

Company respondents were asked to provide financial data on a corporate basis, and for those companies with divisions dedicated to advanced composites, on a division basis as well. Fifty-three of the 66 respondents provided corporate income statements for some or all of the period covering 1987 to 1991. Of these 53, twelve were firms whose sole business is advanced composites. For these firms, the financial information is included in the division level data as well.

There were 34 respondents who reported financial information on a divisional basis for some or all of the years between 1987 and 1991. The aggregated data from these divisions exhibited continuous growth in total sales from $632 million in 1987 to $1.1 billion in 1991. Total net income, however, was more reflective of the corporate net income trend line, with a peak in 1988 and then a steady decline. The aggregated divisional net incomes were much worse than the corporate ones. *Table 12* depicts both the corporate and divisional aggregate data.

Table 12: Industry Financial Information					
Corporate ($ billions)					
	1987	1988	1989	1990	1991
Sales	$ 56	74	87	94	93
Net Income	$ 4.1	6.7	6.6	5.5	4.2
Profit Margin	7.3%	9.1%	7.6%	5.9%	4.5%
# Losses Reported	11/33	11/36	12/42	14/45	15/47
Division ($ millions)					
Sales	$ 632	804	924	1,089	1,094
Net Income	$ -2.2	10.6	-8.7	-19.5	-27.4
Profit Margin	-0.3%	1.3%	-0.9%	-1.8%	-2.5%
# Losses Reported	11/19	12/25	12/28	13/31	12/32

Source: OIRA Survey Data

The percentage of divisions reporting losses was also markedly different from the corporate data. Approximately 58 percent of companies reporting divisional financial data for 1987 had net losses. This percentage decreased each year, with 38 percent of the divisions reporting 1991 data experiencing net losses. However, the number of divisions reporting losses actually grew, from 11 in 1987 to 12 in 1991. The percentage declined because the number of divisions reporting information rose, as shown in the table above.

As discussed earlier, companies were asked to classify their primary activity into three general categories, material suppliers, fabricators, and prime contractors, and were then asked to identify each of the three categories in which they perform some function. These classifications were helpful in separating the information collected from such a diverse set of companies into more meaningful subsets for analysis purposes. The financial information was subdivided into these three primary business activities. While these classifications are general in nature and do not

reflect those companies who reported some secondary activity in more than one category, the subsets are generally more conclusive than using the aggregated set from which they were derived. The shipments discussion will be more reflective of the volume of domestic business in each specific product category.

Materials Suppliers

Twenty companies classified themselves as primarily material suppliers. Aggregated corporate sales for these companies increased 62 percent over the five year period, while net income fluctuated. Corporate profit margins exhibited a decline, dropping by almost half from 9.5 percent in 1987 to 5.1 percent in 1991. The number of individual companies reporting net losses increased each year, ranging from 12.5 percent of respondents in 1987 to 31 percent of respondents in 1991. These percentages are based on an increasing number of respondents and increasing number of respondents with net losses in each year of the five-year period.

Total gross sales reported on a division basis by these materials companies showed a steady increase until 1991, which exhibited a slight decline. The total net incomes over the same time period exhibited a different trend. It peaked in 1988, then dropped dramatically. This is reflected in the profit margins. which fell from 3.6 percent in 1987 to -5.1 percent in 1991.

Table 13: Material Suppliers' Financial Information

Corporate ($ billions)					
	1987	1988	1989	1990	1991
Sales	$ 23.1	23.7	32.3	37.2	37.5
Net Income	$ 2.2	2.2	1.9	2.4	1.9
Profit Margin	9.5%	9.3%	5.8%	6.4%	5.1%
# Losses Reported	1/8	2/9	4/13	4/14	5/16

Current Ratio = 1.2:1 Debt Ratio = 18.4%

Division ($ millions)					
	1987	1988	1989	1990	1991
Sales	$ 328.3	426.7	484.9	590.6	563.1
Net Income	$ 11.7	21.4	18.3	-6.7	-28.5
Profit Margin	3.6%	5.0%	3.8%	-1.1%	-5.1%
# Losses Reported	1/5	3/7	3/8	4/10	5/11

Current Ratio = 3.2:1   Debt Ratio = 22.8%

Source: OIRA Survey Data

Aggregated current ratios were calculated for these companies as well at both the corporate and division level. This ratio measures the ability of a company to pay its debts quickly, usually in less than a year. A standard ratio of 2 to 1 indicates that a company is in sound financial condition and can comfortably pay its bills. Based on the mathematical relationship between these companies' current assets and current liabilities, this subset's corporate current ratio is 1.12 to 1. On the division level, however, the companies appear to be much more conservative, with a strong current ratio of 3.2 to 1. Aggregated debt ratios were calculated as well. This indicates the percentage of assets that are financed by debt. There is no standard against which to compare; such standards vary from industry to industry. In this case the corporate debt ratio was 18.4 percent, while the divisional debt ratio is 22.8 percent.

Fabricators

Thirty-six companies classified themselves as primarily fabricators. Aggregated corporate sales for these companies increased each year between 1987 and 1990, before decreasing somewhat in 1991. During the five-year period total net income peaked in 1989 and then dropped by more than half by 1991. Profit margins peaked in 1988 and then declined each subsequent year. The number of individual companies reporting net losses was fairly constant over the five-year

period, yet their percentage of total reporting companies declined from 45 percent of respondents in 1987 to 36 percent of respondents in 1991.

As was demonstrated when reviewing the materials suppliers, the fabricators' financial performance at the division level was much worse than on a corporate basis, although this is not apparent from the total gross sales figures alone. Total gross sales grew on average 75 percent over the five-year period, with increased sales in each consecutive year. The total net incomes over the same time period exhibited a different trend, with varying degrees of loss. Only in 1991 did the aggregated net income show a profit, which was only slightly over $1 million. The calculated profit margins reflect this trend. The number and percentage of companies experiencing net losses declined during the five-year period, with 71 percent of divisions reporting losses in 1987 to 33 percent of those reporting in 1991.

Table 14:
Fabricators' Financial Information

Corporate ($ billions)					
	1987	1988	1989	1990	1991
Sales	31.1	48.9	52.6	55.0	53.2
Net Income	1.8	4.5	4.7	3.1	2.2
Profit Margin	5.9%	9.2%	8.8%	5.6%	4.1%
# Losses Reported	10/22	10/24	8/26	10/28	10/28

Current Ratio = 2.36:1 Debt Ratio = 12.6%

Division ($ millions)					
Sales	303.2	377.1	438.6	498.3	531.0
Net Income	-13.8	-10.8	-27.0	-12.8	1.0
Profit Margin	-4.6%	-2.9%	-6.1%	-2.6%	0.2%
# Losses Reported	10/14	9/18	9/20	9/21	7/21

Current Ratio = 2.82:1 Debt Ratio = 24.7%

Source: OIRA Survey Data

Aggregated current ratios were calculated for these companies as well at both the corporate and division level. As indicated in the materials suppliers section, the standard ratio is 2 to 1. At the corporate level the fabricators' current ratio is 2.36 to 1. The division current ratio is slightly stronger at 2.82 to 1. The corporate debt ratio was 12.6 percent, while the divisional debt ratio is 24.7 percent.

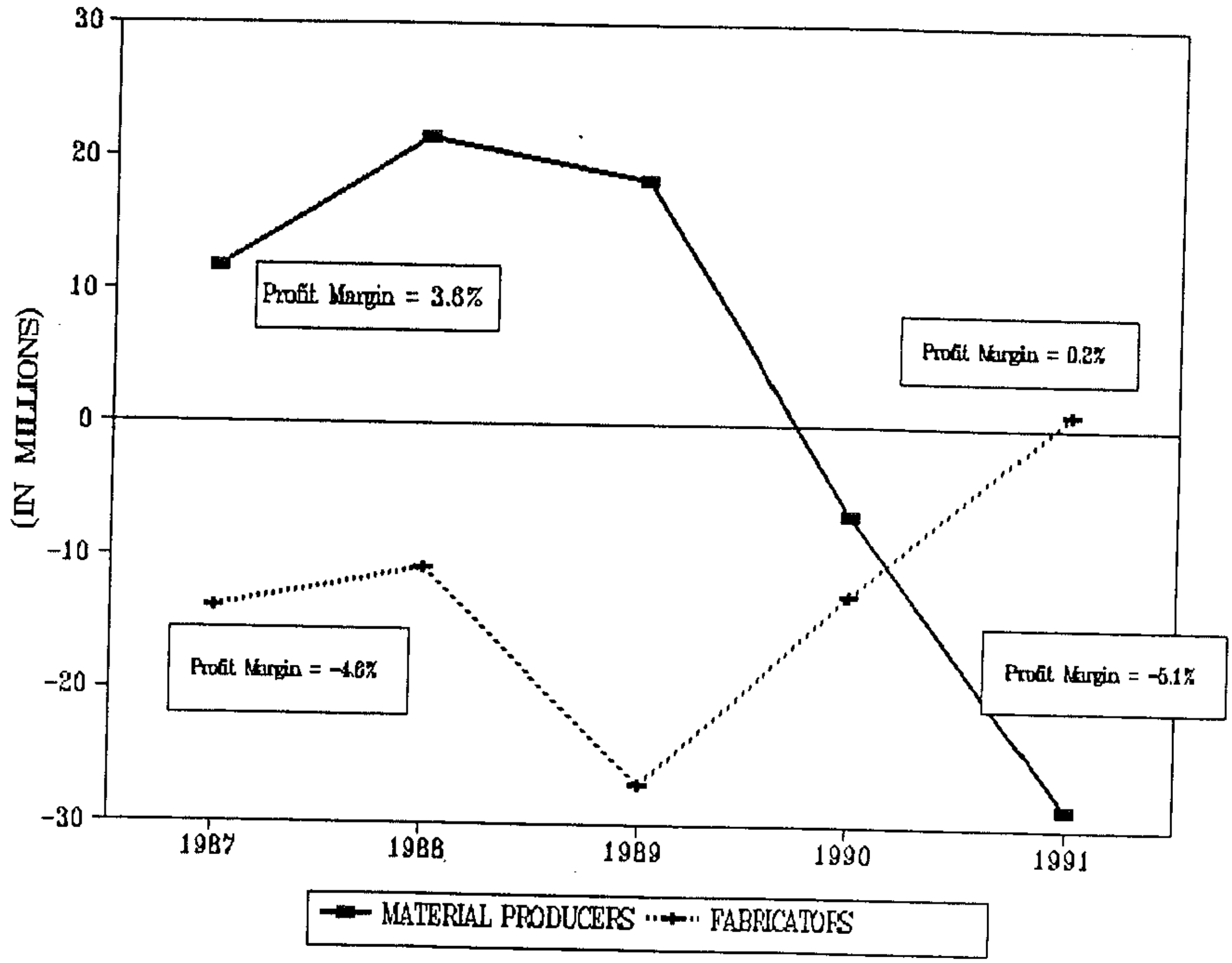
Prime Contractors

Only four respondents primarily classified themselves as prime contractors. Aggregated corporate sales for these companies increased each year during the five-year period, from $1.7 billion to $2.4 billion. Total net income also increased each year during the period, from $55.1 million in 1987 to $92.9 million in 1991. The profit margin for 1987 was 3.2 percent, and then declined somewhat to 2.7 percent the following year. The margin declined again in 1989 to 2.5 percent before increasing to 3.0 percent in 1990 and to 3.8 percent in 1991. None of the companies reported a net loss during the five-year period.

In addition, these prime contracting companies have no operating divisions which specialize predominantly in advanced composites and, therefore, no division income statements were submitted. The aggregated corporate current ratio is 1.59 to 1. The corporate debt ratio was 18.2 percent.

To summarize some of the elements discussed, *Graph 5* illustrates the net income trend lines for the materials suppliers and fabricators who reported advanced composite division financial information.

Graph 5:
Net Income Trend Lines, 1987-1991



Note: No prime contractors provided advanced composites-specific division information.

Source: OIRA Survey Data

VI. EMPLOYMENT TRENDS

Employment was another area where information was collected from study participants. Companies were asked to provide this information based on their type of organization; namely, sales/non-manufacturing firms, manufacturers, and research and development facilities. Within each of these categories, respondents were asked to further qualify the types of employees into such categories as engineering, production, sales, and so forth. The information collected does not represent total employment in the industry; in fact, it is a relatively small sample. Employment by material suppliers alone is known to be greater than the total employment figures reported below. **The trends are therefore more salient than the actual numbers.**

Table 15:
Employment: By Type of Firm and Sample Total

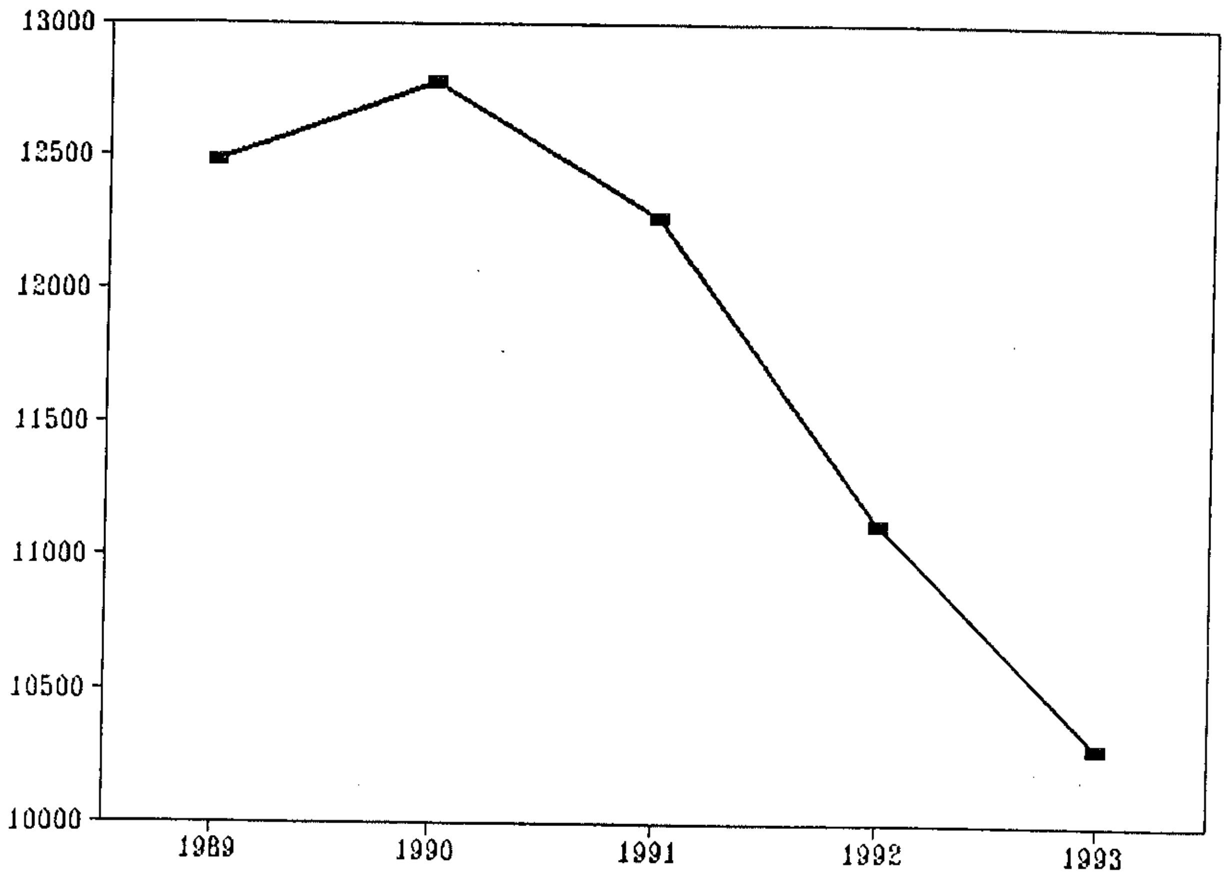
	1989	1990	1991	1992	1993
Sales/Non-Manufacturing Firms	131	208	255	271	334
Manufacturers	11,192	11,429	11,022	10,087	9,424
Research & Development	1,155	1,139	988	756	532
Total, All Firms	12,478	12,776	12,265	11,114	10,290

Source: OIRA Survey Data

As shown in *Table 15*, the total sample employment figures for the respondents indicated that employment peaked in 1990 and has since steadily declined. The 1991 total employment number shown above is in fact understated. In completing our questionnaire, companies with less than 50 employees were only required to report 1991 data. While our resulting 1991 data more accurately reflects the employment levels within the industry, it is overstated for comparison purposes. To eliminate this overstatement in establishing an employment trend line, the employment statistics provided by companies who reported only 1991 data were subtracted from the total 1991 figures in order to provide a balanced trend line, hence the understatement in the figure above. The actual 1991 employment figure including small firms was calculated to be 12,370.

Total employment for the sample dropped by almost ten percent in 1992 from 1991 levels. The year 1993 saw a 7.4 percent decrease from 1992. Between 1989 and 1993 overall employment declined 17.5 percent. *Graph 6* depicts the changes in employment during this time period.

Graph 6:
Total Sample Employment Trend Line, 1989-1993



Source: OIRA Survey Data

Sales/Non-Manufacturing Operations

Table 16 shows that the number of the sample's total employees for sales/non-manufacturing operations was unique within the different classifications of companies in that the number

increased every year from 1989 to 1992. The net change in total sales employment from 1989 to 1993 was 253.4 percent.

Table 16 *Sales/Non-Manufacturing Employment: By Type of Employee and Sample Total*					
	1989	1990	1991	1992	1993
Marketing/Sales	20	24	33	26	28
Technical Services	18	22	30	40	45
Administrative	55	72	84	89	95
All Others	38	90	108	116	166
Total	131	208	255	271	332

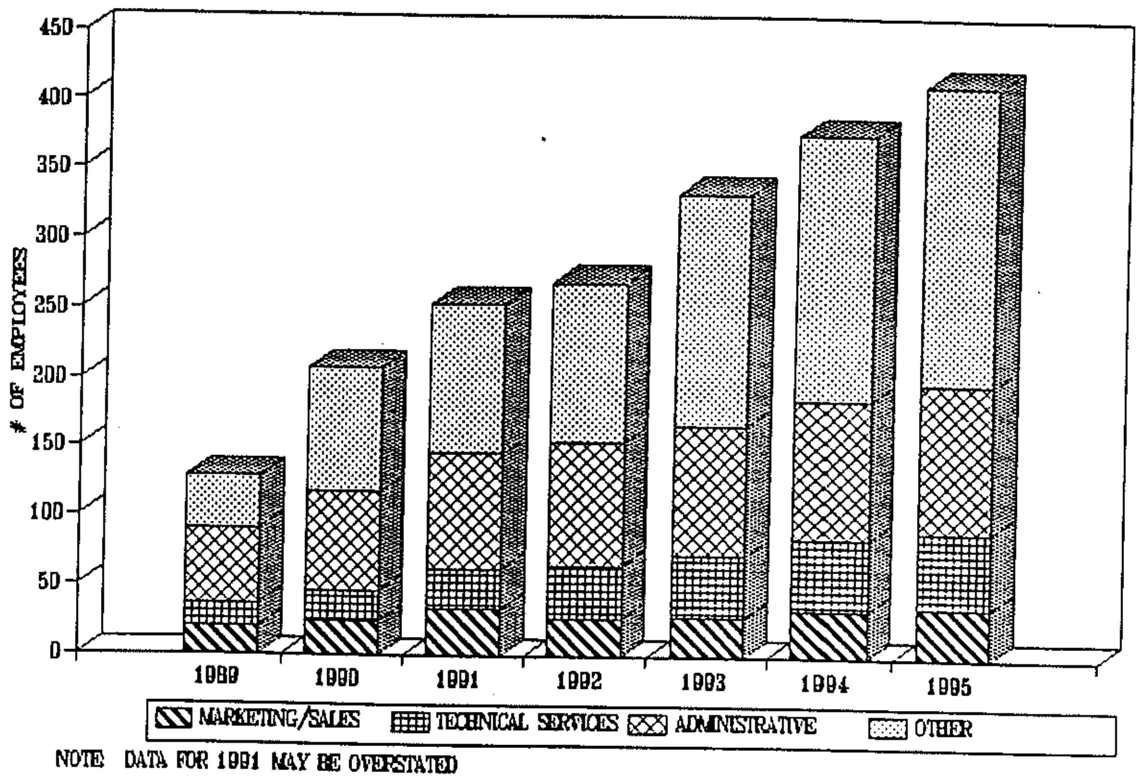
Source: OIRA Survey Data

While sales/non-manufacturing companies experienced the only increase in employment over the reviewed time period, they are still the smallest category by number of employees. In 1989 sales firms accounted for only one percent of total employment reported. This percentage of total employment increased in each subsequent year, partly as a result of the increased number of employees and partly because of the decline in employment levels experienced by both manufacturers and research and development facilities. In 1990 sales firms represented 1.5 percent of total employment; in 1991 2.3 percent; in 1992 again 2.3 percent; and in 1993 3.0 percent.

These sales firms categorized their employees into four general groups: marketing/sales; technical services; administrative; and all others. In general, the sales and marketing category accounted for the smallest concentration of employees in sales firms. Technical services employees grew in number every year during the review period. Administrative employees account for larger numbers of employees. Overall the "all other" category was the largest by number of employees. Unfortunately no sales firms reported what these employees primary functions are.

Graph 7 depicts the employment levels by category in sales/non-manufacturing operations.

Graph 7:
Sample Sales/Non-Manufacturing Operations Employment Levels



Source: OIRA Survey Data

Manufacturers

Manufacturers comprised the vast majority of employees reported, ranging from 89.9 percent of the sample's total employment in 1989 to 91.7 percent in 1993 (see *Table 17*). The number of total employees peaked in 1990 at 12,273, before manufacturers began downsizing in 1991 as employment declined to 11,662 (11,712 including companies reporting only 1991 data). This is a decrease of five percent over comparable 1990 employment levels. The decrease almost doubled in percentage terms 1992 when compared with the 1991 decrease in employment. In 1993 the decrease continued; the net change in total manufacturers employment from 1989 to 1993 was -16.7 percent.

Table 17:
Manufacturers Employment: By Type of Employee and Sample Total

	1989	1990	1991	1992	1993
Scientists/Engineers	1,086	1,079	968	831	772
Production	7,623	7,684	7,253	6,859	6,441
Administrative	1,843	1,989	2,153	1,915	1,770
All Others	640	677	648	482	441
Total	11,192	11,429	11,022	10,087	9,424

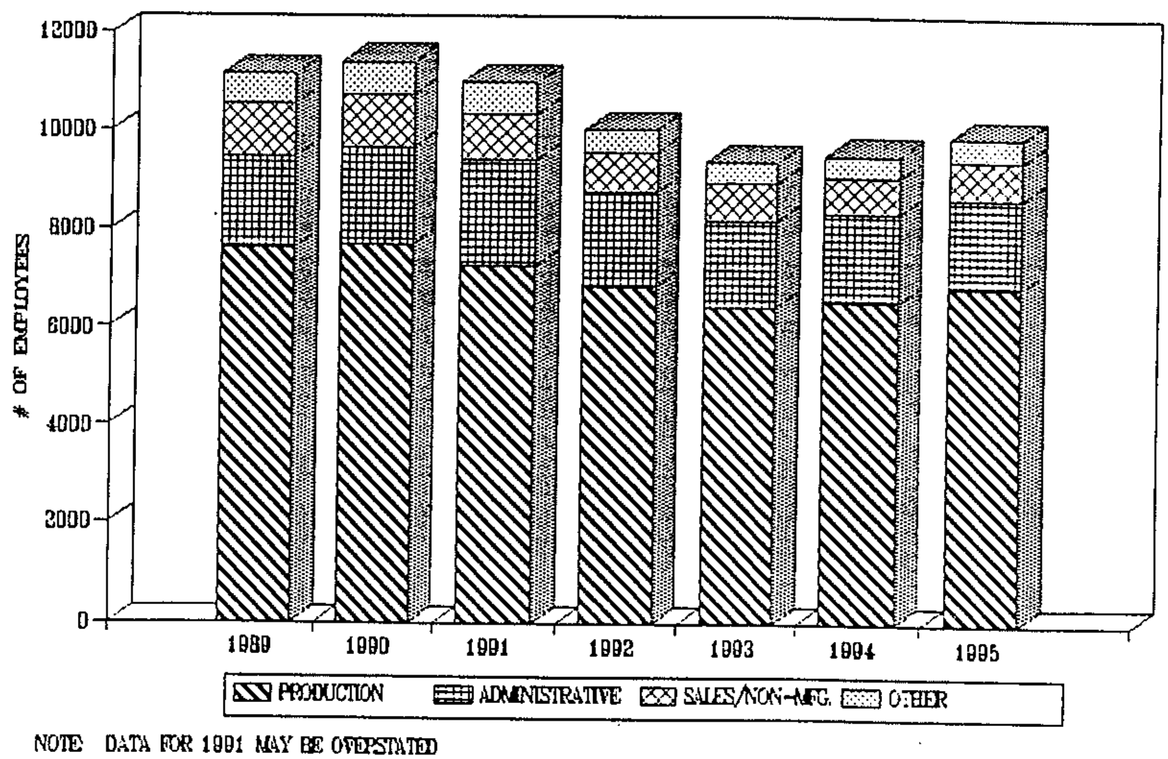
Source: OIRA Survey Data

These manufacturers were also asked to further categorize their employees into four general groups: scientists/engineers; production staff; administrative; and all others. For the 1989-1993 time period manufacturers reduced their scientists and engineering staffs by 28.9 percent. Production employees represented the largest single category of employees for manufacturers. Production staff peaked in 1990 and decreased in each subsequent year of the review period. Overall production employment for 1989 to 1993 decreased 15.5 percent. Administrative employees account for the second largest concentration of manufacturers' employment. Overall administrative employment peaked in 1991 and then declined to result in a four percent decrease in employment between 1989 and 1993. Overall the "all other" category was the smallest by

number of employees. Total "all other" employment peaked in 1991 and then declined through 1993. This employment category experienced a decline of 31.1 percent between 1989 and 1993.

Graph 8 summarizes the manufacturers sample's employment levels by category and total.

Graph 8:
Manufacturer Sample's Employment Levels



Source: OIRA Survey Data

Research and Development Facilities

Research and development (R&D) facilities comprised the second largest group of employees reported, declining from 9.1 percent of total employment in 1989 to 5.3 percent in 1993. As shown in *Table 18*, the number of total R&D employees declined each year in the review period. The net change in total R&D employment from 1989 to 1993 was -53.9 percent.

Table 18: Research & Development Facilities' Employment: By Type of Employee and Total

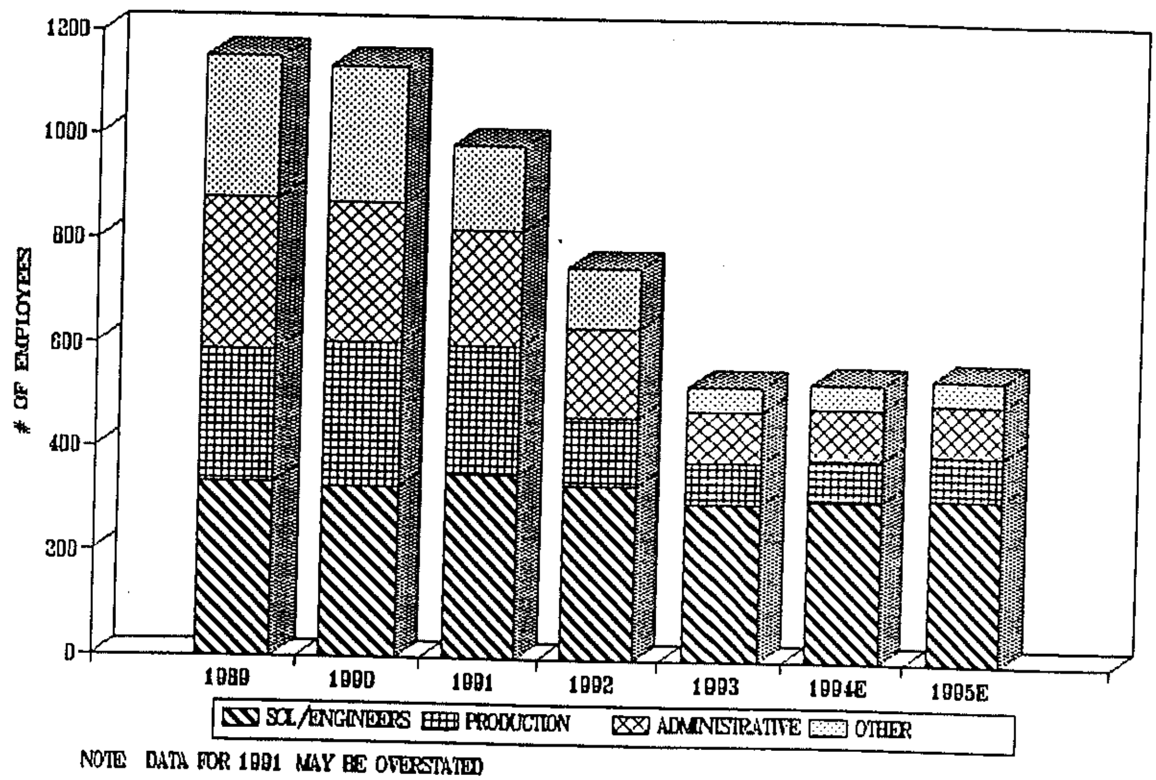
	1989	1990	1991	1992	1993
Scientists/Engineers	334	329	354	337	305
Production	257	275	248	130	80
Administrative	289	272	222	171	101
All Others	275	263	164	118	46
Total	1,155	1,139	988	756	532

Source: OIRA Survey Data

These R&D facilities also categorized their employees into the same four general groups as manufacturers: scientists/engineers; production staff; administrative; and all others. For the 1989-1993 time period R&D facilities reduced their scientists and engineering staffs by 8.7 percent. Production staff employment peaked in 1990 and decreased in each subsequent year of the review period. Overall production employment for 1989 to 1993 decreased 68.9 percent. Overall administrative employment declined continually during the review period with a net change between 1989 and 1993 of -65.1 percent. Total "all other" employment declined each year during the review period.

This overall employment category experienced a decline of 83.3 percent between 1989 and 1993. *Graph 9* summarizes the various employment levels for research and development facilities.

Graph 9:
Research and Development Facilities Employment Levels



Source: OIRA Survey Data

Labor Concerns and Projections

Respondents were asked if they had any labor concerns in the past five years, or anticipate any labor concerns in the next five years, that adversely affected or are expected to adversely affect their advanced composites operations. Twenty-nine companies responded to this question with most (fifteen) indicating that they had no such problems. Areas in which companies did express labor concerns could be broadly categorized as inadequate education and skills, increased insurance costs, and EPA and health regulations.

Most comments related to an available skilled workforce. One company indicated that the U.S. public education system is not able to provide the basic fundamentals in math, reading, and writing to non-college bound students, resulting in very low skills for entry-level employees. Another company expressed a similar concern, reporting that it must invest heavily in in-house training for entry-level employees; the company also indicated that there is excessive turnover in employees, compounding the problem. A third company also raised the issue of excessive turnover. Yet another firm indicated that there is a very small pool of new college engineering graduates who have advanced composites experience. This causes the company to hire experienced industry people rather than new entrants to the industry, adversely affecting the company's ability to diversify its employee mix, and probably contributing to the problem of excessive turnover. Two other companies also stated that they have a shortage of skilled and semi-skilled labor.

Some responses specifically mention the decline in employment because of defense cutbacks. One respondent indicated that the decline in defense business has led to decreased production and decreased employment of skilled labor. Such declining employment results in an older workforce that will be more difficult to replace, given the continuing decline in overall employment rates in this industry. Conversely, two companies reported that their availability of skilled labor has improved, as there are many qualified people available as a consequence of the employment reductions in the aerospace industry. Neither company has major business in the aerospace sector.

Insurance was another area that companies reported as a problem. Two companies indicated that workman's compensation claims have been on the rise, resulting in spiraling insurance costs. Another company reported that increasing health care costs will lead to a reduction in benefits provided to its employees, which could possibly lead to employee dissatisfaction. Another firm cited EPA and health regulations as hampering.

VII. SHIPMENTS

As mentioned earlier, information was collected on a product by product basis. Companies were asked to report their total shipments using the product codes provided in the questionnaire (attached in *Appendix 2*). They were also asked to further quantify their shipment data by their percentage of shipments destined for defense and the percentage destined for export markets. These areas will be discussed in detail by general product category below.

Part of the data provided proved to be unusable, however. Some companies reported aggregated shipment information on multiple product types, preventing the use of the information in the product by product analysis below. These companies, because of their accounting methods, were unable to break out their shipment information by the product classifications outlined in the questionnaire. Where a company provided aggregate information on multiple products between categories, we did not use the information as we were unable to allocate shipments to a specific product type or category.

In other cases companies provided information on a specific product type, but because these companies represent the vast majority of the domestic production of this type, the data could not be published without either directly or indirectly releasing business proprietary information.

A. Fibers

Fifteen companies reported that they either produce or market one or more types of fibers in the United States. Eleven of these companies reported domestic production at a total of twelve plants, while four sales organizations of foreign companies also reported domestic shipments. Because of the proprietary nature of the data provided by the dominant producers of S glass and aramid fiber, this information was not included. Hence the sample is understated.

By value the total reported shipments of fibers fluctuated between 1989 and 1993, ranging from \$121.5 million in 1989 to \$157.5 million in 1993, a net increase of 29.7 percent.

Table 19 *Fiber Shipments ($ Millions)*					
	1989	1990	1991	1992*	1993*
Total Shipments	$121.5	$131.4	$124.3	$145.0	$157.5
Defense Shipments	42.9	43.7	38.4	40.4	44.3
Domestic Non-Defense	67.0	75.8	69.1	83.5	91.2
Export Shipments	11.6	11.9	16.8	21.1	22.0

* Forecast

Source: OIRA Survey Data

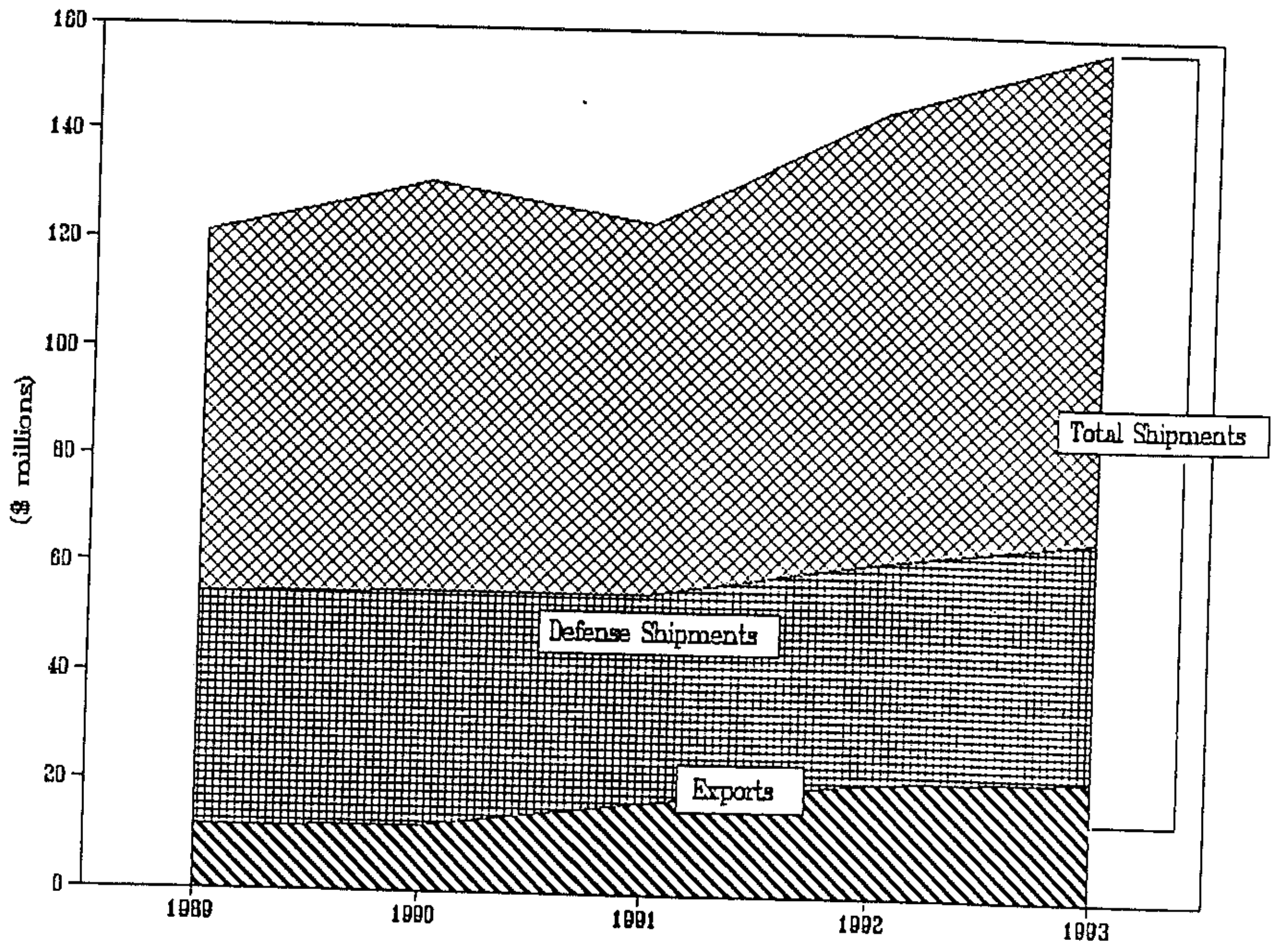
On an aggregate basis the percentage of total shipments destined for defense applications declined steadily during most of the review period. In 1989 defense shipments comprised 35.3 percent of all shipments reported; by 1993, this percentage had dropped to 28.1 percent. This can be attributed directly to reduction in defense spending, through program slow-downs and cancellations.

Companies were also asked to provide the percentage of total shipments destined for export markets. These percentages also fluctuated during the review period, but increased overall, both in absolute terms and as a percentage of all shipments. Exports nearly doubled, growing from $11.6 million to their peak of $22 million, an increase of 90 percent. Exports grew from 9.6 percent of total shipments in 1989 to 14 percent in 1993.

It was mentioned in the employment section that companies with less than 50 employees need only provide 1991 data, rather than multi-year information. For purposes of establishing trend lines, companies who reported only 1991 data were excluded from the discussion above, as their inclusion would artificially inflate the 1991 results in comparison to the other years. The 1991 figures alone, however, are more reflective of the actual shipments which were made in that year. Including shipments from these small firms, total shipments were $143.7 million in 1991,

with $39.3 million (31.7 percent) destined for defense applications. This indicates that by including small firms defense shipments represent a greater portion of total shipments. No small firms reported export shipments.

Graph 10:
Fiber Shipments, 1989-1993



Source: OIRA Survey Data

Carbon Fiber

The fiber shipment data was further qualified by type of fiber. Shipments of carbon fiber were the largest single reported category, with shipments provided by eight domestic plants and three sales offices. Since carbon fibers constituted such a large part of total fiber shipments, it is not surprising that carbon fiber trends closely followed total fiber trends. Like total fiber shipments, carbon fiber shipments generally increased between 1989 and 1993, with the exception of a decline in 1991. Total carbon fiber shipments grew 36 percent. Defense shipments fluctuated over the period, growing 15 percent in dollar terms but declining as a percentage of total carbon fiber shipments after 1990, from 33.3 percent in 1989 to just over 28 percent in 1993. Export shipments more than doubled between 1989 and 1993, growing 106 percent to their peak in 1993. Relative to total shipments, exports grew from 8.7 percent in 1989 to 13.2 percent in 1993.

Table 20
Carbon Fiber Shipments ($ Millions)

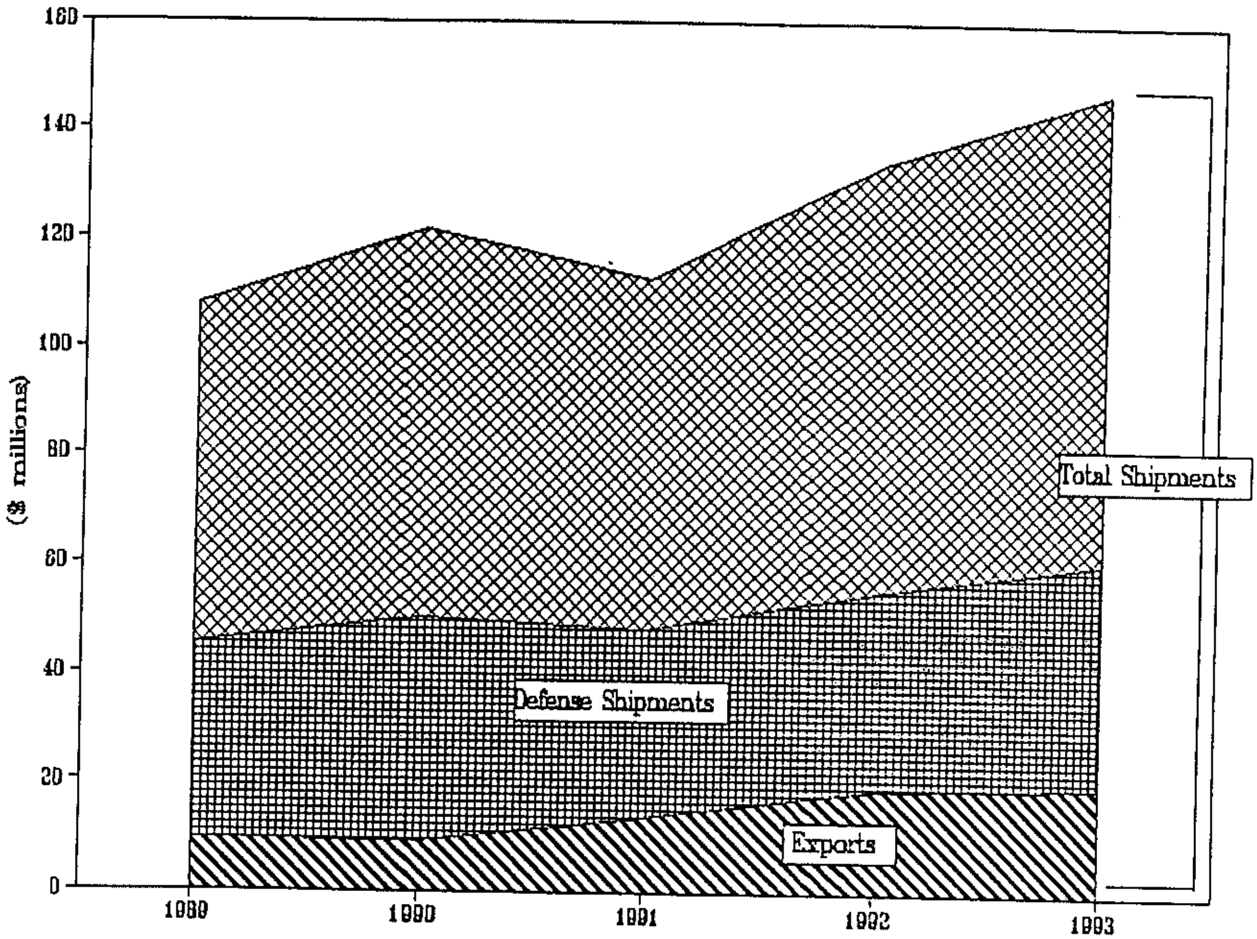
	1989	1990	1991	1992*	1993*
Total Shipments	$108.1	$121.6	$112.7	$134.2	$147.3
Defense Shipments	36.0	41.2	34.8	36.6	41.6
Domestic Non-Defense	62.7	71.4	64.4	78.9	86.3
Export Shipments	9.4	9.0	13.5	18.7	19.4

* Forecast

Source: OIRA Survey Data

As mentioned earlier, 1991 data are understated from what was reported by all respondents. In that year total shipments from both small and large firms were $123.8 million, of which defense accounted for 28.2 percent ($34.9 million) and exports accounted for 10.9 percent (still $13.5 million). The percentage declined because no small firms reported export shipments, yet total shipments were greater.

Graph 11:
Carbon Fiber Shipments, 1989-1993



Source: OIRA Survey Data

<u>Other Fibers</u>

Companies also provided shipment data for a number of other fibers, including aramid fiber, boron fiber, three different types of ceramic fiber, glass fiber, and polymer/organic fiber. This data represents shipments from seven domestic plants and two sales organizations. In some instances the plants and sales organizations are the same as those which reported carbon fiber shipments. Because of the small number of respondents for each individual fiber, and the fact that for two of the fibers it is commonly known that there is predominantly only one company

which produces each, the data cannot be published for each fiber (as was done above with carbon fiber) because to do so could reveal business proprietary information. To protect such information the shipment data for these reported fibers has been aggregated.

As was seen in the carbon fiber discussion, the total reported shipments of these fibers fluctuated between 1989 and 1993. Unlike total and carbon fiber, however, shipments of these other fibers declined during the time frame, falling 24 percent between 1989 and 1993. Also, defense shipments of other fibers fell drastically, dropping 59 percent in dollar terms and from 51.5 percent to 27.5 percent of total shipments. **These products were apparently severely hit by defense cutbacks.** Exports of other fibers grew, both in dollars and as a percent of total shipments. Exports rose 18 percent over the period, and grew from 16.4 percent of total shipments in 1989 to 25.5 percent of total shipments in 1993, peaking at 29.3 percent of shipments in 1990.

Table 21
Other Fiber Shipments ($ Millions)

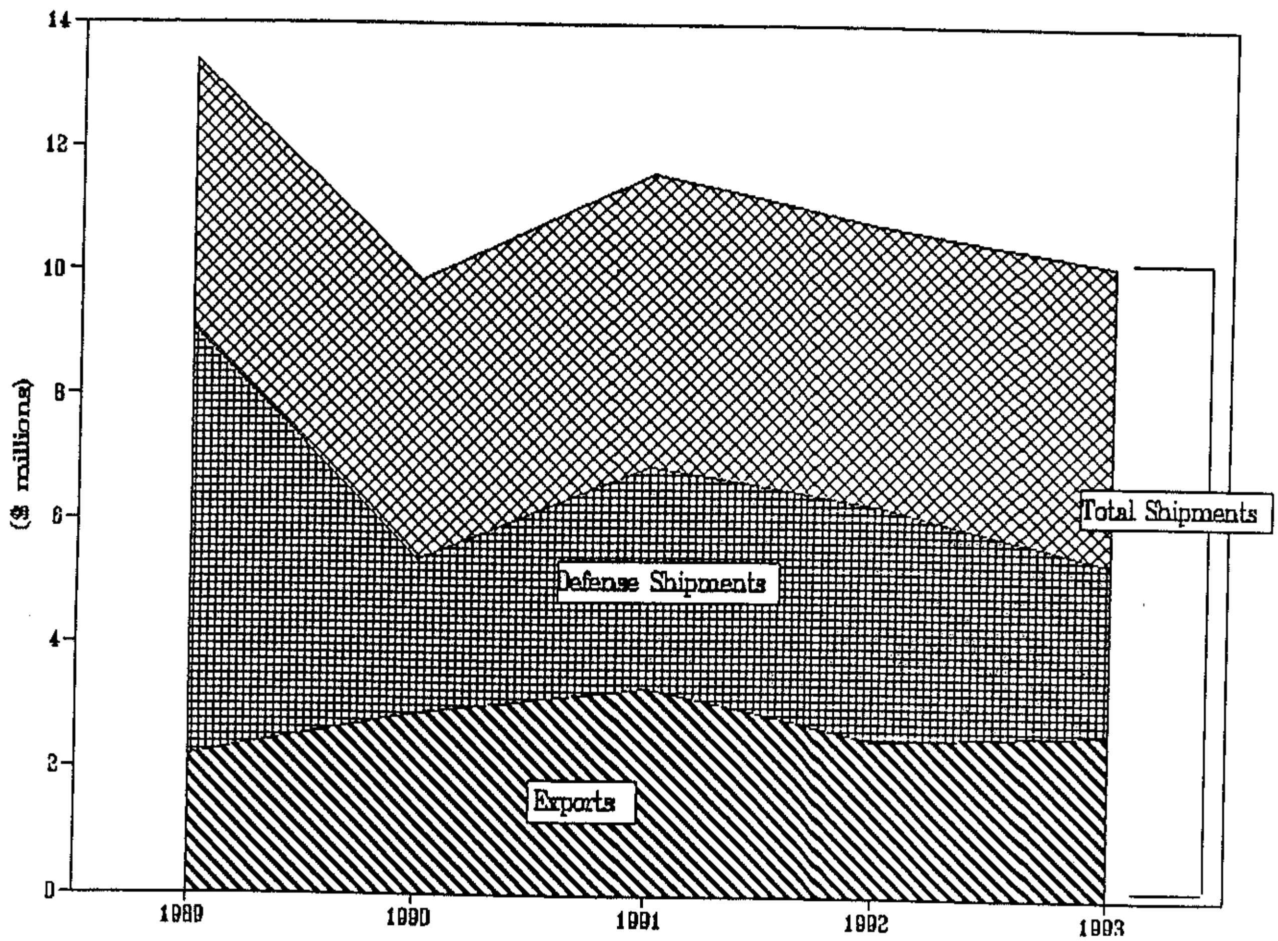
	1989	1990	1991	1992*	1993*
Total Shipments	$13.4	$9.9	$11.6	$10.8	$10.2
Defense Shipments	6.9	2.5	3.6	3.8	2.8
Domestic Non-Defense	4.3	4.5	4.7	4.5	4.8
Export Shipments	2.2	2.9	3.3	2.5	2.6

* Forecast

Source: OIRA Survey Data

The inclusion of small firms significantly increased the reported shipments for 1991 for these fibers. In that year total shipments including these firms were $19.9 million, of which defense accounted for 22.5 percent ($4.5 million). This is much lower than the 30.7 percent calculated from data excluding small firms. No small firms reported any exports, so that the percentage of exports based on total shipments of small and large firms was 16.7 percent.

Graph 12:
Other Fiber Shipments, 1989-1993



Source: OIRA Survey Data

B. Resins

Seven companies reported producing resins at eight different plants. In all cases but one the resin matrices produced are thermosetting, while the one remaining produces thermoplastic matrices. Total shipments of resins rose nearly 35 percent between 1989 and 1993; they peaked in 1991 after strong growth in the previous two years. Defense shipments dropped 13.6 percent over the period; more significant is the drop in defense's share of all shipments, which fell from 28.4 percent in 1989 to 18.3 percent in 1993, and actually went as low as 13 percent in 1990.

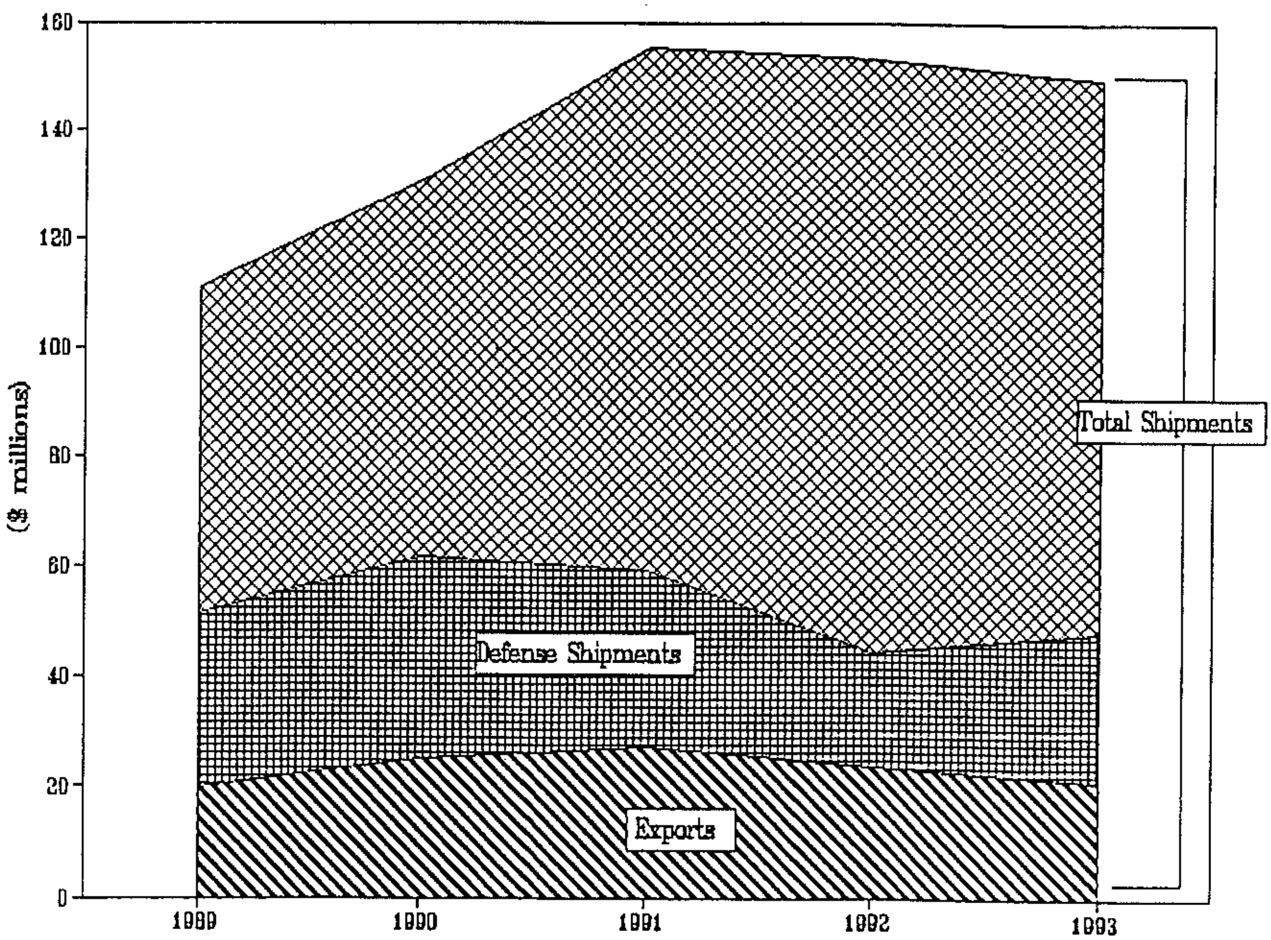
Exports fluctuated during the reporting period but actually ended it with only a 4.5 percent change overall, after rising over 36 percent between 1989 and 1991.

Table 22 *Resin Shipments ($ Millions)*					
	1989	1990	1991	1992*	1993*
Total Shipments	$111.2	$131.0	$155.6	$153.3	$149.6
Defense Shipments	31.6	37.1	32.5	20.8	27.3
Domestic Non-Defense	59.7	68.9	96.0	108.9	101.5
Export Shipments	19.9	25.0	27.1	23.6	20.8

* Forecast

Source: OIRA Survey Data

Graph 13:
Resin Shipments, 1989-1993



Epoxies

The majority of data submitted in the resins category pertained to epoxies. Epoxy resin shipments rose steadily from 1989 through 1991, falling off only slightly in the next two years to end the period with a 34.4 percent increase. **Apparently, however, this growth was not attributable to growth in exports or defense shipments.** Defense and export shipments, in dollars, peaked in the middle of the five-year period, then declined. However, as a percent of total shipments, both declined; defense shipments ended the period as 18.4 percent of the total, down from 28.5 percent in 1989; and exports ended the period at 14 percent of total shipments, from a starting point of 17.9 percent and a peak of 19.2 percent in 1990.

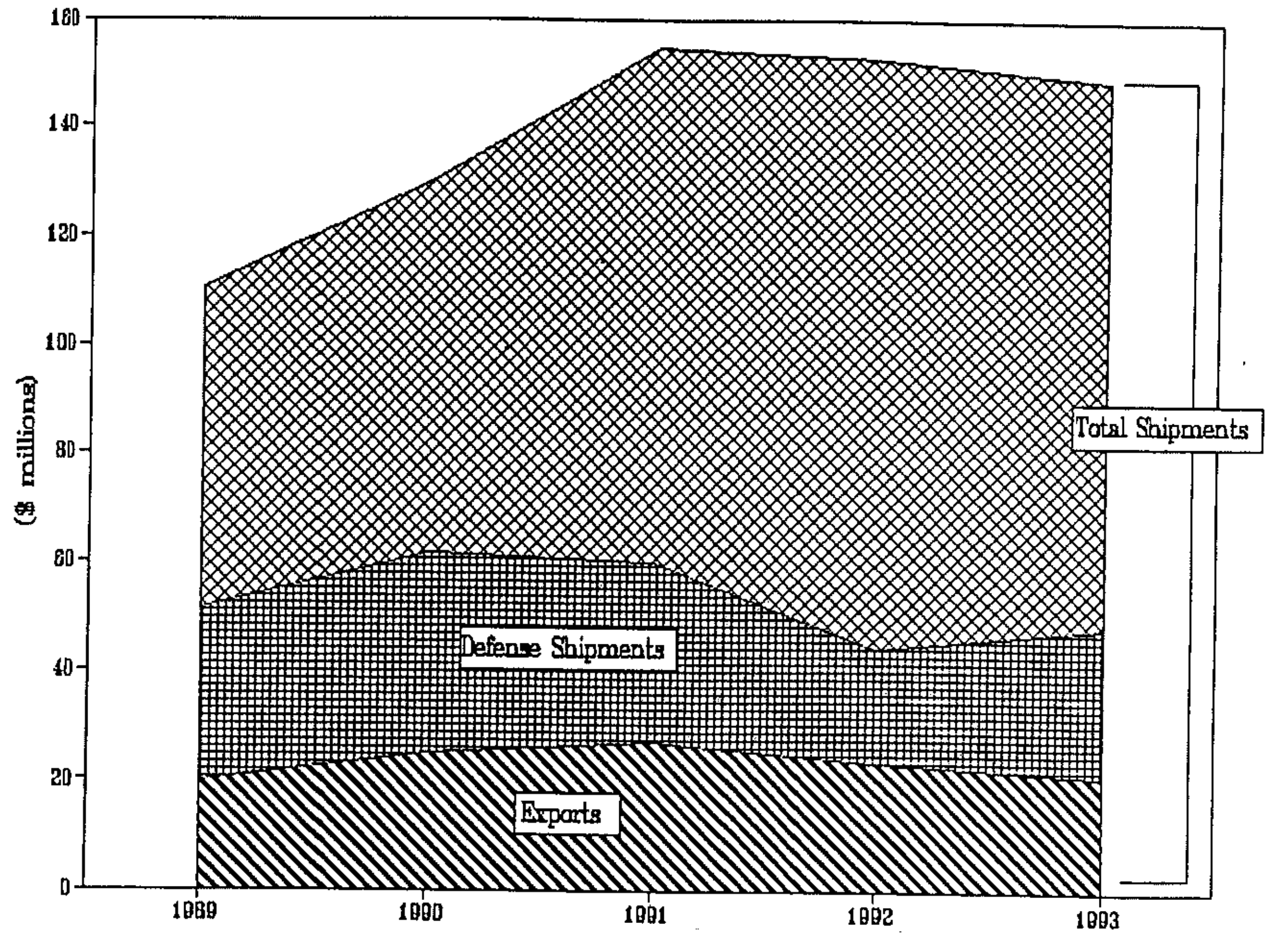
Table 23
Epoxy Resin Shipments ($ Millions)

	1989	1990	1991	1992*	1993*
Total Shipments	$110.8	$130.4	$154.6	$152.6	$148.9
Defense Shipments	31.6	37.1	32.8	20.8	27.3
Domestic Non-Defense	59.3	68.3	94.7	108.3	100.8
Export Shipments	19.9	25.0	27.1	23.5	20.8

* Forecast

Source: OIRA Survey Data

Graph 14:
Epoxy Shipments, 1989-1993



Source: OIRA Survey Data

Other Resins

Minor shipments were reported by respondents for thermoplastic resin matrices and polyester matrices. This data has not be separately described given the minor level of the shipments and the few number of respondents who are classified in this area.

C. Prepregs

Shipment data was submitted for twenty-two domestic plants and one sales organization for prepregs, the largest single category by value of shipments. Total prepreg shipments showed steadier growth throughout the period than did either fibers or resins. Shipments grew 13.3 percent between 1989 and 1993. Prepreg shipments for defense fell, both in dollars and as a percent of total shipments. In 1989, defense applications accounted for 49.4 percent of all prepreg shipments; by 1993, this figure had fallen to 36.3 percent. At the same time, the dollar value of these shipments fell by 16.8 percent. Meanwhile, prepreg exports boomed, growing 42.3 percent between 1989 and 1993, and going from just 4.6 percent of total shipments to 19 percent. The growth in exports, **accompanied apparently by growth in non-defense markets like sporting goods**, boosted prepreg shipments.

Table 24
Prepreg Shipments ($ Millions)

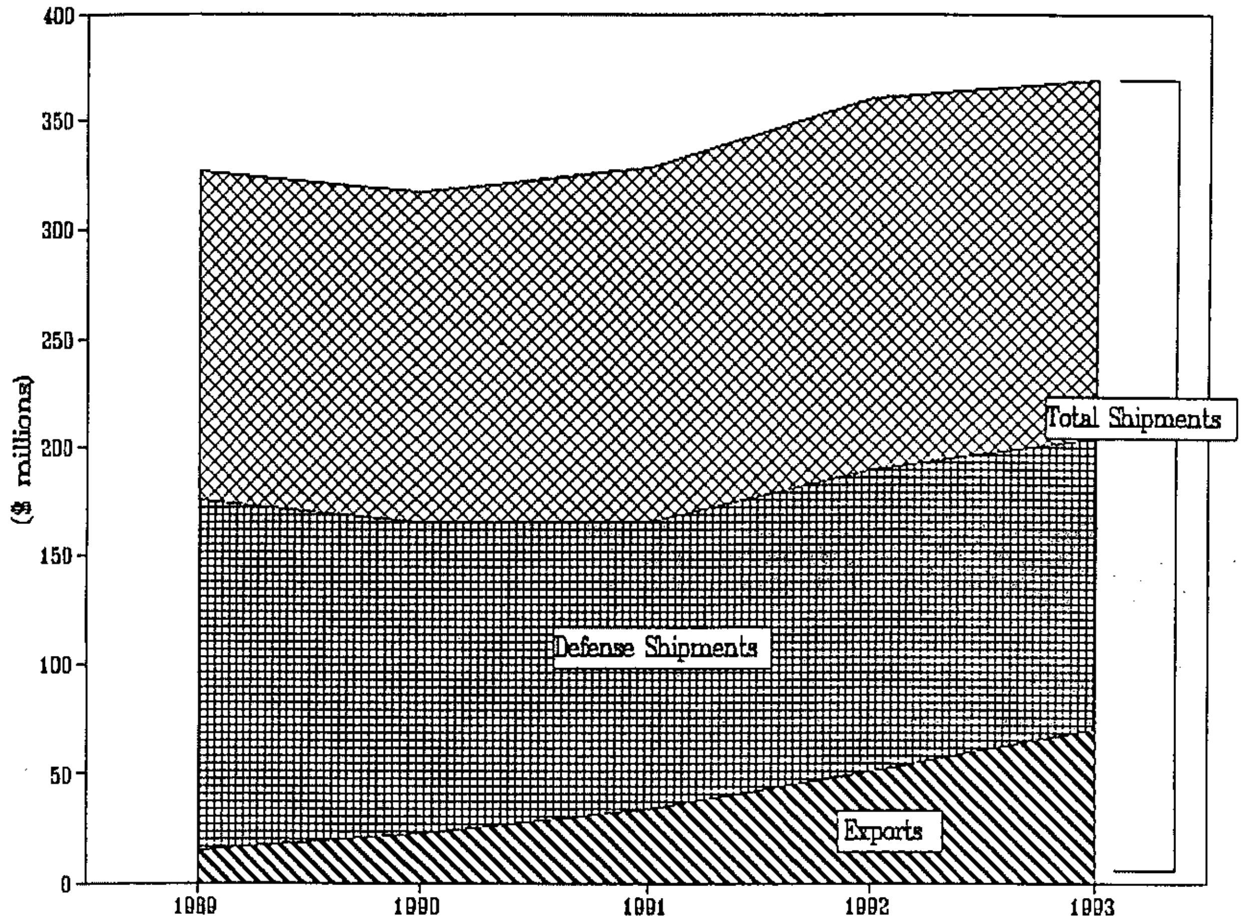
	1989	1990	1991	1992*	1993*
Total Shipments	$327.0	$317.5	$329.5	$361.2	$370.6
Defense Shipments	161.7	143.3	132.8	138.8	134.6
Domestic Non-Defense	115.9	151.6	163.1	171.3	165.7
Export Shipments	49.4	22.6	33.6	51.1	70.3

* Forecast

Source: OIRA Survey Data

Small firms reporting only 1991 data increased the total shipments for that year to $331.5 million, while they reported no defense or export shipments. For this reason defense shipments' share of 1991 total shipments slipped to 40.1 percent, while export shipments dropped slightly to 10.1 percent.

Graph 15:
Prepreg Shipments, 1989-1993



Source: OIRA Survey Data

Specific Prepregs

Shipment data were received for carbon fiber/resin prepregs, glass fiber/resin prepregs, aramid fiber/resin prepregs, and a smaller group of other prepregs. Fourteen domestic plants and one sales organization reported shipment information on **carbon fiber/resin prepregs**, the largest prepreg subcategory by value of shipments. Fifteen domestic plants reported shipment data for **glass/resin prepregs**, the second largest prepreg subcategory by value of shipments. By value

aramid/resin prepregs were the third largest subcategory of shipments reported. Nine domestic plants reported information on their shipments in this subcategory. The remaining reported data for prepregs includes aggregated data by several respondents for all their prepreg shipments. This information was submitted in aggregate form because these companies were unable to allocate their shipment information to the specific subcategories defined in the questionnaire. Other companies also provided information on **boron/resin prepregs** and **ablatives**. Because the information in these two categories were drawn from a very small group of companies, the data has been aggregated in order to protect the proprietary data of these operations.

Shipments of specific prepregs basically mirror the results for the group as a whole, with the exception of aramid fiber/resin prepregs. Total shipments of both carbon and glass fiber/resin prepregs grew even more quickly than did shipments of all prepregs, increasing 19.1 percent and 22.3 percent, respectively, between 1989 and 1993. Other prepreg shipments also increased, by 1.7 percent. Aramid fiber/resin shipments, in contrast, fell by 26.6 percent. Defense shipments of carbon and glass fiber/resin prepregs imitated the trend for all prepregs, falling 16 percent and 31.6 percent, respectively. Defense shipments of other prepregs similarly fell 15.6 percent. Aramid fiber/resin defense shipments showed a different trend, actually rising 23.1 percent between 1989 and 1993. All four groups of prepregs showed increased exports. Carbon fiber/resin shipments grew by over 500 percent; glass fiber/resin shipments increased by more than 400 percent; aramid exports doubled, albeit from a small base; and other prepreg exports also doubled.

As with data for the other materials, the 1991 shipment figures were routinely understated for the various prepregs, as small firms provided information only for that year. The 1991 shipment data for **carbon fiber/resin prepregs** was actually slightly higher than indicated above, once shipments by smaller firms were included. Total shipments were in fact $179.0 million. These smaller firms reported no defense shipments, causing the defense share of total shipments in 1991 to decline from 49.3 to 48.7 percent. No exports were reported by these smaller firms, either, causing the percentage of shipments that were exported to decline from 10.5 to 10.4 percent.

No small firms reported data for 1991 for either **glass fiber/resin prepregs** or **aramid fiber resin prepregs**. For the other prepregs, the 1991 shipment figures were somewhat understated, as several small firms provided 1991 information. Total shipments were actually $58.5 million, while these small firms reported no defense or export shipments. The additional 1991 shipments reported by these small firms were so small that the percentage of total shipments comprised by defense and exports remained the same, 57.8 percent and 14.8 percent, respectively.

Table 25
Carbon Fiber/Resin Prepreg Shipments ($ Millions)

	1989	1990	1991	1992*	1993*
Total Shipments	$186.8	$172.3	$177.1	$206.6	$222.5
Defense Shipments	108.6	95.7	87.3	94.9	91.2
Domestic Non-Defense	71.0	66.4	71.2	78.6	85.3
Export Shipments	7.2	10.2	18.6	33.1	46.0

* Forecast

Graph 16:
Carbon Fiber/Resin Prepreg Shipments, 1989-1993

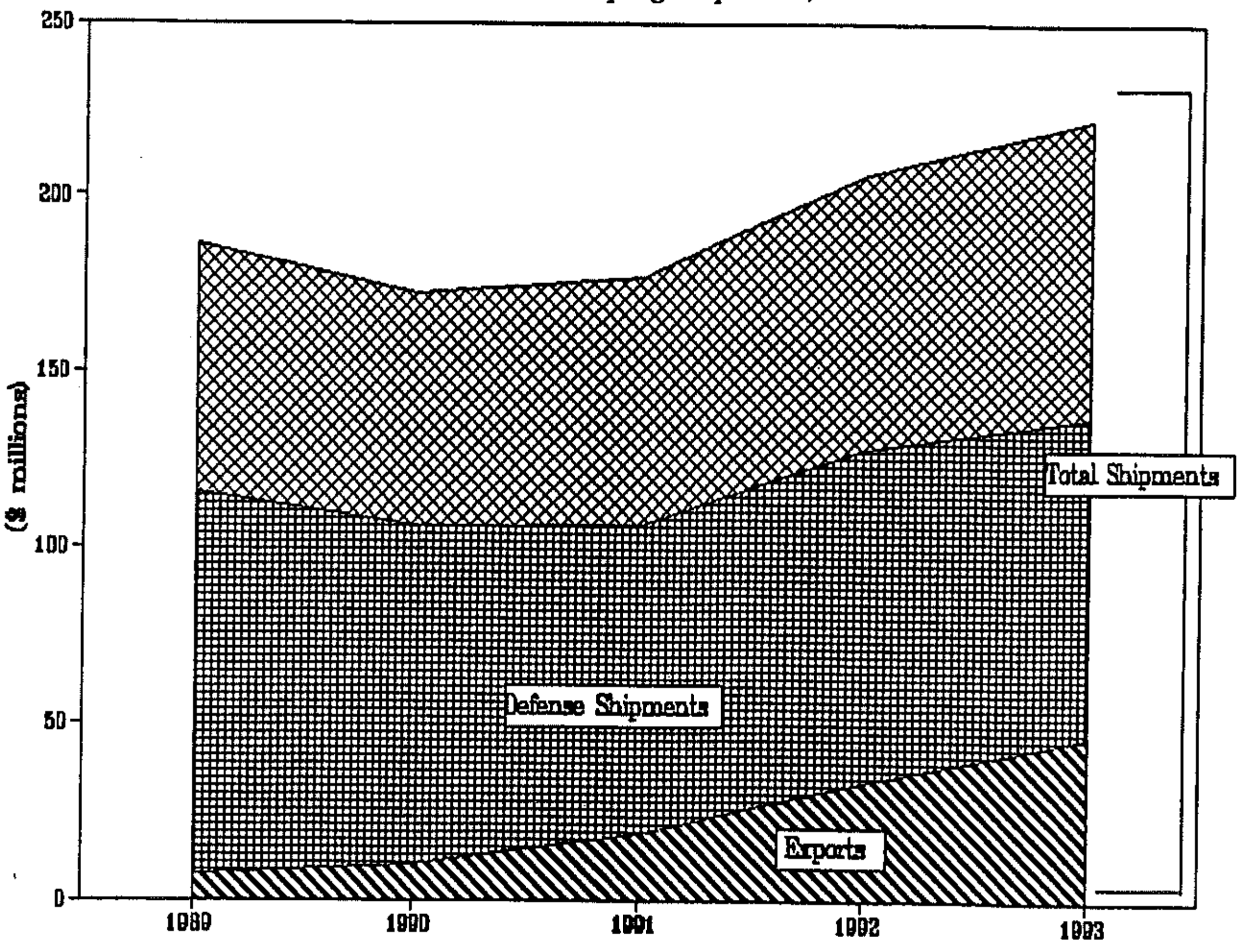
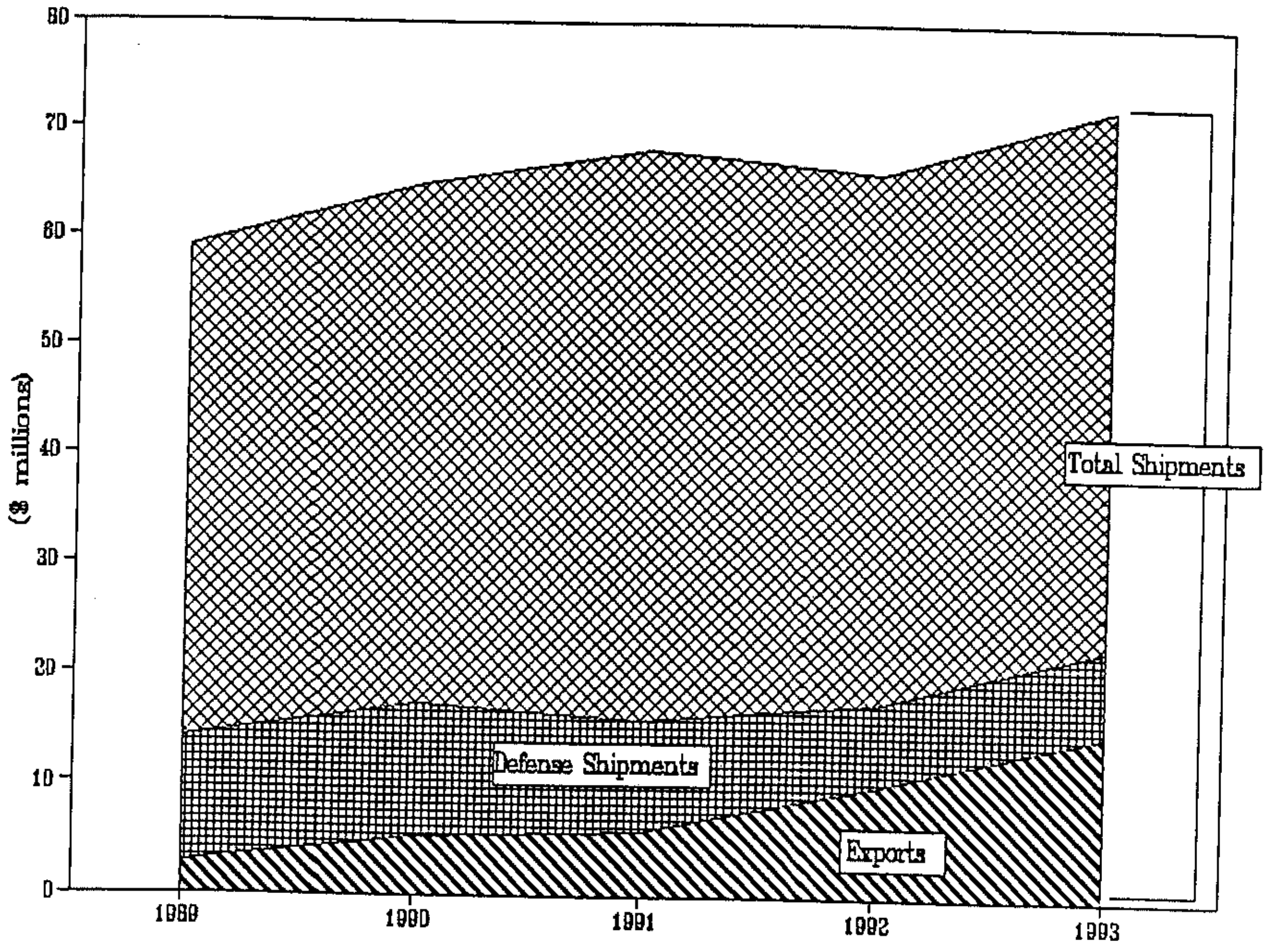


Table 26 Glass Fiber/Resin Prepreg Shipments ($ Millions)					
	1989	1990	1991	1992*	1993*
Total Shipments	$59.1	$65.0	$68.3	$66.1	$72.3
Defense Shipments	11.4	12.1	10.0	7.6	7.8
Domestic Non-Defense	44.8	47.7	52.5	48.6	49.8
Export Shipments	2.9	5.2	5.8	9.9	14.7

* Forecast

Graph 17:
Glass Fiber/Resin Prepreg Shipments, 1989-1993

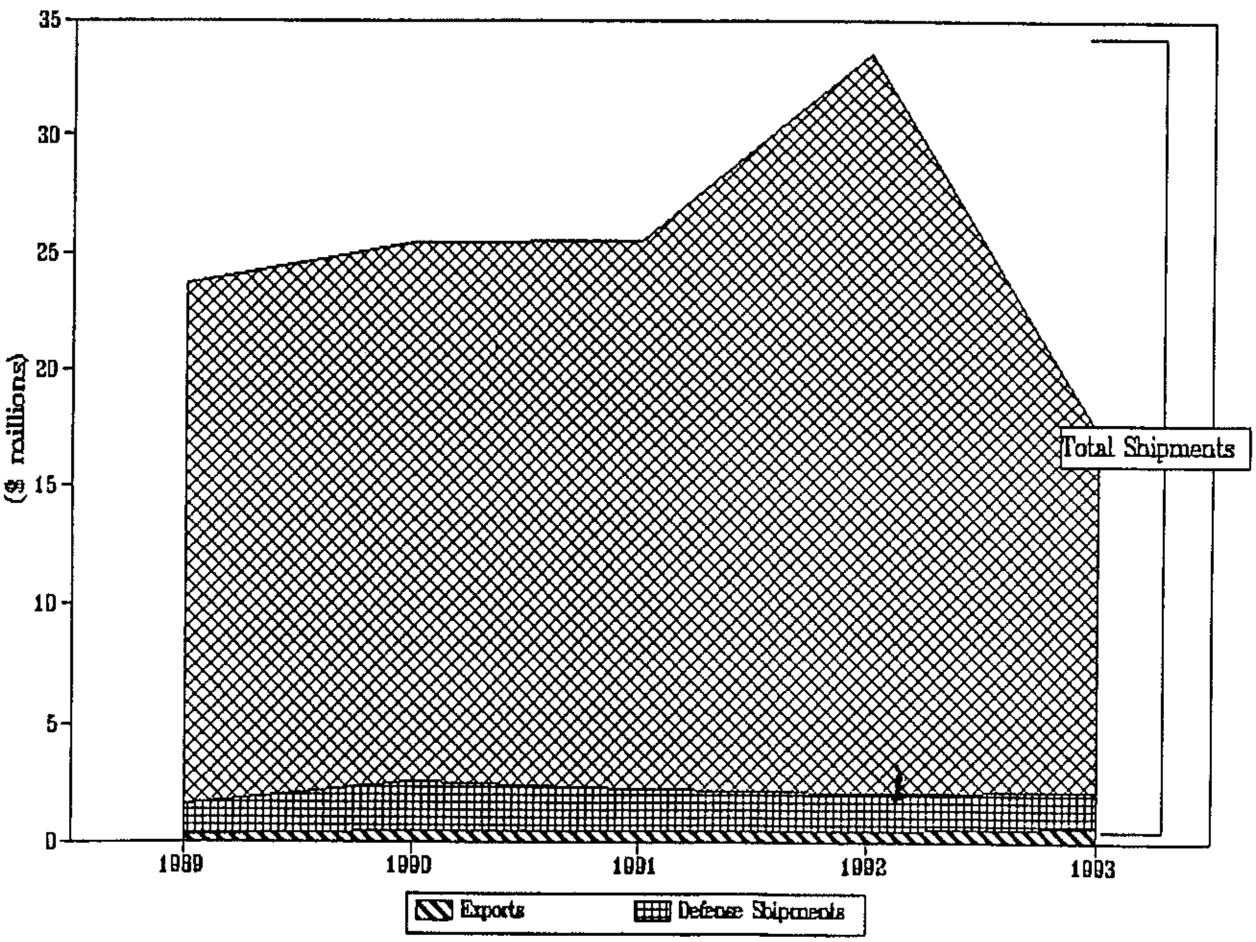


Source: OIRA Survey Data

Table 27 *Aramid Fiber/Resin Prepreg Shipments ($ Millions)*					
	1989	1990	1991	1992*	1993*
Total Shipments	$23.7	$25.5	$25.6	$33.6	$17.4
Defense Shipments	1.3	2.1	1.8	1.6	1.6
Domestic Non-Defense	22.1	22.9	23.3	31.5	15.2
Export Shipments	0.3	0.5	0.5	0.5	0.6

* Forecast

Graph 18:
Aramid Fiber/Resin Prepreg Shipments, 1989-1993



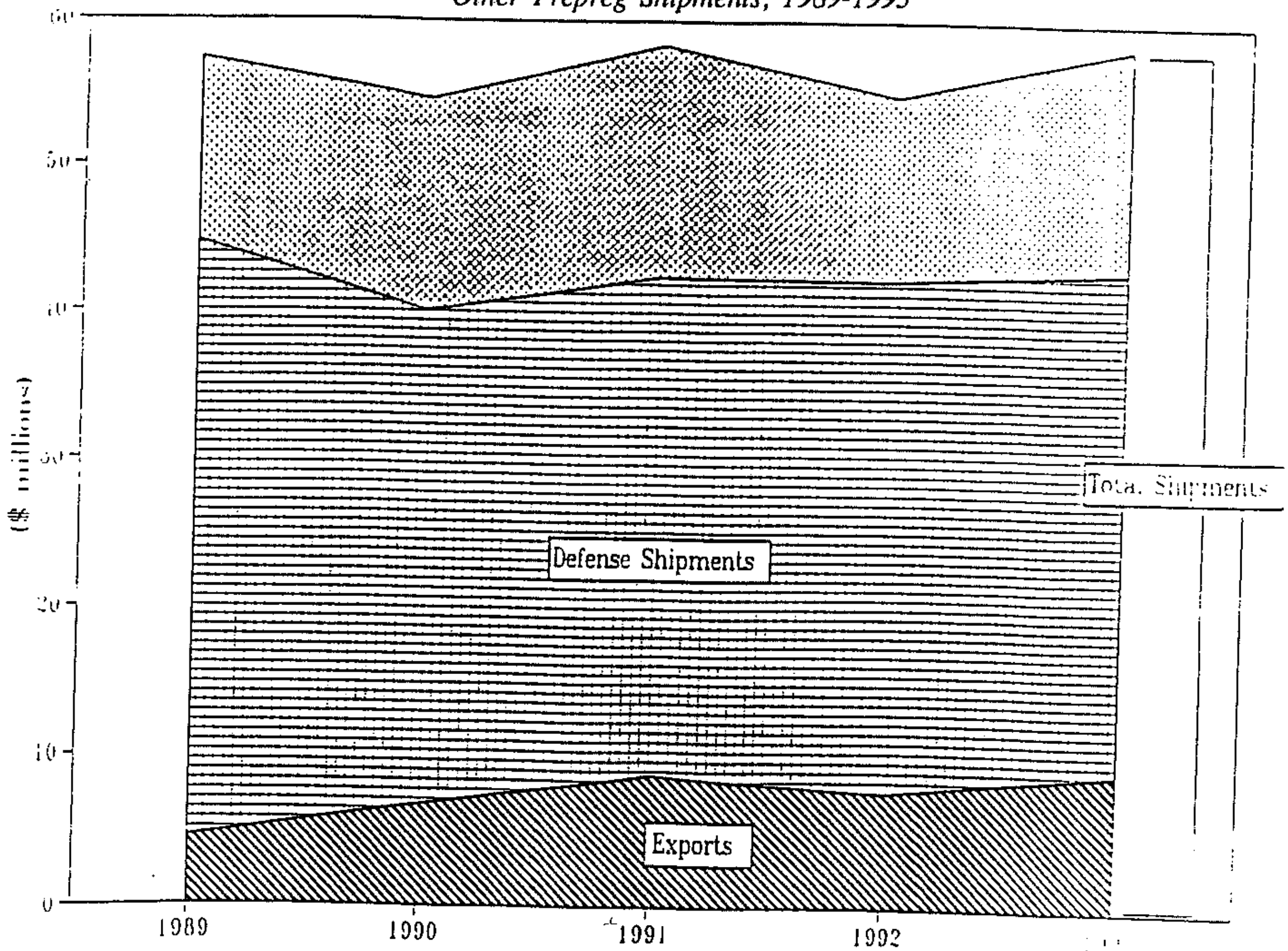
Source: OIRA Survey Data

Table 28
Other Prepreg Shipments ($ Millions)

	1989	1990	1991	1992*	1993*
Total Shipments	$57.4	$54.7	$58.4	$54.9	$58.4
Defense Shipments	40.3	33.4	33.8	34.7	34.0
Domestic Non-Defense	12.6	14.6	15.9	12.6	15.3
Export Shipments	4.5	6.7	8.7	7.6	9.1

* Forecast

Graph 19:
Other Prepreg Shipments, 1989-1993



Source: OIRA Survey Data

D. Non-Polymer Matrix Composites

Relatively few companies reported shipment information on non-polymer matrix composites. Five domestic plants and one sales organization did provide information on their shipments of metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon/carbon composites (C/Cs). Because so few companies reported information in these categories, it was necessary to aggregate the information; otherwise the information submitted by respondents on a product by product basis would be published as reported and not protected.

The shipments reported include three types of MMCs (silicon carbide/aluminum, silicon carbide/titanium, and intermetallics titanium/aluminum), oxide CMCs, and liquid infiltration C/Cs. More than any other **product** discussed so far, reported production of non-polymer matrix composites was almost entirely destined for defense, and none was exported. Total shipments fluctuated over the period, dropping 12.5 percent over the entire reporting period, from a high of $6.4 million in 1989 to $5.6 million in 1993. The low point was $4.13 million, in 1990. Defense shipments fell 31 percent, from $6.4 million in 1989, when defense end uses accounted for all shipments, to $4.4 million in 1993, when defense accounted for only 78.4 percent of total shipments.

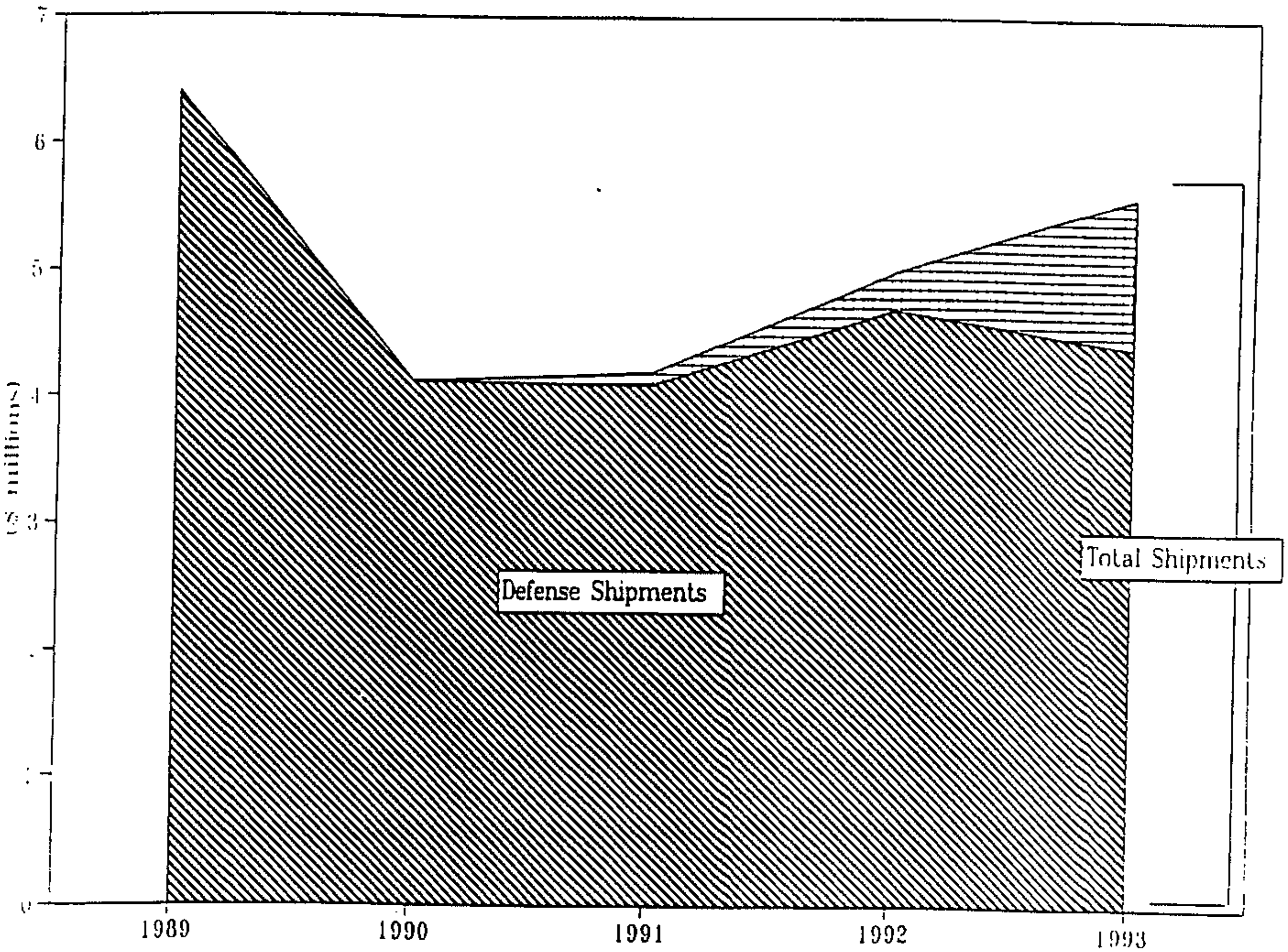
Table 29
Non-Polymer Matrix Composite Shipments ($ Millions)

	1989	1990	1991	1992*	1993*
Total Shipments	$6.4	$4.13	$4.2	$5.0	$5.6
Defense Shipments	6.4	4.12	4.1	4.7	4.4
Domestic Non-Defense	0.0	0.01	0.1	0.3	1.2

Source: OIRA Survey Data

Information submitted by small firms increased the total shipments for 1991 to $5.7 million, while defense shipments in that year increased to $4.9 million. This results in the defense share of total shipments dropping from 97.6 percent to the more accurate 85.0 percent for 1991 alone.

Graph 20:
Non-Polymer Matrix Composite Shipments, 1989-1993



Source: OIRA Survey Data

E. Applications

It was discussed early in this report that information was collected from both suppliers and users of advanced composite materials. Some users of these materials, such as prime contractors, were unable to provide information based on the type of fiber or resin used. For this reason these end users were asked to submit information on an application basis. The vast majority of information provided by application pertained to defense uses, either military aircraft or other non-aircraft military uses.

Defense

Information was submitted by prime contractors who reported shipments that were destined for use in military aircraft. The shipment data provided too small of a sample from which to decisively draw trends. On an aggregate basis the shipments to these companies' plants increased 408 percent between 1989 and 1993.

All respondents were asked to identify any military system for which they used advanced composites domestically since 1987. *Table 30* lists the military aircraft which respondents identified.

Table 30: U.S. Military Aircraft Systems	
AH-64 Apache Attack Helicopter	F-5 Fighter/T-38 Fighter Trainer
Advanced Tactical Air Reconnaissance System (ATARS)	F-14 Tomcat Fighter
Advanced Tactical Fighter	F-15 Eagle Fighter
Avenger Air Defense System	F-16 Fighter
AV-8B Harrier Fighters	F-22 Fighter
Airborne Early Warning & Surveillance (AWACS) Aircraft	F-111 Fighter/Bomber
A-6, 6E, EA6B-1 Intruder Aircraft, Rewing	F/A-18 C/P & E/F-18 Hornet
B-1 Bomber	KC-135 Aerial Refueling Tanker Aircraft
B-2 Stealth Bomber	MH-53, 53-E Minesweeper Helicopter
B-52 Bomber	MH-60-K Black Hawk Helicopter
C-17 Transport Plane	RAH-66 Comanche Helicopter
C-5, C-5A Galaxy Transport Plane	S-61 Helicopter
CH-46 Sea Knight Combat Helicopter	SH-60 Sea Hawk Helicopter
CH-47 Chinook Combat Helicopter	UH-I Helicopter
CH-53 Sea Stallion Heavy-Lift Helicopter	UH-60 Black Hawk Helicopter
EC-130E Volant Solo Rivet Rider Aircraft	V-22 Osprey Tiltrotor Aircraft
E-8C Joint Surveillance Target Attack Radar System (JSTARS) Aircraft	VH-60 Black Hawk Helicopter

Source: OIRA Survey Data

Other military systems supported have been categorized as missile and rocket systems, as shown in *Table 31*, and other U.S. military or space systems, as listed in *Table 32*.

Table 31: U.S. Missile and Rocket Systems	
AAI Projectile	Maverick Air-to-Ground Missile
Advanced Cruise Missile (ACM)	Minuteman, Minuteman III Missiles
Aegis Missile	Patriot Missile
Air Launched Cruise Missile (ALCM)	Peacekeeper Missile
Castor Rocket	Sea Sparrow Missile
Cruise Missile (TSSAM)	Short Range Attack Missile (SRAM), SRAM II
Delta II Rocket	Small Intercontinental Ballistic Missile
Extended Range Interceptor (ERINT) Missile	Standard Missile
Harpoon/Slam Antiship Missile	Titan IV Rocket Boosters
Hawk Missile	Tomahawk Cruise Missile
High-Speed Anti-Radiation (HARM) Missile	TOW (Tube-Launched, Optically-Tracked, Wire-Guided) Missile
Intercontinental Ballistic Missile (ICBM)	Trident D-5 Submarine-Launched Missile; Guidance System; Nozzle; Trident II

Source: OIRA Survey Data

Table 32: Other U.S. Military or Space Systems	
AN/SLQ-32 Electronic Warfare System	PASGT Helmet
Army Ordnance Program	PASGT Vest
Bradley Fighting Vehicle	Prototype Naval Shipboard Antenna
GPSIIR Satellite System	Prototype SDIO (now Ballistic Missile Defense Organization-BMDO)
Hubble Space Telescope	Shelters
M9 Armored Combat Earthmover	Space Shuttle
M109 Paladin Howitzer	Tank Ammunition 120mm
M113 Armored Personnel Carrier	

Source: OIRA Survey Data

Companies were also asked to identify any foreign-produced weapon systems or components for which they exported advanced composites since 1987. They were also asked to indicate the country or countries to which they exported. These weapon systems and countries are listed in *Table 33*.

Table 33:
Foreign Military Systems

Aircraft Systems	*Country*
A-129 Antitank Helicopter	Italy
Ching Kuo Fighter	Taiwan
Dassault Mirage Fighter	France
European Fighter Program	Germany, Spain
F-15 Eagle Fighter	Japan
F/A-18 C/D Fighter	Spain
JAS-39 Gripen Lightweight Fighter	Sweden
UH-60 Black Hawk Helicopter	Japan, South Korea

Missile Systems	*Country*
Harpoon Antiship Missile	Singapore, Taiwan
Patriot Missile	Japan
Popeye (Have Nap) Air-to-Surface Missile	Israel
VT-1 Hypervelocity Missile	France

Other Military Systems	*Country*
Mark 13	Canada, France, Italy, Spain
Missile Launch Pads	Japan

Source: OIRA Survey Data

Commercial Aircraft and Other Applications

Only a few companies reported shipments for applications other than military uses. Again, the information collected from these companies comprised too small a sample from which to draw meaningful conclusions. Companies who reported these non-military shipments listed endmarkets which included commercial aircraft applications, sports/recreation use, automotive, industrial (unspecified), and non-defense space structures other than ablatives. Most of these shipments were reported by foreign-owned sales organizations who participated in this assessment.

VIII. RESEARCH AND DEVELOPMENT EXPENDITURES

Companies provided information on their total research and development expenditures, and qualified these expenditures by source of funding. As can be seen from *Table 34* below, total expenditures grew rapidly between 1989 and 1991, rising by 73 percent from $80.8 million to $139.5 million; after 1991, however, total spending fell to $127.7 million. The table also shows a drastic change in the source of research and development funding. In 1989, private funds accounted for nearly 80 percent of expenditures; by 1993, private funds made up less than half of support for research and development.

Table 34:
Research & Development Expenditures
Total and % By Source of Funds
($ Millions)

	1989	1990	1991	1992*	1993*
Total R&D Spending	$80.8	$106.7	$139.5	$128.5	$127.7
% Private	79.1	65.5	53.7	48.6	47.4
% Public	20.9	34.5	46.3	51.4	52.6

* Forecast

Source: OIRA Survey Data

The next tables further detail the private and public sources of funds. As shown in *Table 35*, privately-funded research expenditures dropped five percent, from $63.9 million to $60.5 million between 1989 and 1993, while peaking at $74.9 million in 1991. Through the years, in-house sources made up the majority of private funding; however, the dominance of this source lessened somewhat, and domestic customers grew in importance, eventually representing more than a third of private funding. The other private sources remained fairly stable and not significant.

Table 35: Private Research & Development Funding Total and % By Private Source of Funds ($ Millions)					
	1989	1990	1991	1992*	1993*
Privately-Funded R&D	$63.9	$69.9	$74.9	$62.5	$60.5
% In-house	77.0	75.5	71.9	71.9	65.2
% Domestic Customers	19.9	21.4	25.8	26.7	33.8
% Foreign Customers	0.8	1.0	1.2	0.6	0.3
% Foreign Parent	2.3	2.1	1.1	NA	NA
% State, Local Govt.	NA	NA	NA	0.2	NA
% Domestic Parent	NA	NA	NA	0.6	0.7

* Forecast

Source: OIRA Survey Data

In contrast, as shown in *Table 36*, public funding of research skyrocketed between 1989 and 1993, particularly in the first two years. Funds from public sources grew by nearly 300 percent, rising from $16.9 million in 1989 to $67.2 million in 1993. The Department of Defense consistently accounted for the majority of the funding, while non-defense government entities never provided more than 19 percent of total public support. In the first two years, the Air Force played the largest role in defense backing of advanced composites R&D; then, in 1991, ARPA's support became more significant, accounting for over half of all DOD funds and, in 1992 and 1993, over half of total public support.

Table 36:
Public Research & Development Funding
Total and By Public Source of Funds
($ Millions)

	1989	1990	1991	1992*	1993*
Publicly-Funded R&D	$16.9	$36.8	$64.6	$66.0	$67.2
Department of Defense	$15.0	$29.7	$54.1	$61.4	$61.9
Air Force	$12.0	$16.6	$18.5	$19.5	$21.9
ARPA	$1.3	$9.9	$29.6	$35.4	$36.3
Navy and Army	$1.7	$3.2	$5.9	$6.4	$3.7
Non-Defense	$1.9	$7.1	$10.5	$4.7	$5.3

* Forecast

Source: OIRA Survey Data

Table 37 displays R&D spending by the three types of firms - - material suppliers, fabricators, and primes. For all three groups, expenditures generally increased over the period, with some fluctuation. The division of public and private funds for fabricators' R&D remained fairly constant between 1989 and 1993. However, for material suppliers and primes, private funds accounted for a decreasing proportion of total funds, by the end of the period. **Material suppliers relied almost entirely on private funding in 1989; by 1993, private funds made up less than half of support for R&D, again reflecting the financial hardship in this industry sector. For primes, private funding made up half of all funding in 1989; by 1993, these funds accounted for less than a quarter of support.**

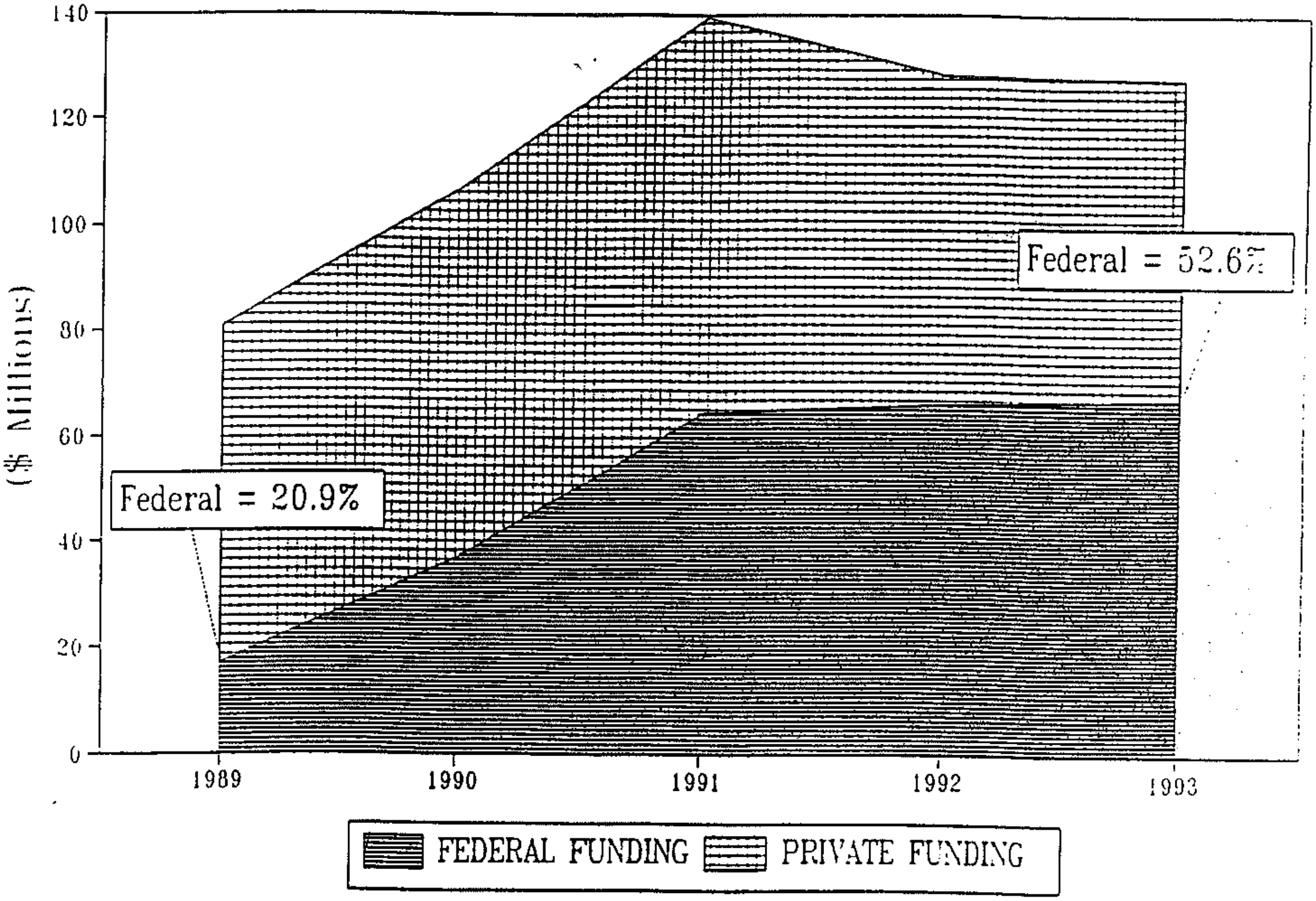
Table 37: Research & Development Expenditures Total and By Type of Firm ($ Millions)					
	1989	1990	1991	1992*	1993*
Total R&D Spending	$80.8	$106.7	$139.5	$128.5	$127.7
Material Suppliers R&D	$33.0	$46.6	$60.2	$55.3	$46.4
% Private Funds	98.1	75.4	52.5	48.0	47.6
% Public Funds	1.9	24.6	47.5	52.0	52.4
Fabricators R&D	$39.8	$46.9	$57.4	$46.9	$54.7
% Private	68.8	63.6	66.0	63.1	58.9
% Public	31.2	36.4	34.0	36.9	41.1
Primes R&D	$8.2	$13.2	$21.9	$26.3	$26.6
% Private	50.9	37.8	25.1	23.9	23.2
% Public	49.1	62.2	74.9	76.1	76.8

* Forecast

Source: OIRA Survey Data

Graph 21 summarizes the percentage shares of total R&D funding by the private sector and by the federal government during the review period.

Graph 21:
Total R&D Funding
Private vs. Federal
1989-1993



Source: OIRA Survey Data

Material Suppliers R&D Expenditures

Research and development expenditures were also analyzed by category of companies, material suppliers, fabricators, and prime contractors. Each category's expenditures were also studied by source of funding. In 1989 total R&D funding from all sources by material suppliers was $33.0 million, of which 98.1 percent ($32.4 million) was generated from private sources. The overwhelming majority of these private funds were generated in-house by the reporting material

suppliers, who accounted for 93.8 percent ($30.4 million) of the private total. Even when compared to the $33.0 million total 1989 R&D expenditures (both private and public), in-house funded accounted for 92.3 percent. The other sources of 1989 private funds were domestic customers (1.5 percent of private funds) and foreign parent corporations (4.6 percent).

Public funds accounted for only 1.6 percent of total 1989 R&D expenditures by reporting companies. This totals only $0.5 million. DOD accounted for the majority of these funds, 90.6 percent. These DOD funds thus accounted for only 1.5 percent of total reported R&D expenditures in 1989. The Navy provided the majority of this DOD funding, with $0.4 million or 89.6 percent of DOD funding. The Army accounted for the DOD balance. The non-DOD public funds of $50,000 were provided by NASA and an unidentified agency.

In 1990 total R&D expenditures increased 41 percent to $46.6 million, of which 75.4 percent were private funds and 24.6 percent public funds. The vast majority of the private funds of $35.1 million were generated in-house by reporting companies, with 93.8 percent or $32.9 million. The remaining private R&D funds came from domestic customers (1.9 percent) and foreign parent corporations (4.3 percent).

The Federal Government provided 24.6 percent of total reported R&D expenditures in 1989, up significantly from only 1.6 percent the year before. DOD's share of this total still comprised the vast majority of reported public funds, 98.0 percent, higher than the 90.6 percent from 1989. The actual dollar value was also much higher, from $0.5 million in 1989 to $11.2 million in 1990. ARPA represented the majority of DOD funding, 66.7 percent, totaling $7.5 million. The Air Force accounted for another 21.4 percent or $2.4 million. The Army and Navy accounted for the DOD balance of $1.3 million. The remaining public funds of $235,000 came from NASA and a third agency.

Total R&D expenditures in 1991 increased 29 percent over 1990 levels to $60.2 million, of which 52.5 percent were private funds and 47.5 percent public funds. The vast majority of the private funds of $31.6 million were generated in-house by reporting materials companies, with

87.3 percent or $27.6 million. This is a decrease from in-house funding levels of the year before. The remaining private R&D funds came from domestic customers (10.1 percent) and domestic parent corporations (2.5 percent).

The Federal Government provided 46.5 percent of total reported R&D expenditures in 1991, up from 24.6 percent the year before. DOD's share of this total still comprised the majority of reported public funds, 94.9 percent, a decrease from its 98.0 percent share in 1990. The actual dollar value of DOD funding is significantly higher, however, from $11.2 million in 1990 to $27.1 million in 1991, an increase of 141.5 percent. ARPA funding increased from $7.5 million in 1990 to $23.5 million in 1991, an increase of 213.3 percent. The ARPA funding comprised 86.6 percent of 1991 DOD funding. Funding by the Services also increased, with the Navy providing $2.2 million (8.3 percent) and the Army $1.4 million (5.1 percent). The remaining public funds came from NASA, which increased its funding to $0.6 million, and another agency, with $0.9 million.

The 1992 total R&D expenditures exhibited the first decrease in funding in comparison to the previous year. Funding declined by eight percent to $55.3 million, of which 48.0 percent were private funds and 52.0 percent public funds. The vast majority of the private funds of $26.5 million were generated in-house by reporting companies, with 85.0 percent or $22.6 million. This is a decrease of 18.2 percent from in-house funding levels of 1991. The remaining private R&D funds came from domestic customers (13.5 percent) and domestic parent corporations (1.5 percent).

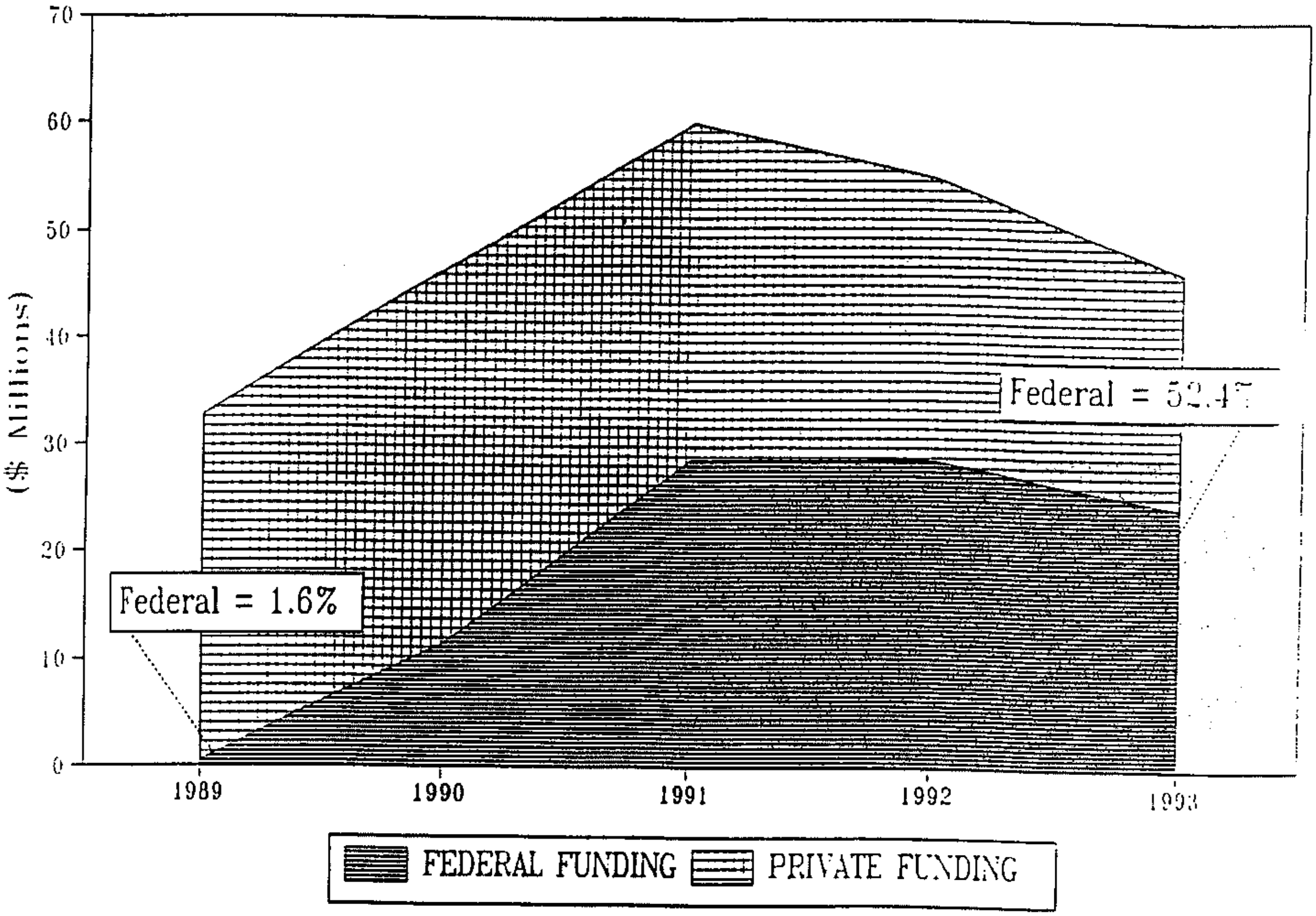
The Federal Government provided 52.0 percent of total reported R&D expenditures in 1992, up from 47.5 percent the year before. DOD's share of this total still comprised the majority of reported public funds, 98.8 percent, an increase over its 94.9 percent share in 1991. The actual dollar value of DOD funding is slightly higher, from $27.1 million in 1991 to $28.4 million in 1992. ARPA funding level was fairly constant at $23.4 million in 1992, 82.4 percent of DOD funding. Funding by the Army increased to $2.5 million, 8.9 percent of total DOD funding. The Navy's funding decreased from $2.2 million in 1991 to $1.6 million in 1992 (5.5 percent).

The Air Force provided $0.9 million or 3.2 percent of DOD funding. The remaining public funds came from NASA, which decreased its funding to $135,000 from $0.6 million the year before, and another agency, down to $202,000 from $0.9 million in 1991.

The 1993 total R&D expenditures exhibited another decrease in funding in comparison to the previous year. Funding declined by 16 percent to $46.4 million, of which 47.6 percent were private funds and 52.4 percent public funds. The majority of the private funds of $22.1 million were generated in-house by reporting companies, with 84.2 percent or $18.6 million. This is a decrease of 17.5 percent from in-house funding levels of 1992. The remaining private R&D funds came from domestic customers (14.0 percent) and domestic parent corporations (1.8 percent).

The Federal Government provided 52.4 percent of total reported R&D expenditures in 1993, up slightly from 52.0 percent the year before. DOD accounted for basically all of reported public funds, 99.9 percent, a slight increase from 98.8 percent share in 1992. The actual dollar value of DOD funding is slightly lower, from $28.4 million in 1992 to $24.3 million in 1993. ARPA was once again the major source of the DOD funds with $23.6 million in 1993. This accounts for 97.2 percent of the total DOD funding. Funding by the Services - - Air Force, Army, and Navy - - dwindled by 86 percent from 1992 levels, dropping from $5.0 million to $690,000 in 1993, representing only 2.8 percent of total 1993 DOD funding. The remaining public funds of $30,000 came from NASA, which decreased its funding from $135,000 the year before. *Graph 22* summarizes the percentage shares of material suppliers R&D funding by the private sector and by the Federal Government during the review period.

Graph 22:
Material Suppliers R&D Funding
Private vs. Federal
1989-1993



Source: OIRA Survey Data

Fabricators R&D Expenditures

The total funding from all sources in 1989 by fabricators was $39.8 million, of which 68.8 percent ($27.3 million) was generated from private sources. Over half (53.4 percent) of these private funds were generated in-house by the reporting fabricators, $14.6 million. Domestic customers were the other major source of private R&D funds, $12.2 million, 44.8 percent of total 1989 private funds.

Public funds accounted for 31.2 percent of total 1989 R&D expenditures by reporting companies, $12.4 million. DOD accounted for the majority of these funds, 89.5 percent, with $11.1 million. These DOD funds thus account for 27.9 percent of total reported R&D expenditures in 1989. The Air Force, in turn, provided the majority of this DOD funding, with $9.3 million or 84.1 percent of DOD funding. ARPA funded $1.0 million, while the Navy and Army accounted for the DOD balance of $0.8 million. The non-DOD public funds were provided by NASA at $1.1 million, with the remaining balance provided by Energy.

In 1990 total R&D expenditures increased 18 percent to $46.9 million, of which 63.6 percent were private funds and 36.4 percent public funds. Half of the private funds of $29.9 million were generated in-house by reporting companies, with 49.8 percent or $14.8 million. Domestic customers funded the bulk of the remainder with $14.3 million or 47.9 percent of the total. Foreign customers provided the remaining $0.7 million.

The Federal Government provided 36.4 percent of total reported R&D expenditures in 1989, up from 31.2 percent the year before. DOD's share of this total still comprised the majority of reported public funds, 65.5 percent, but this is much lower than the 89.5 percent from 1989. While the percentage is lower, the actual dollar value is slightly higher, from $11.1 million in 1989 to $11.2 million in 1990. The Air Force funded 88.4 percent or $9.9 million of this total. ARPA's funding dropped by half from 1989 to $0.4 million. The Army and Navy account for the DOD balance of $0.9 million. NASA provided $5.7 million, up from $1.1 million the year before. The remaining public funds of $200,000 came from Energy and another agency.

Total R&D expenditures in 1991 increased 22 percent over 1990 levels to $57.4 million, of which 66.0 percent were private funds and 34.0 percent public funds. In-house funding accounted for 55.0 percent of the total private funds of $37.9 million. This is a 40 percent increase over in-house funding levels of the year before. Domestic customers were once again the second largest source of private funds with 42.6 percent or $16.1 million. Foreign customers provided the private funds balance of $0.7 million (1.8 percent).

The Federal Government provided 34.0 percent of total reported R&D expenditures in 1991, down from 36.4 percent the year before. DOD's share of this total still comprised the majority of reported public funds, 62.1 percent, a decrease from its 65.5 percent share in 1990. The actual dollar value of DOD funding is higher, from $11.2 million in 1990 to $12.1 million in 1991, an increase of eight percent. The Air Force funded 88.5 percent or $10.7 million of this total. ARPA's funding dropped from $0.4 million in 1990 to $100,000 in 1991. Funding by the Army increased slightly to $200,000, while the Navy provided $1.1 million. The remaining public funds came from NASA, which increased its funding to $7.3 million, and another agency, with $100,000. No funds were reported from the Energy Department in 1991.

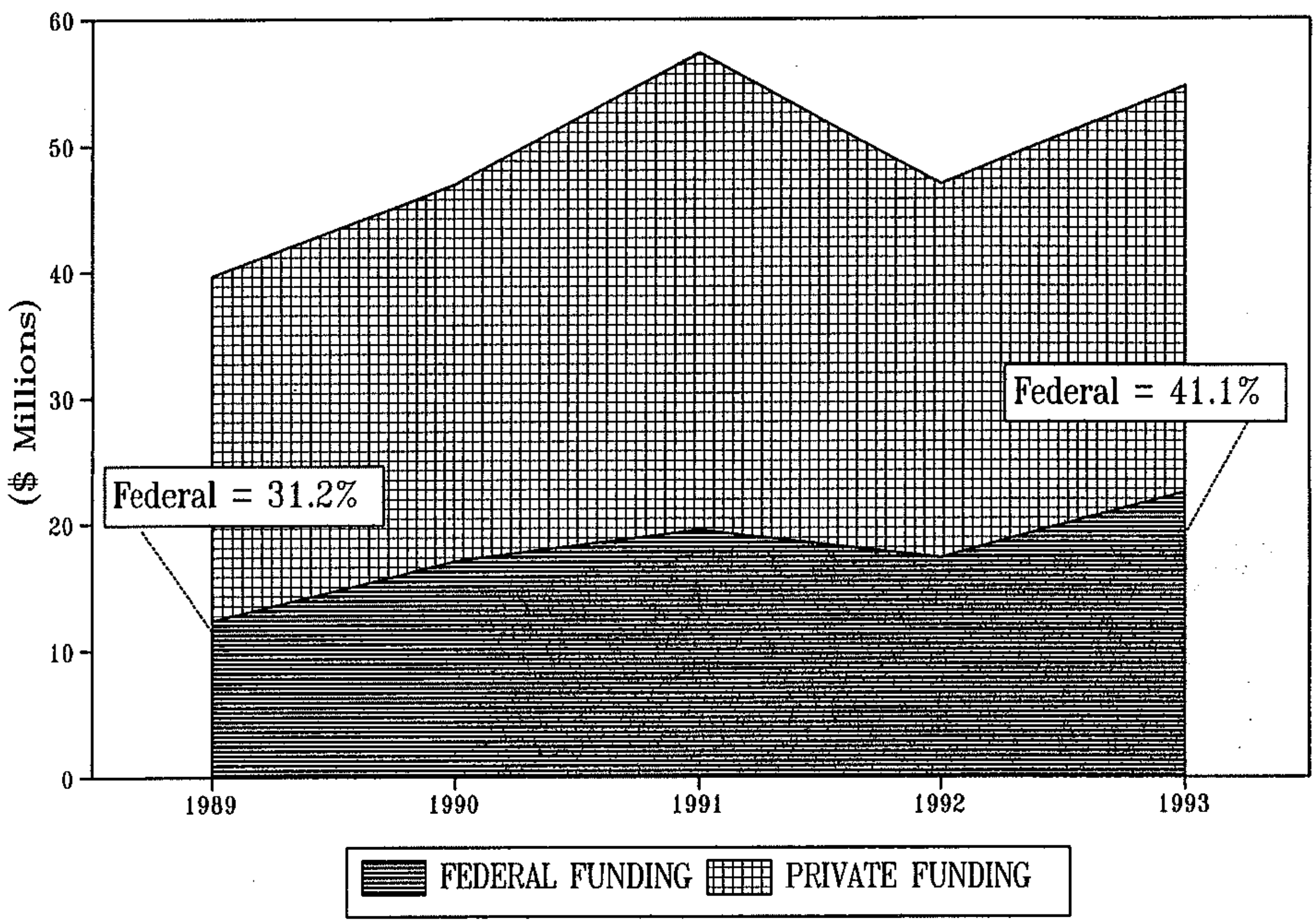
The 1992 total R&D expenditures exhibited the first decrease in funding in comparison to the previous year. Funding declined by 18 percent to $46.9 million, of which 63.1 percent were private funds and 36.9 percent public funds. In-house funding provided $16.1 million, or 54.2 percent of the total private funds of $29.6 million. This is a decrease of 22.8 percent from in-house funding levels of 1991. Domestic customers provided $13.1 million, or 44.1 percent of the total. The remaining private R&D funds came from foreign customers (1.3 percent) and state or local governments (0.3 percent).

The Federal Government provided 36.9 percent of total reported R&D expenditures in 1992, up from 34.0 percent the year before. DOD's share of this total comprised an increased majority of reported public funds, 85.5 percent, significantly higher than its 62.1 percent share in 1991. The actual dollar value of DOD funding is also somewhat higher, from $12.1 million in 1991 to $14.8 million in 1992, an increase of 21.2 percent. The Air Force funded 76.8 percent or $11.4 million of this total. ARPA's funding increased, climbing from $100,000 in 1991 to $2.1 million in 1992. Funding by the Army remained the roughly the same as 1991, 1.4 percent of total DOD funding. The Navy's funding increased slightly from $1.1 million in 1991 to $1.2 million in 1992 (8.0 percent). The remaining public funds came from NASA, which decreased its funding to $2.2 million from $7.3 million the year before, and the Energy Department with $0.3 million.

The 1993 total R&D expenditures recovered after the decrease the year before. Funding increased by 17 percent to $54.7 million, of which 58.9 percent were private funds and 41.1 percent public funds. In-house funding accounted for 45.5 percent of the total private funds of $32.2 million. This is a decrease of 8.8 percent from in-house funding levels of 1992. Domestic customers for the first time were the largest single source of private funding, with $17.4 million, or 53.8 percent of total private R&D. The remaining private R&D funds came from foreign customers (0.6 percent) and state or local governments (less than one percent).

The Federal Government provided 41.1 percent of total reported R&D expenditures in 1993, up from 36.9 percent the year before. DOD's share increased to 90.4 percent, an increase from 85.5 percent share in 1992. The actual dollar value of DOD funding increased from $14.8 million in 1992 to $20.3 million in 1993. Air Force funding rose to $13.9 million or 68.1 percent of this total. ARPA's funding more than doubled from $2.1 million in 1992 to $4.7 million in 1993. Funding by the Army dwindled to only $50,000 in 1993, representing only 0.2 percent of total 1993 DOD funding. Funding by the Navy was fairly constant, increasing from $1.2 million in 1992 to $1.7 million in 1993 (8.5 percent). NASA's funding decreased in 1993 in comparison to 1992, from $2.2 million to $1.4 million. The remaining public funds came from Energy, which increased its funding to $0.4 million from $0.3 million the year before, and another agency with $0.4 million. *Graph 23* summarizes the percentage shares of fabricators R&D funding by the private sector and by the Federal Government during the review period.

Graph 23:
Fabricators R&D Funding
Private vs. Federal
1989-1993



Source: OIRA Survey Data

Prime Contractors R&D Expenditures

Prime contractors also provided information on their total research and development expenditures, and qualified these expenditures by source of funding. The total funding from all sources in 1989 was $8.2 million, of which 50.9 percent ($4.2 million) was generated from private sources. All of these private funds were generated in-house by the reporting companies.

Public funds accounted for 49.1 percent of total 1989 R&D expenditures by reporting companies. This totals $4.0 million. DOD accounted for the majority of these funds, 86.3 percent, with $3.5 million. These DOD funds thus accounted for 42.3 percent of total reported R&D expenditures in 1989. The Air Force, in turn, provided the majority of this DOD funding, with $2.8 million or 79.7 percent of DOD funding. The Navy accounted for $0.4 million or 11.6 percent of the DOD total. ARPA accounted for the remaining $0.3 million DOD balance. The non-DOD funds of $0.6 million were provided by NASA and another Federal agency.

In 1990 total R&D expenditures increased 62 percent to $13.2 million, of which 37.8 percent were private funds and 62.2 percent public funds. As in 1989, all of the private funds of $5.0 million were generated in-house. The Federal Government provided 62.2 percent of total reported R&D expenditures in 1989, up from 49.1 percent the year before. DOD's share of this total still comprised the majority of reported public funds, 88.4 percent, up slightly from 1989. The actual dollar value is higher, growing from $3.5 million in 1989 to $7.3 million in 1990. The Air Force funded 59.3 percent or $4.3 million of this total. ARPA's funding increased almost seven fold from 1989, totaling $2.0 million. Funding by the Navy increased to almost $0.8 million, almost double the 1989 funding. The Army accounted for the DOD balance of $200,000. The remaining public funds came from NASA, whose funding was the same from the previous year, and another Federal agency whose funding doubled over 1989 levels to $0.8 million.

Total R&D expenditures in 1991 increased 66 percent over 1990 levels to $21.9 million, of which 25.1 percent were private funds and 74.9 percent public funds. All of the private funds of $5.5 million were generated in-house. This is a ten percent increase over in-house funding levels of the year before.

The Federal Government provided 74.9 percent of total reported R&D expenditures in 1991, up from 62.2 percent the year before. DOD's share of this total comprised 90.2 percent, an increase over its 88.4 percent share in 1990. DOD funding doubled from 1990 levels to $14.8 million in 1991. Air Force funding increased to $7.8 million or 52.7 percent of the DOD total.

ARPA's funding tripled 1990 levels, jumping from $2.0 million in 1990 to $6.0 million in 1991. Funding by the Navy increased to $1.0 million, while Army funding ended. The remaining public funds came from NASA, which increased its funding by one-third to $200,000, and another agency, with its funding increasing to $1.4 million.

The 1992 total R&D expenditures increased by 20 percent to $26.3 million, of which 23.9 percent were private funds and 76.1 percent public funds. All of the private funds of $6.3 million were generated in-house.

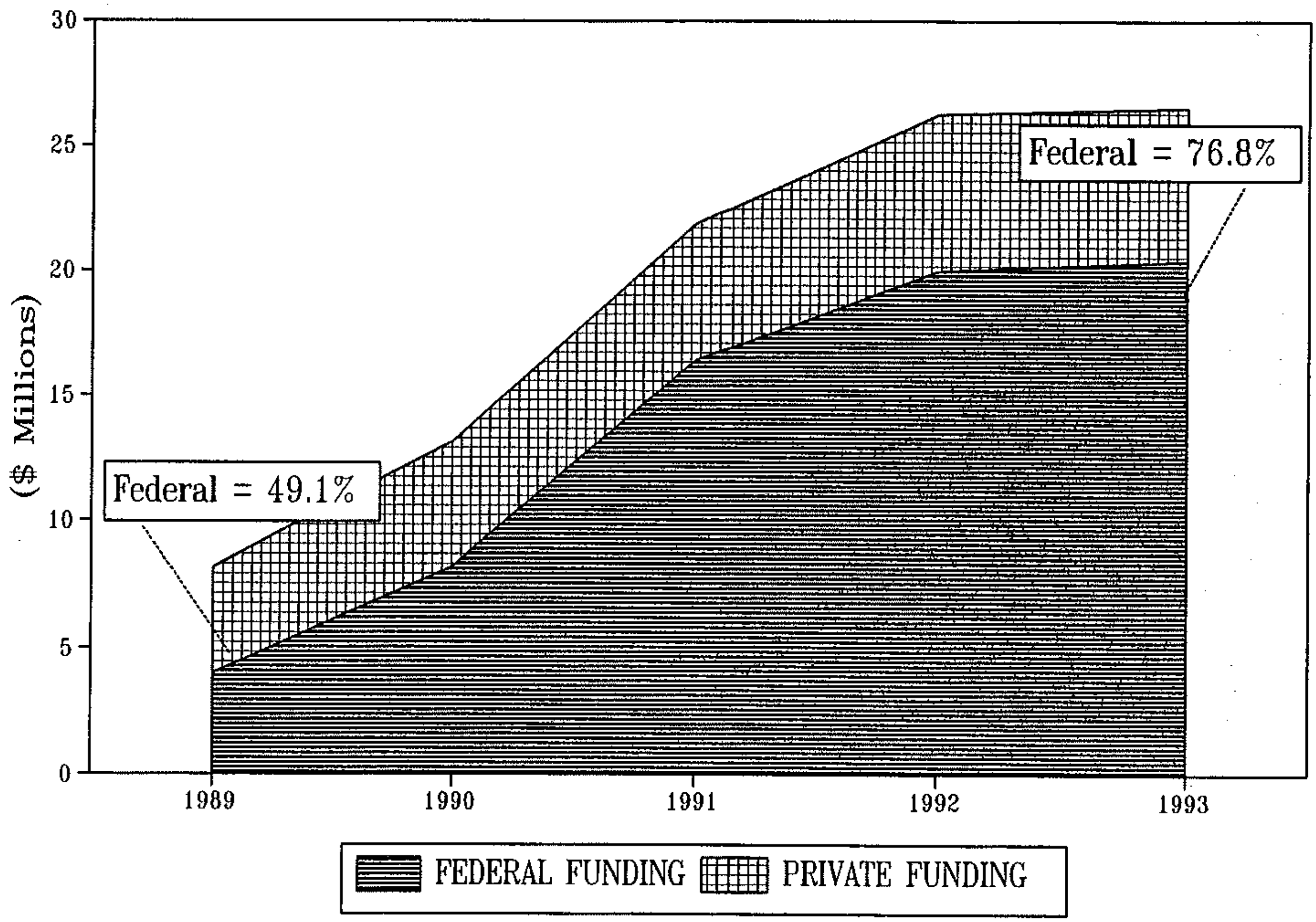
The Federal Government provided 76.1 percent of total reported R&D expenditures in 1992, up from 74.9 percent the year before. DOD's share of this total increased to 91.1 percent, up from its 90.2 percent share in 1991. The dollar value of DOD funding increased from $14.8 million in 1991 to $18.2 million in 1992. The Air Force funding decreased to 40.1 percent or $7.3 million of this total, a decrease both in percentage of total DOD funding and in actual Air Force funding. ARPA's funding once again increased, accounting for the largest portion of DOD funding, 54.9 percent. This funding climbed from $6.0 million in 1991 to $10.0 million in 1992. The Navy's funding decreased from $1.0 million in 1991 to $0.9 million in 1992 (4.9 percent). The remaining public funds came from NASA, which increased its funding to $225,000 from $200,000 the year before, and another agency, up to $1.6 million from $1.4 million in 1991.

The 1993 total R&D expenditures exhibited another increase in funding in comparison to the previous year. Funding grew by about one percent to $26.6 million, of which 23.2 percent were private funds and 76.8 percent public funds. All of the private funds of $6.2 million were generated in-house by reporting companies. This is a decrease of 2.0 percent from in-house funding levels of 1992, the first decline during the review period.

The Federal Government provided 76.8 percent of total reported R&D expenditures in 1993, up slightly from 76.1 percent the year before. DOD's share of this total comprised 84.8 percent of the DOD total, a decrease from 91.1 percent share in 1992. The actual dollar value of DOD

funding also declined, from $18.2 million in 1992 to $17.3 million in 1993. ARPA's funding decreased from $10.0 million in 1992 to $8.0 million in 1993, still accounting for the largest share of DOD funding, 46.2 percent. Air Force funding increased slightly to $7.8 million, 44.8 percent of the DOD total. Funding by the Navy increased from $0.9 million in 1992 to $1.6 million in 1993 (9.0 percent). The remaining public funds came from NASA, which increased its funding to $1.5 million from $225,000 the year before, and another agency, at $1.6 million. *Graph 24* summarizes the percentage shares of prime contractors R&D funding by the private sector and by the Federal Government during the review period.

Graph 24:
Prime Contractors R&D Funding
Private vs. Federal
1989-1993



Source: OIRA Survey Data

Impact of Defense Cuts on R&D

Thirty-five companies provided a variety of comments on the effect of defense cuts on research and development activities. Companies were asked what effect these reductions would have on their advanced composites business, and what steps they are considering to offset any negative impact that these reductions may have.

The most common response was that reduced overall sales correlate to reduced profits and reduced funds available for R&D. Fourteen companies mentioned this in some capacity; these companies tended to be the largest producers, indicating that those companies who account for the majority of domestic production are being hurt most by defense cuts. The next most frequently mentioned response came from twelve companies who reported that defense cuts will have no impact on their operations, primarily because of the small nature of these companies' business. Interestingly four of these companies did indicate that, while the cuts will not affect their operations directly, they will have the indirect effect of creating new competitors. Each of these four firms is engaged in various commercial or industrial sectors where traditionally defense-dedicated firms are now beginning to venture for the first time. One company indicated that government conversion assistance to defense companies would give those companies an unfair advantage.

Seven companies indicated that the defense cuts will impede product development in the advanced composites field. Comments ranged from specific examples, such as hampered development of CMCs for use in aircraft engines and high temperature structures for hypervelocity vehicles, to general sector comments such as the retardation of the entire emerging U.S. thermoplastics industry or the bismaleimide industry. One company indicated that it has had little success in converting to commercial markets because commercial customers cannot afford the necessary R&D for advanced composites. Most companies indicated that the government should continue to play a role in offsetting these high development costs and creating a market pull for this technology.

While companies reported that their R&D funding decreased commensurate with sales reductions, seven companies reported that a greater percentage of their falling R&D funds were being dedicated to commercial developments. Only three companies reported that the cutbacks are causing them to switch away from composites work. One indicated that it will not add any new resources to its composites business and may ultimately shift its current resources to its ceramics business. Another indicated that it is shutting down its R&D facility because of the reductions.

IX. OPERATIONS

A. Supplier Base

Respondents also provided information on a wide variety of issues pertaining to their production capabilities. This included identification by those companies who are sole or single source producers, companies who have sole and single source suppliers, and the related issue of shortages or other potential production bottlenecks.

1. Single and Sole Sources

Companies were asked to identify any defense-related advanced composite product for which they are considered a sole source or single source producer. A sole source producer is defined as the only available source for a given product, while a single source producer may not be the only available producer but is the only source used or qualified for a given product.

Seventeen companies provided responses to this question. Most companies further qualified the definitions of sole and single sources by reporting those items for which they are the sole or single DOD qualified producer. The DOD qualification process is typically lengthy and costly, which contributes to the creation of sole and single source producers and suppliers. Thirteen companies reported that they were a single DOD qualified producer for 33 specific weapon system uses. Two of these thirteen indicated that they support a range of defense products but were not more specific. Generally these companies explained that they were the only qualified producer because of previous experience with a given part or application, sometimes offered the lowest bid, and had the necessary tooling already in a given facility. None of these companies

indicated that the processes utilized are necessarily proprietary or unique. One company stated that they are simply the only one qualified to do the work, based on DOD specifications and drawings. *Table 38* lists the weapon systems supported by sole qualified source producers of some advanced composite component or part.

Table 38: U.S. Weapon Systems Supported by Sole Qualified Source Producers of Some Advanced Composite Product
Advanced Tactical Fighter (Fiber)
Antenna Window Preforms
Army Ordnance Program
AV-8B Harrier Fighter (Resin)
A-6 Intruder Aircraft (2 Fibers), Wing Component
B1-B Rotary Launch Tube
CFM56 Turbofan Engine Transcowl (Prepreg)
C-17 Transport Plane Wing Tip, Wing-to-Body Fairing
Delta-II Booster (Fiber)
F/A-18, C/D and E/F-18 Hornet Fighters (2 Fibers)
Inertial Upper Stage SRM-1/SRM-2 Nozzle Assemblies
MH-60K Black Hawk Helicopter Fuel Tank
MX Missile MK-21 Re-entry Vehicle Nosetip
Patriot Missile Radome
Peacekeeper Missile Motor Case
Small Intercontinental Ballistic Missile Motor Case
Third Stage Nozzle Materials
Titan Rocket Booster (Fiber)
Trident D-5 (Fiber), Nosetip, Trident II Nozzle Assembly
Tri-Service Standoff Attack Missile (Fiber)
Turbine Blade (for U.S. Air Force)
V-22 Osprey (2 Fibers)

NOTE: Companies provided varying levels of detail on weapon systems and/or items supplied.

Source: OIRA Survey Data

Four companies also indicated that they are the single qualified producer for other Federal non-military programs. One of these companies indicated that the product in question is an ablative; another indicated performing some function for General Dynamics for the NASP program. Another supplies several fiber types for space vehicle production.

In contrast, respondents reported only a few items for which they are sole sources. One company reported that it is a sole source for a specific type of nose cone used for missiles. The uniqueness is based on the proprietary material used for the cone production. Another company reported that it is a sole source producer of boron fiber for both military and non-military government programs, namely, several fighter aircraft and a nuclear satellite program.

There were many more responses from companies who identified sole and single source suppliers for manufacturing equipment and parts or materials used in connection with their advanced composites operations. Twenty-nine companies provided information on such suppliers. There were a wider variety of responses, with a broader range of reasons.

Eight companies reported that they have single qualified suppliers for fourteen specific items for DOD programs. Once again, this is attributed in part to the DOD qualification process. Only one of the eight companies reported an adverse impact on their operations should their supplier be lost. The item supplied would have to be designed and produced in-house, as there is no other available supplier. The difficulty rises in designing the item while avoiding patent infringement. Another of the companies indicated that replacing its single qualified supplier for a specific type of fiber would cost an estimated $500,000. Only one of the reported fourteen items is foreign-sourced. This foreign supplier is used because it is the qualified supplier and it is a sister company to the respondent. The respondent indicated that loss of this supplier for whatever reason would have no adverse impact, as an alternate U.S.-based supplier is available. The fourteen items reported are listed in *Table 39*.

Table 39: Items from Single Qualified Source Suppliers, U.S. Military Programs
Aircraft Brakes (Fiber, Resins)
Aircraft Nosecone Latches
A-6 Intruder Aircraft (Prepreg), Wing (Fiber, Resins)
C-17 Transport Plane (Prepreg)
F/A-18 Hornet Fighter (Fiber, Resins)
Resin Ingredient
Stainless Steel Honeycomb

NOTE: Companies provided varying levels of detail on weapon systems and/or items sourced.

Source: OIRA Survey Data

Two companies reported using single source suppliers for non-military government programs. Both companies use these suppliers in support of space applications. One company is involved in the Space Shuttle program; the other company reported using a single source foreign supplier because the company is a related party. This company also indicated that there is an alternate U.S. supplier available if needed.

Ten companies reported having single source suppliers for 19 different items not specifically for military programs. None of these respondents indicated that the loss of these suppliers would have an adverse impact on their operations. Several companies in this category reported having many single sources for various items, but did not identify the items sourced. Two of the unspecified items were sourced abroad. One company reported sourcing silicon carbide whiskers from a Japanese-owned U.S. company. The respondent indicated that the loss of this supplier would necessitate finding a foreign source of supply. No other foreign-sourced items were reported in this category. *Table 40* lists the identified items.

Table 40: Items from Single Source Suppliers, Not Specifically Military
Adhesives
Carbon Fiber, Pitch-Based Carbon Fiber
Carbon/Bismaleimide Prepreg
Methyl Trichlorosilane
Nomex Paper
Rayons
Rubber Compounds
S2 Glass Fiber
Silicon Carbide Whiskers

NOTE: Companies provided varying levels of detail on weapon systems and/or items sourced.

Source: OIRA Survey Data

Three companies reported having sole source suppliers for military programs. Loss of each of these suppliers would have an adverse impact on these companies' operations. One reported sourcing graphite tape from a sole source supplier; loss of this supplier would halt one of the company's six military production programs. Another company reported that E. I. DuPont de Nemours is its sole source for aramid fiber ("Kevlar", DuPont's registered trade name). The company indicated that U.S. Government would have to revise its procurement laws in order for them to replace DuPont as its supplier, should the DuPont product become unavailable and if an alternate fiber be located. The third respondent reported that a British company is its sole source for a case material for a specific missile program. The material is an aramid/epoxy prepreg (the aramid fiber once again being DuPont's Kevlar). The loss of this case material would shut down the company's missile production.

Thirteen companies reported having sole sources of supply for 19 items not specifically destined for military programs. Six companies indicated that the loss of suppliers for seven of these items would have a detrimental effect on operations. One company indicated that the loss of its sole source for phenolic resin would halt its production line until a new source could be generated. Another company reported that the loss of its supplier of specific materials and finishes for carbon fiber production could jeopardize its operations. One respondent's offshore supplier is its sole source for silicon carbide fiber; the loss of this foreign supplier would shut down all composite production. Three companies reported that the loss of their common foreign supplier of PAN fiber would have an adverse impact on their operations. One of these three stated that the loss would cause a short-term production interruption. Another maintained that their facility would be shut down until an alternate supply could be located. The array of items reported in this category are listed in *Table 41*.

Table 41: Items from Sole Source Suppliers, Not Specifically Military
Aramid Fiber ("Kevlar")
Boron Fiber
Boron Trichloride Gas
Carbon Fiber Materials and Finishes, Prepreg Materials, PAN-Based Carbon Fiber
Olive Drab Pigment
PEEK Prepreg
Phenolic Resin
S2 Glass Fiber
Silicon Carbide Fibers
Titanium Alloys

Source: OIRA Survey Data

The overall number of items reported as sole and single sourced is misleadingly high and denotes a greater dependency than actually exists. The DOD qualification process is one major reason for this misrepresentation. Another reason can be attributed to the proprietary material formulation used by companies which results in many advanced composite materials being essentially sole sourced, although other materials may have similar properties and be qualified to the same specification. As such, very few items reported in this section are truly sole sources. Only boron and silicon fibers are known to be valid sole sourced items, while all other items have competing products available on the market. Even DuPont's Kevlar, the predominant aramid fiber available, is produced at multiple production sites around the world and relies on DOD for a very small portion of their business.

2. Shortages of Supplies

Companies were asked if in the past five years they had experienced shortages or extended leadtimes in obtaining materials or supplies, machinery, or equipment that resulted in modifying or curtailing operations. Only five companies provided responses, with no common items identified. One company indicated that it has difficulty in obtaining silicon carbide fiber and has recently added a second supplier to try to alleviate the problem. Another reported a shortage of E-glass material, indicating a lack of awareness on the part of the respondent of the abundant domestic supply available. A third company reported long leadtimes on government-contract specified honeycomb and prepregs. The fourth firm indicated that a problem has developed with one supplier who is going out of business. The phase-out process will take between six months and two years, so the company has begun building its inventory as an interim effort while qualifying a new source. The fifth company reporting a problem indicated that acquisition of specification-grade pitch materials continues to require long lead times and compromises in the pitch characteristics. These materials are vital to the company's carbon/carbon composite production.

Based on these few reported shortages, it could be concluded that there are no major shortages affecting the industry, except for a few long leadtimes.

3. Key Equipment/Item Imports and Related Dependencies

Companies were asked to report their imports of key manufacturing equipment, components, parts, or raw materials needed for their advanced composites operations. They were also asked to indicate why a foreign source was used. Twenty-seven companies reported a total of 36 key items or types of equipment imported for a variety of reasons. The most frequently cited country of origin for these items and equipment was the United Kingdom, with 15 mentions. Japan was second, with 12, followed by Germany with six, France and Switzerland both with four, Russia with two, and Austria, Canada, and Italy each with one mention. Three items were reported foreign-sourced but the countries of origin were not reported.

Eight of these 36 items are types of equipment, as itemized in *Table 42* along with the country of origin. Three of these types of equipment, bandsaws, quartz tubes, and weaving looms, were reported to be a foreign dependency. The company which reported sourcing bandsaws and repair parts for bandsaws sources them from a related company in Luxembourg because of better quality and because the related companies use the same technology, machinery, and raw materials. For this reason the loss of supply of new bandsaws (should they be needed) or repair parts for currently equipment would terminate the company's domestic manufacturing operations. No measures could be taken to minimize this adverse impact, given the foreign parent's policy of using identical equipment, materials, and technology.

Quartz tubes were reported sourced from France and Germany because there is no known domestic source. An interruption in the supply of this key equipment would cause delays in the production of large parts, should the current equipment break or become unusable. No measures could be taken to minimize any adverse impacts. It is unknown to the company why there are no U.S. producers. The company which reported weaving looms indicated that it sources them from suppliers in Germany and Switzerland because there are no known domestic sources of supply. An interruption in supply of either replacement machines (if needed) or repair parts would require the firm to shut down its weaving operation, necessitating the purchase of woven broad goods. The company further explained that the looms are not produced in the United States because the U.S. is lagging in the technology.

Table 42: Key Manufacturing Equipment	
Type of Equipment	***Country of Origin***
Bandsaws and Parts	Luxembourg
Choppers	France
Fabric Cutter	Austria
PAN Reactor	Japan
PAN Spinnerettes	Japan
Quartz Tubes	France, Germany
Weaving Looms	Germany, Switzerland
Winder	Germany

Source: OIRA Survey Data

One company reported importing chopping equipment from France as well as the winder from Germany. Both machines were foreign-sourced because they are comparable with the equipment used by the company's foreign parent. The respondent who imported an Austrian fabric cutter did so because of better quality. The company which reported importing spinnerettes from Japan for PAN fiber did so because of lower cost and better quality. The reactor for PAN fiber was imported in order to duplicate the technology and because of lower costs.

The key equipment imports accounted for eight of the 36 reported imported items. Of the remaining 28 items, 17 were reported as foreign dependencies. These 17 items comprise ten different types of products. The most commonly mentioned products were **PAN fibers**, which were reported as a foreign dependency by five different companies. Interestingly, one of these firms sourced from a Japanese firm, while the remaining four companies reported sourcing from a single Asian-owned European company. The company sourcing from Japan does so because it knows of no domestic source. Domestic PAN precursor plants are available and have been

DOD qualified, although domestic PAN is typically higher priced than foreign-made product.

Three of the other four companies reported that they source from the European firm because there are no known domestic sources of supply. Each reported that an interruption in supply would shut down their operations until alternate sources could be found. One of these firms indicated that it has attempted in vain to interest U.S. acrylic fiber manufacturers in developing a suitable PAN (acrylic) precursor. It suggested that a more coordinated approach, with U.S. Government backing, would be more effective. At present the volume of PAN (acrylic) precursor required by any single U.S. carbon fiber producer is not adequate to justify a special effort on the part of existing U.S. acrylic fiber manufacturers. One of the other firms stated that the United States simply is not competitive, hence the lack of domestic production. While respondents questioned the availability of domestically-produced PAN precursor, it is known that domestic production exists. The issue thus becomes one of awareness rather than of foreign dependency.

The remaining company reported sourcing PAN fibers for brake manufacturing because the British company has a lower price and domestic sources are inadequate. The company further reported that an interruption in its British supply would stop its brake production until an alternate yet more costly process could be installed. Such conversion would take more than a year. To offset the loss of supply, the company would seek alternate sources, citing Japanese suppliers. The company indicated that there is an insufficient domestic market for PAN fiber used for brake manufacturing to sustain multiple, cost-competitive domestic suppliers.

Several **other fibers** were also reported as foreign dependencies. One firm sources a ceramic fiber from a British company because domestic sources are inadequate. The loss of this material would adversely impact the company's fiber composites manufacturing until an alternate fiber source could be located. The company indicated that this fiber is not produced in the United States because of the high costs of market entry. Another company reported sourcing silicon carbide fiber from a British company because there is no domestic source. The impact of the loss of this supplier is questionable at this point, as the product that the company is producing

from this fiber has not yet been introduced to the market. Another supplier would have to be located. The fiber is not produced in the United States because of the minimal demand for it. As with the PAN precursor discussed above, these identified dependencies can be attributed in large part to a lack of awareness rather than an actual dependency on foreign sources of supply.

Another respondent reported sourcing silicon carbide from both Russia and the United Kingdom because domestic sources are inadequate. Purchases of boron were also reported from both Russia and the United Kingdom, again because domestic sources are inadequate.

Several **resins** were also reported as foreign dependencies; in all cases, the loss of the foreign source would halt production. Two companies reported sourcing bismaleimide components from Germany and the United Kingdom because they know of no domestic sources. One of the firms indicated that it has entered a venture to jointly produce the monomer and polymers offshore; this new source of supply will then satisfy the company's domestic requirements. The other firm indicated that the loss of its foreign supply of BMI components would result in delays in production for certain AV-8B Harrier fighter parts. Locating a new supplier would require requalification of the alternate resin, as well as the Navy's approval. The resin is not produced domestically because the requisite patents and licenses are all held by foreign companies.

Another firm reported foreign sourcing cyanate esters because there is no known domestic source. The loss of this supply would halt the company's sales of a specific product line. To offset any delay in shipments or the possible loss of the supplier, the company typically maintains at least a six month inventory. This has been an effective policy over the past five years. Sales of the product lines involved are too small to justify the investment in building domestic manufacturing capability, so the company has a sourcing agreement with the Swiss supplier, who has the capital equipment in place to manufacture cyanate ester resins.

One other company reported sourcing resin materials from two companies in Japan and one in Germany because there are no known domestic sources. An interruption in supply of these materials would seriously jeopardize the company's operations because locating a substitute

supplier would be difficult. Even if such a supplier could be located, the materials would required requalification, a process that takes months. This situation could be avoided if the U.S. Government maintained a stockpile of strategic resin raw materials and implemented easier requalification procedures. The company further reported that it uses foreign suppliers because no U.S. manufacturer would devote the long term resources to make these materials available as a standard product, primarily because the start-up costs are too high and the return too uncertain.

Two companies reported **prepregs** as foreign dependencies to their operations. One company sources a prepreg from a Swiss-owned company in the United Kingdom because there are no known domestic sources. An interruption in supply would halt the production of key commercial programs, as the material is sole source qualified from the British supplier. The other company sources a prepreg tape from a French-owned Canadian company because there are no known U.S. producers. An interruption in supply would cause the company to stop production of certain products until the tape could be produced in-house. The company indicated that it has the impregnation technology to do this, yet it would take time to implement in-house production. A list of all materials reported as foreign dependencies, as well as their country of origin, is provided in *Table 43*.

*Table 43: Perceived Foreign Dependencies of Key Material Imports**	
Type of Material	***Country of Origin***
Bismaleimide Components	Germany, United Kingdom
Boron	Russia, United Kingdom
Ceramic Fiber	United Kingdom
Cyanate Ester Resins	Switzerland
PAN Precursor	Japan, United Kingdom
Prepreg, Prepreg Tape	Canada, United Kingdom
Resin Materials	Germany, Japan
Silicon Carbide	Russia, United Kingdom
Silicon Carbide Fiber	United Kingdom

* The phrase "Perceived Foreign Dependencies" is used because in most cases the use of foreign sources is attributed to the non-availability of DOD-qualified sources, costs, and lack of awareness, among other factors.

Source: OIRA Survey Data

There were a number of other items which were foreign sourced for a variety of reasons, yet were not reported as foreign dependencies. The most frequently mentioned item in this category is carbon fiber, which three companies reported sourcing from a single company in Japan. (One company reported that it also sources from a second Japanese producer.) Another company reported sourcing PAN fiber from a British supplier. This is the only company who did not report PAN fiber as a foreign dependency, although it sources from the same Japanese-owned British company that was reported by four other companies mentioned in the PAN fiber discussion earlier. *Table 44* lists all the non-foreign dependent items or materials reported, as well as their country of origin and the reason(s) that they are foreign-sourced.

Table 44: Key Material Imports, Non-Foreign Dependencies		
Type of Material	*Country of Origin*	*Reason Foreign-Sourced*
Carbon Fiber	Japan	(1) Better Quality (2) Lower Price
Fiber Tape	United Kingdom	(1) Supplier Required by Customer
Fused Quartz Rod	France	(1) Lower Price (2) DOD Qualified Supplier
Graphite Fiber	Unspecified	(1) Supplement domestic supply (2) Lower Price (3) Faster Delivery
Paint	Germany, United Kingdom	(1) Suppliers Required by Customer
PAN Fiber	United Kingdom	(1) Supplier is Original Qualifier on DOD Program
Rayon	Japan	(1) Lower Price (2) Better Quality
Sealant	France	(1) Supplier Required by Customer
Silicon Carbide Whiskers	Japan	(1) Better Quality
Tungsten Wire	Japan	(1) Better Quality

Source: OIRA Survey Data

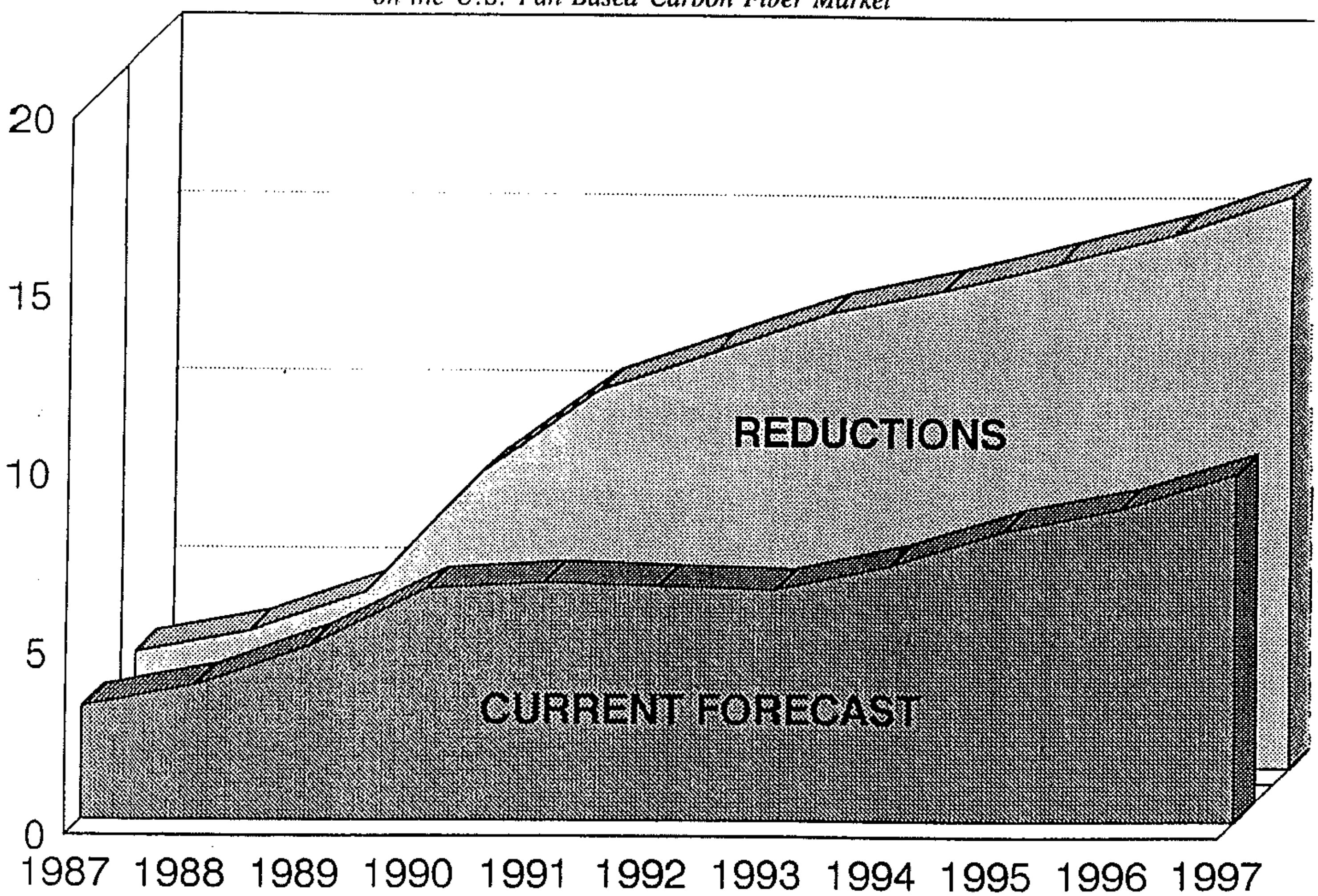
B. Federal Customer Base

Most of the companies who participated in this assessment are suppliers to the U.S. Government in some capacity, predominantly to DOD but to other Federal agencies as well. Companies were asked a series of questions regarding their business with the Federal government.

1. Impact of Defense Cuts

Comments by study participants on the impact of defense cuts on their R&D activities were discussed earlier in the research and development section. Respondents were, however, asked what impact defense cuts would have on their entire business. Forty-four companies provided comments in this area. There is no question that defense cutbacks are having a negative impact on the advanced composites industry. SACMA has indicated that in the PAN-based carbon fiber market alone, business in 1993 is only half anticipated levels, as indicated in *Graph 33* below.

Graph 25:
Impact of Defense and Commercial Aircraft Reductions on the U.S. Pan-Based Carbon Fiber Market



Source: Suppliers of Advanced Composite Materials Association

Six of the 44 companies responding reported that defense cuts will have no impact on their operations. An additional five companies indicated that, while defense cuts will not affect them directly, their market shares are threatened because defense companies are now entering their traditional commercial markets, increasing competition. One of these companies indicated that defense firms are cutting prices to the commercial sector in order to establish market share, to the detriment of everyone.

The most common response came from 27 companies who all indicated that their sales have declined. Corporate sales reductions ranged from a 10 percent reduction in sales for one respondent to 48 percent for another. Twelve firms reported declines in all lines of business. One of these firms indicated that sales were down even in the commercial aerospace sector, which is suffering from the impact on the economy of the significant defense cutbacks. Another of these firms indicated that the sales decline it is experiencing is resulting in increased costs, which in turn decreases the company's ability to expand into commercial markets. Three companies reported declines specifically in their carbon fiber business; one of these firms reported that its carbon fiber sales have dropped 78 percent from its projections in 1987. Two companies reported major drops in sales of helmet and other armor lines.

Other companies reported specific lines of business that have been adversely affected. One company reported a loss of sales for titanium-based composites, which may prohibit the company from staying in this market segment. Another reported reduced sales for missile exhaust tube applications and helicopter rotor blade applications. Yet another firm reported that its sales volume has dropped on composite ablative materials, making it prohibitive to stay in this line of business. Other lines of business which have been adversely affected include missile component section sales down 50 percent; CMC line of business down, resulting in stagnant corporate sales with no foreseeable growth potential; engine spare parts business down; decline in cyanate ester resin business, where the company may not recover its investment; sales down for all carbon/carbon materials; business for test cells dropping off; aircraft spare parts business cut by one-half; structures business experiences sales decline of 30 percent; and sales reductions for motor casings.

With these sales reductions have come comparable drops in employment and in expertise. Twenty-two companies mentioned these areas. Nine of these companies, however, reported that, in spite of reduced sales, they will not lose expertise. One of these firms attributes this to its commercial/defense sales mix, which will minimize any loss in expertise or employment. Another indicated that it is retaining its expertise by transferring its military aerostructures production technology to commercial aircraft applications. Yet another firm indicated that it will retain its expertise, although it is doing so with fewer employees. Another firm reported a similar pattern, where it will not lose a specific expertise but it will drastically reduce employment because of the major loss of business. The company reported that this downsizing will have an enormous impact on employment and the economy of their entire community.

Most of the other respondents reported varying levels of expertise and employment loss as a result of defense cuts. One company reported the first layoffs in its history. Another reported losing 50 percent of its workforce; if the company's sales were to recover, it would be necessary to train any new employees that it hires. One firm indicated that its level of business has been cut in half. Its employees are leaving not just the company but the industry, further hurting future uses for and developments of advanced composites.

Areas where companies reported a loss in expertise include filament winding; high temperature composites and low observable material systems; large scale processing of C/Cs and CMCs; coatings for MMCs; and thermoplastic prepregs and epoxy resin prepregs. A loss of procedures as well as expertise for radomes and thermal barriers on high speed missiles was also mentioned. One company reported a reduction in all engineering expertise, while another mentioned reduced expertise in all areas, from design engineering to skilled labor.

Nine companies reported that the cutbacks will hurt further technical developments in the industry. One company explained that **military programs have driven numerous technological advances in the advanced composites business. The cuts will not cause technologies to be lost, but they will cause the full costs of future technological advances to be borne entirely by civilian industries, which are unable to afford the investment necessary.** Another

company indicated that the defense cuts will eliminate any new use of advanced composite materials in commercial aircraft. Respondents reported several product-specific adverse impacts resulting from the reductions: slower development of new applications for C/C and CMC materials; loss of market for ultra-high modulus pitch fiber prepregs dependent on SDI follow-ons; serious restrictions on development funding for MMCs and CMCs; limited application of new fiber placement fabrication technology; thermoplastic prepreg development dependent on one Air Force program in danger of being eliminated; epoxy resin prepreg developments dependent on a similar Army program; and impairment of pitch fiber process development.

There were also a few specialized comments from several companies. One firm reported that it is focusing more on diversifying away from defense work, but expressed concern from a national security viewpoint that their ability to gear up for significant production of defense components, should the need ever arise, will be diminished. Another firm reported that little of its advanced composites work is in the defense arena. The company in fact has identified certain defense projects on which it plans to bid as a new market niche, but sees it market entry as becoming more difficult given the more aggressive marketing efforts by already existing defense suppliers.

Another issue that was raised was that of the Federal Acquisition Regulation on PAN fiber. Congress passed a law, PL100-202 Section 8088, which requires carbon fiber producers to domestically produce a certain portion of PAN fiber. Domestic carbon fiber producers built and/or expanded domestic PAN facilities in compliance with this law. These plants were used to produce carbon fiber for many of the DOD systems which have subsequently been stretched out or canceled. The defense cutbacks have now led to severe overcapacity and a tremendous financial burden for carbon fiber producers.

2. Defense Conversion Awareness and Need

Companies were asked if they are aware of any Federal, state, or local government defense conversion programs. Fifty-three companies provided responses, with the vast majority, 49 firms, indicating that they were unaware of any such efforts. Only four companies indicated that

they had knowledge of such programs, citing the Trade Adjustment Assistance Act, the Federal program Manufacturing 2000, conversion programs provided through the U.S. Air Force, and the 1992 Defense Conversion and Reinvestment legislation.

In March 1993 President Clinton announced an initiative to distribute the $1.4 billion appropriated by the Congress in 1992 plus an additional $300 million. About $500 million will be available this fiscal year for the Technology Reinvestment Program (TRP), an interagency project to accelerate the application of military technology to civilian manufacturing, develop extension programs and partnerships, and support education for manufacturing employees.[46] Advanced composites are included in the TRP redbook as a suggested proposal activity area. ARPA is coordinating the TRP, whose members include the National Science Foundation, the Department of Energy, NASA, and Commerce's NIST. ARPA has already begun sponsorship of the Advanced Composites Technology Consortium, one of eight consortium which are receiving ARPA funds. NIST researchers of high-performance composites are also a part of the TRP program.[47]

As a follow-up question, respondents were also asked what the Federal Government could do to assist in defense conversion efforts. Fifty companies responded, with the most frequent answer from fourteen defense companies offering suggestions for new Federal funding programs, the most common being to provide Federal R&D funds for commercial applications. Seven companies suggested education and training assistance, ranging from retraining, financial aid, and outplacement assistance for current employees to more assistance to local public schools and vocational centers to improve the quality of education for the next generation of employees. A number of SACMA members cited that organization's market pull statements, which call for the

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[46] "NSF Welcomes Role in President's Defense Conversion Initiative." PR Newswire. March 12, 1993.

[47] U.S. Department of Defense, Advanced Research Projects Agency. Program Information Package for Defense Technology Conversion, Reinvestment, and Transition Assistance. Arlington, Virginia: ARPA. March 10, 1993. pp. A-3, D-2, and D-5.

creation of demonstration and utilization progarms for parts made from advanced materials that can be introduced into a wide array of systems critical to U.S. industries, such as aerospace, chemical, construction, electronics, energy, environmental control, industrial processes, marine, medical, recreational goods, and surface transportation. Each government agency could play a role based on its specific charter and budget to stimulate the adoption, production, and field experience with advanced material products.

Six companies suggested that the Federal Government could provide assistance in locating new customers and/or suppliers. Two firms suggested a continuation or modification of existing Federal programs. One of these suggestions is to continue to support existing initiatives like the NASP program that would have positive repercussions for U.S. industry. The other suggested that DOD move to long-term contracts rather than annual buys and establish civilian technology demonstration programs.

Two other firms suggested that the U.S. Government provide tax incentives to stimulate reinvestment in non-military areas for advanced composites. One company indicated that Government assistance in defense conversion would be unfair and detrimental to current non-defense dedicated companies.

3. Dual Uses

Companies were asked what efforts the Defense Department has made to expand its use of commercially viable advanced composites, and were then asked in what ways Defense could do more. Thirty-five companies provided responses.

Twenty companies responded to the first question, identifying what efforts DOD has made to expand use of commercially viable advanced composites. The majority of these companies, 18 of the 20, reported that DOD has done nothing thus far. Two companies indicated that DOD has worked only with major prime contractors in this area and has provided no guidance or expressed any interest in small subcontractors. Another company reported that it has seen little DOD support or interest in dual use applications for its advanced carbon, MMC, and CMC

materials. One firm has discussed some applications that it has developed with DOD but there was no resulting activity. This firm indicated that DOD-type applications are very slow in developing and little interest is exhibited in changing them. It further stated that DOD is impressed with bigness, not cleverness. Several companies reported that DOD has made no efforts to implement the public law mentioned earlier which requires the use of domestically produced PAN fiber. These companies complain that DOD's failure to implement this law has hurt their businesses, and that DOD seems uninterested in helping these domestic companies or accepting some responsibility for the state of this industry sector.

In contrast, two companies reported that DOD has had some success in promoting commercially viable advanced composites. They reported that DOD programs like the B-2 bomber and the C-17 transport plane use a much higher percentage of advanced composites than previous military aircraft. This increased usage by DOD encourages commercial manufacturers to increase their use of advanced composites based on the reliability and service history established in military programs.

Twenty companies provided suggestions on what ways DOD could do more to expand its use of commercially viable advanced composites. The most frequently mentioned suggestion was to provide more funding. Eight companies mentioned this. Three companies suggested that DOD provide R&D grants for commercially viable products. Three other companies suggested that DOD fund demonstration and insertion projects in areas such as aircraft engines, aircraft wings, composite natural gas fuel tanks for vehicles, composite portable bridges, and general DOD infrastructure projects. These programs would help industry reduce production costs and promote commercial use. Another company indicated that funding should be continued and increased for multiple years for such "transition" programs as the NASP program, which would help high speed civil transport developments, and the Integrated High Performance Turbine Engine Technology program. This company further suggested that DOD should create a central office that focuses on these efforts.

The suggestion for a central technology development office was reported by several other firms who suggested that DOD/ARPA should lead in the development and implementation of new technology. Development and implementation assistance was the second most frequently mentioned suggestion, with seven companies providing a variety of ideas in this area. Two companies advocated the coordination of defense and commercial technology activities under a central agency, a theme which SACMA also supports. They cite ARPA as an example of how such an agency should work. Creating a central office would allow DOD to draw easily from the commercial sector to meet national security needs and would also allow DOD to contribute substantially more to the nation's commercial performance and growth of the economy. The focus of the office should continue to support military-only technology but would expand to include dual-use technologies. Another company commended ARPA's development program for civil structure applications and suggested additional commercial programs.

A firm suggested that DOD should encourage use of pultruded, filament wound, and injection molded components containing carbon fibers in epoxy, polyester, and thermoplastic polymers, all of which are commercially viable forms of composites. These materials could be widely used to reduce the weight of military equipment and substantially improve mobility. An increased rate of development and much shorter times to introduction could be of significant benefit to the advanced composites industry. Another firm suggested that DOD should take steps to assure the continued development of high temperature composites.

Seven companies also suggested that DOD promote the use of standards and/or revise its standards to promote commercial uses. One company suggested that DOD publish its test matrices for qualified materials. Another encouraged DOD to use more "flyable" parts, even if the design is simple and there is a slight weight penalty. This would increase the volume of advanced composites production and allow suppliers to develop acceptable manufacturing methods and quality standards. Another company had a similar suggestion, stating that DOD should use some of the more affordable technologies available instead of pursuing exotic technologies for airframe uses. One company suggested that DOD should do more technology transfers to the commercial aerospace sector. Another firm stated that DOD should review the

qualification process and requirements for domestic PAN fibers, a topic that was mentioned by several other companies earlier. Yet another firm indicated that it would welcome DOD assistance in promoting fused quartz composites for commercial applications.

Two companies suggested that DOD should do more work directly with small companies, bypassing the prime contractors. Another company suggested that DOD keep a low level procurement ongoing in order to maintain the composites base.

C. Competitiveness

Domestic Competitors

Companies were asked to identify their major competitors, both domestically and abroad. A number of companies requested that we maintain the confidentiality of their competitiveness rankings. For this reason all companies mentioned as major competitors have been tabulated together, along with the number of times each was mentioned.

There were 129 different companies reported as major domestic competitors. Eighteen of these companies, roughly 14 percent, are foreign-owned companies. The number of times these 129 companies were mentioned totals 301; the 18 foreign-owned companies were mentioned 82 times, or 27 percent of total mentions. A tabulated list of the top ten reported domestic competitors is presented in *Table 45*. As can be seen from the types of companies cited, material producers were most frequently mentioned, rather than fabricators or prime contractors.

Table 45: Top Ten Domestic Competitors Reported	
Company	***Number of Times Mentioned***
Hercules	16
Ciba-Geigy	15
Hexcel	14
BASF	10
Heath Tecna Aerospace	10
ICI Fiberite	10
BP/Hitco	9
Amoco Performance Products	8
Brunswick Defense Systems	6
Northwest Technical Plastics	6

Source: OIRA Survey Data

2. Foreign Competitors

Responding companies also provided information on who they consider to be their major foreign competitors. There were 64 different companies reported from 19 different countries. Only three of these companies, roughly five percent, are U.S.-owned firms. The number of times these 64 companies were mentioned totals 121; the three U.S.-owned companies were mentioned only five times, or about four percent of total mentions. The tabulated list of the top ten foreign competitors reported, their country of operation, and the number of times each company was mentioned is presented in *Table 46*. The companies are ranked by the number of times mentioned. As was seen with domestic competitors, material suppliers dominate the list.

Table 46: Top Ten Foreign Competitors Reported		
Company	*Country*	*Number of Times Mentioned*
Toray Industries	Japan	11
Ciba-Geigy	France Switzerland United Kingdom	7 (1 French, 4 Swiss, 2 British)
Mitsubishi Rayon	Japan	6
Westland Aerospace	United Kingdom	5
ICI Fiberite	Germany United Kingdom	4 (1 German, 3 British)
Toho Rayon	Japan	4
BASF	Germany	3
RK Carbon Fibers	United Kingdom	3
SIGRI	Germany	3
Société Européene de Propulsion	France	3

Source: OIRA Survey Data

The information on major foreign competitors was also tabulated by country. *Table 47* ranks each country by the number of times it was mentioned and also lists the number of individual companies identified in each country.

Table 47: Nationality of Major Foreign Competitors		
Country	*Number of Times Mentioned*	*Number of Companies*
Japan	43	20
United Kingdom	23	12
France	12	10
Germany	11	6
Switzerland	5	2
Israel	4	3
South Korea	4	3
Australia	3	2
Spain	3	2
Ireland	2	1
Italy	2	1
Singapore	2	1
Austria	1	1
Belgium	1	1
Brazil	1	1
Canada	1	1
Luxembourg	1	1
Netherlands	1	1
Sweden	1	1

NOTE: The number of companies listed is greater than the number of corporate entities listed earlier. Some companies were reported in more than one country, hence the higher count.

Source: OIRA Survey Data

Appendix 1

U.S. Department of Commerce
Bureau of Export Administration

OMB Control # 0694-0077
Expires 12-31-92

CRITICAL TECHNOLOGY ASSESSMENT: ADVANCED COMPOSITES

PURPOSE OF THIS ASSESSMENT

This critical technology assessment was initiated under Section 825 of the Defense Authorization Act of 1991. Section 825 requires the Department of Defense and Department of Commerce to submit an annual report to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of industries supporting the Department of Defense's (DOD's) list of 21 critical technologies. This report will also be released to the public.

The objective of this assessment is to provide government policymakers and industry planners with needed information and analysis on the advanced composites industry, a sector which DOD has deemed essential to the development of the next generation of weapon systems needed to ensure our national security. In completing this survey your firm will assist the U.S. Government in understanding the consequences of DOD spending cutbacks for your sector as well as the opportunities for defense conversion activities.

YOUR RESPONSE IS REQUIRED BY LAW

Your report is required by law (50 U.S.C. App. Sec. 2155 and Presidential Executive Order 12656). Failure to report can result in a maximum fine of $1,000 or imprisonment up to one year, or both. Information furnished herewith is deemed confidential and will not be published or disclosed except in accordance with Section 705 of the Defense Production Act of 1950, as amended (50 U.S.C. App. Sec. 2155). Where appropriate, information and material submitted should be designated "BUSINESS CONFIDENTIAL."

Please note that no business proprietary information will be released under a Freedom of Information Act request.

If, during 1989-1991, your firm did not produce or use the advanced composite materials listed in the enclosed *Critical Technology Assessment: Advanced Composites List of Product Codes*, you are not required to complete this form. If this is the case, please provide the information requested below and return this page only by FAX or mail (the remainder of the form may thus be discarded):

______________________________ ____________________
Printed Name & Signature of Authorized Official — Date

______________________________ ____________________
Name of Company - Please Print — City/State

____
Telephone

Please return this completed form by Monday, December 7, 1992.

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Appendix 2

CRITICAL TECHNOLOGY ASSESSMENT: ADVANCED COMPOSITES
LIST OF PRODUCT CODES

MATERIAL TYPE

1. <u>Fibers</u>

- 1-A. Carbon Fibers
- 1-B. Ceramic Fibers:
  - 1-B-1. Silicon Carbide/Silicon Aluminum Fibers (non-oxide)
    - 1-B-1a. organic precursor
    - 1-B-1b. CVD onto carbon fiber
    - 1-B-1c. sintered silicon carbide
  - 1-B-2. Oxide Fibers
  - 1-B-3. E-Glass Fibers
  - 1-B-4. Whiskers
  - 1-B-5. Particulates
- 1-C. Polymer/Organic Fibers
- 1-D. Metallic Fibers
- 1-E. Aramid Fibers
- 1-F. Glass Fibers
- 1-G. Boron Fibers

2. <u>Resins</u>

- 2-A. Epoxy Composites
- 2-B. Bismaleimide Composites
- 2-C. Polyimide Composites
- 2-D. Thermoplastic Composites
- 2-E. Vinylester
- 2-F. Polyester
- 2-G. Cyanate Esters

3. <u>Prepreg</u>

- 3-A. CF/Resin
- 3-B. Glass/Resin
- 3-C. Aramid/Resin
- 3-D. Boron/Resin
- 3-E. Hybrids
  - 3-E-1. GR/G/Resin
  - 3-E-2. GR/K/Resin
  - 3-E-3. Other
- 3-F. Ablatives

4. <u>Metal Matrix Composites</u>

   4-A. Silicon Carbide/Aluminum
   4-B. Silicon Carbide/Titanium
   4-C. Intermetallics Titanium/Aluminum

5. <u>Ceramic Matrix Composites</u>

   5-A. Nonoxide
   5-B. Oxide
   5-C. Glass

6. <u>Carbon/Carbon Composites</u>

   6-A. Liquid Infiltration
   6-B. CVD/CVI

APPLICATIONS

7. <u>Dept. of Defense - Aircraft</u>

8. <u>Dept. of Defense - Other</u>

9. <u>Commercial Aircraft</u>

10. <u>Sports/Recreation</u>

11. <u>Automotive</u>

12. <u>Industrial</u>:

    12-A. Corrosion Resistant
    12-B. Other

13. <u>Non-Defense Space Structures (Other than Ablatives)</u>

14. <u>Printed Wiring Board</u>

15. <u>Other</u>:

    15-A. Mass Transit
    15-B. Civil Engineering/Construction
    15-C. Other

Appendix 3

CONSORTIA MEMBERSHIP LISTS
(In Alphabetical Order)

Advanced Composite Technology Transfer Consortium (ACTT):

Full Members:

Amoco Performance Products, Inc.
BP Chemical (Hitco), Inc.
E. I. DuPont de Nemours & Co.
Hercules Composite Products Group, Inc.
J. Muller International
Lockheed Missiles and Space Co., Inc.
Trans-Science Corporation
University of California-San Diego
University of Delaware
XXsys Technologies, Inc.

Affiliates:

American Society for the Advancement of Materials and Process Engineering
California Department of Transportation
Civil Engineering Research Foundation
Federal Highway Administration
Institute for Applied Composite Technology
Institute for Mechanics and Materials
National Institute of Standards and Technology

Composite Materials Characterization, Inc.

Dow Chemical
General Electric
Grumman Corp.
Lockheed Aeronautical Systems Co.
Rohr Industries

Ford Motor Corp. Structural Composite Auto Parts Research Team

American Leistritz
Ford Motor Co.
General Electric
Industrial Technology Institute
PPG Industries
Rensselaer Polytech
University of Tulsa

Great Lakes Composites Consortium:

Principal Members:

Bell Helicopter-Textron, Inc.
Grumman Corporation
Lockheed Corporation
McDonnell Douglas Corporation
Northrop Corporation
Rockwell International Corporation

Supporting Members:

Airtech International, Inc.
Allied Signal Fluid Systems
Atlantic Research Corporation
Charles Stark Draper Laboratory, Inc.
Cincinnati Milacron
Courtaulds Aerospace
Crucible Composites Co.
Dow Corning Corporation
DuPont Composites
Eaton Corporation
Foster-Miller, Inc.
Hercules Composite Products Group, Inc.
Hexcel Corporation
ICI Fiberite
Ingalls Shipbuilding, Inc.
Johnson Controls, Inc.
Kaman Aerospace Corporation
Newport News Shipbuilding
Northwestern (BIRL)
Production Products Mfg. & Sales
Snap-on Tools Corporation
SP Systems, Inc.
SPARTA, Inc.
Sundstrand Corporation
Texas Instruments (DS & EG)
Textron Lycoming/Turbine Engine Div.

Associate Members:

A. O. Smith Corporation
Anderson/Roethle, Inc.
Aztec Plastics Co.
BF Goodrich Aerospace/Engin. Polymer Pdts.
Buehler Ltd.
Centerline Equipment Corporation
Cerritos College
Clemson University
Computer Devices International
Conesler Automotive
D & Z Inc., Mid-Atlantic
Dexter Hysol Aerospace, Inc.
Drexel University (FMRC)
Georgia Tech Research Corporation
Global Composites
Hi-Tech Engineering, Inc.
Intermarine USA
Kaiser Aerotech
KAPCO Service Company
M. C. Gill Company
Michigan Molecular Institute
Ocenco, Inc.
Packer Engineering, Inc.
Penn State University
Peterson Builders, Inc.
PPG Industries/Fiberglass Div.
Stevens Institute of Technology
Structural Composites, Inc.
University of California/Los Angeles
University of Illinois/Chicago
Washington University/St. Louis
Wayne State University
Wilson Composite Group

Partners:

Blackhawk Technical College
Carthage College
Gateway Technical College
John Hopkins University
Marquette University
Michigan State University
Michigan Technological University
Milwaukee Area Technical College (MATC)
Milwaukee School of Engineering
University of Dayton
University of Kansas
University of Kentucky
University of Wisconsin/Milwaukee
University of Wisconson/Parkside
West Virginia University
Wichita State University

Michigan Materials & Processing Institute

Full Members:

A. O. Smith
Allied Signal
BASF
Brunswick Composites
Chrysler Corp.
Dow Chemical
DSM
E. I. DuPont de Nemours & Co.
Ford Motor Co.
General Electric Co.
General Motors
Himont Advanced Materials
Miles
Owens Corning
Shell

Associate Members:

Auto-Air Composites, Inc.
Chem-Trend
Martec Plastics, Inc.
Moldflow, Inc.
Quantum Composites
Thermoplastic Pultrusions
Wavemat

University Members:

Michigan Molecular Institute
Michigan State University
Michigan Technological University
University of Detroit Mercy
University of Michigan
Wayne State University
Western Michigan University

National Science Foundation Center for Molecular and Microstructure of Composites (CMMC)

Case Western Reserve University
Edison Polymer Innovation Corporation (EPIC)
National Science Foundation
State of Ohio
University of Akron

Northrop Advanced Technology Bus Team

Aegir Systems
Allison Transmission Division
Astronautics
Aura Systems
Automotive Products, Inc.
Detroit Diesel
FMC Corporation
Futura
Graham Sales
HAJ Computer Consulting
Hughes Aircraft/Power Systems Div.
I/O Controls
Loeffler/MacConkey, Inc.
Mechanical Technology, Inc.
NEVCOR
Thermal King
TMC Corporation
Transit Research

Pennsylvania State University Center for Advanced Materials

3M Company
Air Products & Chemicals, Inc.
Allied Signal, Inc.
Aluminum Co. of America
Coors Ceramics Co.
E. I. DuPont de Nemours & Co.
Martin Marietta Energy Systems

Suppliers of Advanced Composite Materials Association (SACMA):

Regular Members:

Akzo/Fortafil Fibers, Inc.
Amoco Performance Products, Inc.
BP Chemicals (Hitco), Inc.
Ciba-Geigy Corporation
Dow Chemical Co.
E. I. DuPont de Nemours & Co.
Grafil, Inc.
Hercules Composite Products Group, Inc.
Hexcel Corporation
ICI Fiberite
Quadrax Corporation
Shell Chemical Co.
3M Company
Toho Rayon Co., Ltd.
Toray Industries, Inc.

SACMA Associate Members:

Advanced Technology & Research
Harper Electric Furnace Corporation
Lockheed Aeronautical Systems Co.
Loctite Corporation
Northrop Corporation
Sikorsky Aircraft Division
Westinghouse Electric Corporation
XXsys Technologies, Inc.

U.S. Council for Automotive Research (USCAR)/U.S. Advanced Materials Program

Chrysler Corporation
Ford Motor Corp.
General Motors

U.S. Department of Energy Continuous Fiber Ceramic Composites (CFCC) Program

Allied Signal Aerospace/Garrett Ceramic Components Division Team:

Caterpillar, Inc.
Garrett Ceramic Components
Quinn Engineering Systems

Alzeta Team:

3M Corporation
Alzeta Corporation
Southern California Gas Company

Amercom, Inc., Team:

ABB/Combustion Engineering
Amercom, Inc.
Detroit Diesel Corp.
MSNW, Inc.
Materials Sciences Corporation
Solar Turbines, Inc.
Surface Combustion, Inc.
University of Virginia

Babcock and Wilcox Corporation Team:

Babcock and Wilcox
Cleveland State University
Fiber Materials, Inc.
General Electric
Northwestern University
Technology Assessment & Transfer, Inc.
Virginia Polytechnic Institute & State University

Dow Chemical Company Team:

3M Co.
Dow Chemical
Dow Corning
Textron Specialty Materials, Inc.

Dow Corning Corporation Team:

Argonne National Laboratory
Dow Corning Corp.
Kaiser Aerotech
MSC
MSNW, Inc.
Solar Turbines, Inc.
Techniweave, Inc.

DuPont-Lanxide Composites Team:

DuPont-Lanxide Composites
Foster Wheeler Development Corp.
General Electric Power Generation
Solar Turbines, Inc.
Westinghouse Electric Co.

E. I. DuPont de Nemours & Co. Team:

E. I. DuPont de Nemours & Co.
Foster Wheeler Development Corp.

General Electric Corporate Research and Development Team:

GE-Corporate Research and Development
GE-Power Generation
Textron Specialty Materials

Oak Ridge National Laboratory Team:

Argonne National Laboratory
Institute for Defense Analyses
Materials Sciences Corporation
National Institute of Standards & Technology
Oak Ridge National Laboratory
Pennsylvania State University
R. J. Lee Group
Virginia Polytechnic Institute

Textron Specialty Materials Team:

Hauck Burner Co.
Materials Sciences Corp.
Nova Industrial Ceramics, Inc.
Stone & Webster Engineering Corp.
Textron Specialty Materials

University of Delaware Center for Composite Materials:

- Alcoa
- BMY
- Boeing Co.
- Daimler-Benz
- E. I. DuPont de Nemours & Co.
- Fiber Materials Co.
- Ford Motor Co.
- General Dynamics
- General Motors
- Grumman Corporation
- Hercules Composite Products Group, Inc.
- Honda
- ICI Composites
- Lanxide Corporation
- Lockheed Aeronautical Systems Co.
- Mitsubishi Kasei
- Montecatini
- United Technologies

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