POLYMER MATRIX COMPOSITES RESEARCH: A SURVEY OF FEDERALLY SPONSORED PROGRAMS

Final Report

June 1990

Prepared for:

**U.S. Department of Energy
Office of Energy Research
Washington, DC 20585**

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Under Contract No. DE-AC01-89ER30152

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ABSTRACT

This report identifies research conducted by agencies of the Federal government other than the Department of Energy (DOE) in the area of advanced polymer matrix composites (PMCs). DOE commissioned the report to avoid duplicating other agencies' efforts in planning its own research program for PMCs. PMC materials consist of high-strength, short or continuous fibers fused together by an organic matrix. Compared to traditional structural metals, PMCs provide greater strength and stiffness, reduced weight and increased heat resistance. The key contributors to PMC research identified by the survey are the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Department of Transportation (DOT). DoD, with budget forecasts of more than \$60 million per year, leads Federally sponsored PMC research. NASA plays a prominent role through its Advanced Composites Technology program, which from 1990 to 1994 will receive \$130 million, much of which will go toward PMC research. Over the last 4 years, NSF funded more than \$15 million for PMC research through several divisions and programs within the agency.

The survey identified a total of 778 projects. More than half of the total projects identified emphasize materials research with a goal toward developing materials with improved performance. Although an almost equal number of identified materials projects focus on thermosets and thermoplastics, thermoplastics receive more attention because of their increased impact resistance and their easy formability and re-formability. Slightly more than one third of projects identified target structures research. Only 15 percent of the projects identified focus on manufacturing techniques, despite the need for efficient, economical methods of manufacturing products constructed of PMCs—techniques required for PMCs to gain widespread acceptance.

NASA sponsors considerable research efforts to study the use of PMC aircraft components, particularly wings and fuselages, and spacecraft components. DoD is investigating ways to improve composites and increase their use in military aircraft. None of the projects identified investigate the use of PMCs in automobile construction despite the potential energy savings and other benefits that could result.

Three issues to be addressed concerning PMCs research are economy of use, improvements in processing, and education and training. Five target technologies have been identified that could benefit greatly from increased use of PMCs: aircraft fuselages, automobile frames, high-speed machinery, electronic packaging, and construction.

EXECUTIVE SUMMARY

This report for the Department of Energy (DOE) Office of Energy Research identifies research conducted by other agencies of the Federal government in the area of advanced polymer matrix composites (PMCs). PMCs are advanced structural materials that consist of high-strength, short or continuous fibers fused together by an organic matrix. Compared to traditional structural metals, PMCs provide greater strength and stiffness, reduced weight and increased heat resistance. In addition, they can be customized for a variety of applications. These characteristics make them particularly attractive as potential materials for the construction of aircraft and automobiles, where their use could result in substantial energy savings. However, although significant progress has been made in advanced structural materials technologies, as of the mid-1980s, only about 2 percent of these materials could have been used in high-technology applications. Nevertheless, as new advanced PMC materials enter the marketplace, their consumption rate increases. To capitalize on the energy savings that more widespread use of PMCs can bring, DOE desires to influence more rapid development and commercial acceptability of these materials.

Through the Office of Industrial Programs (OIP) and the Office of Conservation and Renewable Energy, DOE supports research in composites of all types. However, few existing programs focus on advanced PMCs. As part of its effort to establish future PMC research goals that will best influence PMC development and acceptability, DOE must first assess the nature and scope of PMC research taking place in other Federal programs. To identify these programs, DOE retained Walcoff & Associates to conduct a survey of PMC research sponsored by Federal agencies other than DOE to determine where potential research advances might be applied to DOE's current program. The specific objectives of the study were to (1) identify applicable projects, (2) compile all project data collected in order to categorize research and identify trends in research and development, and (3) present the survey findings in a report that concisely describes the relevant non-DOE PMC science research and identifies sponsors and locations of activities being conducted. James E. McGrath, Ph.D., Ethyl Professor of Polymer Chemistry and Director of the Science and Technology Center at Virginia Polytechnic Institute and State University (VPI&SU), provided technical expertise to the Walcoff effort.

To identify pertinent ongoing and recently completed (since 1985) projects and to collect project data, the project team surveyed three primary sources: (1) computerized, online literature searches, (2) personal interviews, and (3) print publications. The information obtained from the survey was compiled into a computerized data base designed specifically for the survey. Subject experts assessed the data to determine each project's scope and objective and to categorize it by the following areas of research: materials, structures, or manufacturing techniques.

This report summarizes the survey's findings by presenting (1) the funding information available for the key contributors to PMC research (Department of Defense (DoD), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and Department of Transportation (DOT)); (2) trends noted in PMC research; and (3) a complete listing of the projects identified. Finally, the report summarizes current research, addresses challenges for the future, and indicates target technologies for potential further research.

RESEARCH FUNDING

Because the availability of specific PMC funding information varies greatly among the Federal agencies, direct comparisons are not possible. However, it is clear that DoD, NASA, NSF, and DOT have substantial PMC research budgets. Furthermore, DoD and NASA, the two primary contributors to PMC research, have already budgeted increased funding over the next 2 to 5 years.

DoD spends more PMC research dollars per year and sponsors a greater number of projects than any other Federal agency. Over the next 2 years, DoD has budgeted \$65 million and \$67 million, respectively, for PMC research. Funds are allocated through five different DoD agencies: the Army, Air Force, Navy, Defense Advanced Research Projects Agency (DARPA), and Strategic Defense Initiative Office (SDIO). (However, SDIO funding is not included in these figures and specific data for SDIO funding are not available.) Although these agencies use PMCs to meet different application needs, a common factor in their continued PMC research is that the PMC's performance advantages far outweigh their high cost. Therefore, the military market is expected to be the fastest growing in upcoming years. A key contributor to DoD's PMC research is the Air Force's Materials Technology Area Plan (MTAP) at Wright-Patterson Air Force Base, Ohio. Reported figures indicate that MTAP alone will spend more than \$5 million per year over the next 5 years on PMC research.

NASA funds a substantial amount of PMC research under various programs. The most significant of these is the Advanced Composites Technology (ACT) program, directed by the Materials and Structures Division of the Office of Aeronautics and Space Technology, at Langley Research Center. NASA has budgeted the following annual amounts for ACT: \$20 million for 1990, \$30 million each for 1991 and 1992, and \$25 million each for 1993 and 1994. The program emphasizes innovative structural design concepts, cost-effective fabrication techniques, and advanced organic matrix materials. ACT projects are few in number, but they reflect a high-dollar level of funding. A large proportion of these projects (and those with the highest funding) focus on research to develop PMCs for aircraft construction, particularly wing structures and pressurized fuselages. These projects involve the entire construction process, including innovative structural concepts, structural mechanics, manufacturing technology, and verification. Unlike DoD, which often guards its developments to prevent unfriendly nations from obtaining them, NASA views technology transfer as important to its mission and pledges to work with DoD to integrate the ACT technologies with DoD-developed, cost-effective manufacturing processes.

Over the last 4 years, NSF funded more than \$15 million for PMC research through several divisions and programs within the agency. The Mechanical and Structural Systems Division and the Division of Materials Research each spend close to \$1 million each year on PMC research. NSF's Center for High-Performance Polymeric Adhesives and Composites at VPI&SU, under the Science and Technology Centers program, is conducting a 5-year, \$8 million program focusing on the creation of new materials, the study of mechanical and molecular behavior on a microscopic level within and between adhesives and composite layers, and the measurement and prediction of large-scale mechanical properties. This work will help advance the design and production of high-performance polymeric adhesives and composites.

Although DOT is currently funding only ongoing projects and has budgeted no money for new projects, one DOT representative predicted a major expansion in DOT's PMC research in upcoming years, particularly for the Federal Highway Administration. However, this research is directed at strengthening our highway system using the stronger PMC materials; the survey revealed no research related to reducing energy needs for travel purposes. The automobile industry has conducted extensive research in the development of composite-structure automobiles; however, the current manufacturing processes are too slow and costly to economically justify their production. The production process would require a complete revision, and the industry presently is not positioned to make these changes. Therefore, interest in composites is declining in Detroit, and no incentives exist to encourage manufacturers to accelerate the development of manufacturing processes for mass production. DOT does not appear to have any plans for offering these incentives.

SURVEY RESULTS

From the three survey sources (computerized literature searches, print research, and personal interviews) and the subject experts' screening, the survey team identified 778 PMC research projects that meet the following criteria: (1) the project must be Federally sponsored, (2) the project must be sponsored by an agency other than DOE, and (3) the project must be either ongoing or completed in 1985 or later. The survey includes both in-house and contracted research. The key contributors identified by the survey are DoD, NASA, NSF, and DOT. To identify trends in the research, the subject experts categorized the projects into three broad areas: materials, structures, and manufacturing techniques.

Materials Research

The "materials" classification identifies projects aimed at developing new PMC materials or at analyzing or improving existing materials. More than half of the projects identified in the survey fall into this category, i.e., 407 of the 778 projects. Another 19 projects involve research dealing with materials in combination with the structures they form or techniques for manufacture of the materials. These projects bring the total number of materials projects to 426, or 55 percent of the 778 projects. The proportion of materials research performed by each of the key contributors parallels this figure.

Projects within the materials category were divided further into the following subcategories: thermosets, thermoplastics, or molecular composites. More than 90 percent of the 426 materials projects focus on thermoset and thermoplastic research, with an almost equal number of projects devoted to each. Thermosets' ability to withstand high temperatures and resist corrosion and their recently improved toughness make them viable for advanced uses. Although thermoplastics do not have the high-temperature strength of thermosets, their processed flexibility (ability to be reformed) appeals to industry. Some projects study both thermosets and thermoplastics, comparing their characteristics or attempting to make them stronger and more durable by combining them. Table 1 provides a complete listing of the projects categorized within materials research.

Structures Research

Projects classified under "structures" research concentrate on the development and use of structural components made from PMC materials. Slightly more than one-third of the projects (246 of the 778) involve structures research. This proportion is paralleled among the projects of individual key contributors, except for DOT, which has only 7 projects focusing on structures research among a total of 43 sponsored projects. NASA leads in structures research as a result of its efforts to develop aircraft constructed from PMC components. DoD's structures research covers a broad range of product-specific topics, including aircraft and conventional weapons.

Projects within the structures category were subcategorized among the following topics: mechanics of material, structural mechanics, and structural concepts. The structures projects were divided relatively evenly among the subcategories, with only slightly more projects dealing with mechanics of materials. Table 2 lists all of the projects classified under structures research.

Manufacturing Techniques

Research in "manufacturing techniques" seeks to find efficient, economical methods for manufacturing, repairing, and recycling products constructed from PMCs. Although various sources indicate that this research is essential for wide-range industry acceptance of such products (particularly automobiles), only 133 of the 778 projects identified focus on this area. NSF devotes a higher percentage of its projects (20 percent) to research in manufacturing techniques than any other agency. Although DOT sponsors a significant amount of research in manufacturing techniques, none of the projects identified involve automobile manufacturing. All of the DOT projects deal with highway and bridge construction.

Manufacturing techniques were further classified as processing techniques, repair/in-service maintenance, and joining. The vast majority of projects devoted to manufacturing techniques (94 projects) deal with processing. Seventeen projects investigate repair/in-service maintenance; of these, DOT sponsors more than half and DoD sponsors the bulk of the remainder. Table 3 is a complete listing of the projects categorized under manufacturing techniques.

SUMMARY OF FINDINGS

The results of this survey indicate that Federal agencies recognize the potential benefits of PMCs and reveal clear trends in the research efforts. However, despite the magnitude of past and present Federal research conducted, several issues still need to be addressed.

Trends in Federal Research

With budget forecasts of more than \$60 million per year, DoD continues as the leading Federal sponsor of PMC research, although NASA is taking on an increasingly prominent role through its ACT program, which began in FY89. PMCs, however, are not the only focus of the ACT program, which also investigates other advanced composites.

All of the Federal agencies place the greatest emphasis on PMC materials research with a goal toward developing materials with improved performance. Although an almost equal number of projects focus on thermosets and thermoplastics, thermoplastics receive more attention because of their increased impact resistance and their easy formability and re-formability. Current research trends include creating thermoplastic "prepregs," increasing the temperature resistance of thermoplastics, and improving the shelf life of thermosets.

Research in structures and manufacturing techniques trails materials research in both number and dollars. Structures and manufacturing research trends include improved adhesive bonding, fasteners, and mechanical joints. Also, ways to improve PMC processability and quality using matrix resins are being researched. Some projects investigate ways to use artificial intelligence to improve the curing process and reduce manufacturing costs. However, in spite of the need to enhance the acceptance of PMCs by finding efficient, economical manufacturing methods, only 15 percent of the projects identified focus on manufacturing techniques.

Federal researchers are seeking ways to use PMCs in a wide variety of applications. Two applications of potential interest to DOE include aircraft and automobile construction. NASA sponsors considerable research efforts to study the use of PMC aircraft components, particularly wings and fuselages, and spacecraft components. DoD is investigating ways to improve composites and increase their use in military aircraft. On the other hand, none of the projects identified investigate the use of PMCs in automobile construction despite the potential energy savings and other benefits that could result.

Research Challenges

The greatest challenge in PMC research is reducing manufacturing costs to make the use of PMCs acceptable to industry. Three issues to be addressed in this challenge are economy of use, improvements in processing, and education and training. Economy of use involves design multifunctionality, standardization, maintainability, durability, and lifetime cost. To address this issue, researchers must establish new design philosophies and standards for the application of materials to structures. Fabrication (processing) methods currently are too slow and costly and often result in variable quality. Materials that can be fabricated easily, especially matrix materials, must be developed. Education is needed to integrate the broad disciplinary perspectives needed for PMC development and to allow creative technical exchange in various directions. Creation of university programs, laboratories and technical centers, and relationships among universities, government organizations, and industries can help create this creative technical environment.

Target Technologies

Five target technologies have been identified that could benefit greatly from increased use of PMCs. These industries and remaining issues that hinder widespread use of PMCs follow below:

- Aircraft fuselages—Technology developed by NASA and DoD must be transferred to the commercial sector.

- ❑ Automobile frames—Manufacturing technology must be developed to address several issues, including the basic automobile design and performance considerations.
- ❑ High-speed machinery—Widespread awareness of the benefits of PMCs in this application is lacking; this information must be disseminated to the industrial audience.
- ❑ Electronic packaging—Improvements in processing techniques for the manufacture of circuit boards and methods to prevent their warping would benefit this field. Basic design issues also need to be addressed.
- ❑ Construction—Additional knowledge and technology is needed in the joining of composite materials to other materials to make construction components. Standard construction materials and components must be specified, and low-cost material development techniques are needed.

Global Perspective

Although the U.S. leads the world in developing major PMC applications, other nations have had more success in commercializing their materials. Joint government-industry programs such as those in Japan, France, the United Kingdom, and West Germany could help U.S. industry overcome its hesitation to invest in PMCs while technical and economic problems remain.

1. INTRODUCTION

BACKGROUND

In the past three decades, remarkable advances in structural materials technologies have been achieved. The United States, West Germany, Japan, and other nations now produce advanced-composite materials that offer superior properties when compared with traditional structural metals, such as steel and aluminum. The strength of these advanced materials—when combined with their stiffness, their resistance to high temperatures, their ability to be customized for a variety of applications, and their light weight—make them viable for use in constructing products ranging from spacecraft to artificial limbs. Their use in building some products, most notably aircraft and automobiles, could result in substantial energy savings. These savings may reduce U.S. requirements for imported oil, which, at \$47 billion per year, is currently the largest contributor to the nation's trade deficit.¹

Because of their potential for energy savings, the Department of Energy (DOE), through the Office of Industrial Programs (OIP) and the Office of Conservation and Renewable Energy, supports research on composites. In the past, most DOE programs have consisted of both laboratory-scale developments and small pilot tests of metal matrix composites (MMCs) and ceramic matrix composites (CMCs). Few programs have focused on advanced polymer matrix composites (PMCs).

PMCs consist of high-strength, short or continuous fibers held together by a common organic matrix. Manufacturers have used one class of PMC, "reinforced plastic," for 30 years or more to make boat hulls, corrugated sheet, pipe, automotive panels, sporting goods, and other products. However, as of the mid-1980s only about 2 percent of PMCs could be classified as "advanced composites," i.e., viable for use in high-technology applications. According to the Office of Technology Assessment (OTA), however, the consumption rate for advanced PMCs could increase by 15 percent per year.² Today, several advanced PMC technologies have entered the marketplace, and DOE recognizes a need to determine how it can best influence the rapid development and commercial acceptability of these promising composites.

To build a research program that will speed the development and acceptability of PMCs, DOE must first assess the nature and the scope of PMC research taking place in other programs. Based on that assessment, DOE can identify gaps in research and technology that DOE might appropriately fill. As part of that effort, DOE enlisted the aid of Walcoff & Associates, a management consulting firm specializing in technology transfer. Under Contract No. DE-AC01-89ER30152, DOE directed Walcoff to conduct a survey of PMC research sponsored by Federal agencies other than DOE. Lending technical expertise to the Walcoff effort was

1 "U.S. Loses Edge in Composite Materials," *Wall Street Journal*, December 29, 1989.

2 U.S. Congress, Office of Technology Assessment, *Advanced Materials By Design*, OTA-E-351 (Washington, DC: Government Printing Office, June 1988), 12.

James E. McGrath, Ph.D., Ethyl Professor of Polymer Chemistry and Director of the Science and Technology Center at Virginia Polytechnic Institute and State University (VPI&SU).

PURPOSE AND OBJECTIVES OF THE SURVEY

As indicated by DOE in the Statement of Work that describes this project, "The purpose of this study is to survey non-DOE sectors of the Federal Research program in PMCs to determine where potential research advances, little known to DOE researchers, might be applied to DOE's current program." Walcoff's specific objectives in carrying out the study were to:

- ❑ Identify applicable projects.
- ❑ Compile all project data collected in order to categorize research and identify trends in research and development.
- ❑ Present the survey findings to DOE in a report that concisely describes the relevant non-DOE PMC science research and identifies sponsors and locations of activities.

DATA COMPILATION METHODS

In conducting the survey, Walcoff used three primary sources to identify projects and collect project data: (1) computerized, online literature searches; (2) personal interviews; and (3) print publications. Walcoff concentrated special efforts on the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Department of Transportation (DOT), on the premise that these organizations sponsor the majority of Federal research. Based on the assumption that completed research may still reflect the state of the art, Walcoff searched not only for ongoing research, but also for projects completed since 1985.

As the Walcoff survey team identified PMC research, it compiled the data collected in a computerized data base designed specifically for this survey. A team of subject experts led by Dr. McGrath then assessed the data to determine each project's scope and objective and to categorize it by area of research, i.e., materials, structures, or manufacturing techniques.

For a more detailed description of the research methodology applied, see appendix A. Appendix B, a "Bibliography of Sources," is a complete list of all online and print resources used. It also lists the names and addresses of survey interviewees.

OVERVIEW OF THIS REPORT

This report presents the findings of the survey. It incorporates an overview of the programs sponsored by key Federal contributors to PMC research as well as a tabular listing of all identified projects that meet the survey criteria. The report concludes with a summary of findings.

2. RESEARCH FUNDING

The survey indicates that four federal agencies—DoD, NASA, NSF, and DOT—have substantial budgets to support PMC research. In addition, information gathered via telephone interviews with program staff reveals that each agency recognizes the need for continued funding. DoD and NASA have already allocated increases in funding during the next two to five years. Although NSF and DOT have yet to allocate increased funds, divisions within these agencies plan to submit expanded budgets for the coming years. The availability of specific funding information varies from agency to agency, prohibiting any direct comparison of funding data among agencies. Some agencies have no information available on an agency-wide basis; in these instances, information was obtained from specific divisions within the agencies. Other agencies indicate total dollars allocated agency-wide. Likewise, some agencies categorize funding amounts specific to PMC research, while others include PMC research among the larger research area of advanced composites. Furthermore, some agencies have information on dollars budgeted per year for PMC research, and others have data available on specific programs that span several years.

The following paragraphs summarize the funding information gathered during this survey on an agency-by-agency basis. Also briefly described are selected research projects and programs that illustrate the focus of research within the agencies.

DEPARTMENT OF DEFENSE

Total Annual Funding

DoD funds more advanced PMC research with more total annual dollars than any other Federal agency. Each year, DoD spends roughly 70 to 80 percent of all PMC research dollars allocated by Federal sponsors. Five organizations within DoD make significant contributions to PMC research: the Army, Air Force, Navy, Defense Advanced Research Projects Agency (DARPA), and Strategic Defense Initiative Office (SDIO).

DoD funds PMC research under three categories of its budget: Category 6.1 (Basic Research), Category 6.2 (Exploratory Development), and Category 6.3A (Advanced Technology Development). Via these categories, DoD has budgeted the following amounts for PMC research for the years 1985 - 1991.¹

1 Figures for 1985-87 are from U.S. Congress, Office of Technology Assessment, *Advanced Materials by Design*, OTA-E-351 (Washington, DC: Government Printing Office, June 1988), 93. Figures for 1988-91 are from a telephone interview with Jerome Persh, Staff Specialist for Materials and Structures, Office of the Deputy Director of Defense, May 1990. These figures do not include allocations by SDIO. SDIO budget data was unavailable.

<u>Fiscal Year</u>	<u>Amount Budgeted</u>
1985	\$55.9 million
1986	\$29.2 million
1987	\$33.8 million
1988	\$46.0 million
1989	\$63.0 million
1990	\$65.0 million
1991	\$67.0 million

According to OTA, the sizeable decrease in the PMC research budget between 1985 and 1986 reflects the completion of large programs and the transition of the associated technology out of the basic and applied research categories (6.1, 6.2, and 6.3A). As the figures indicate, PMC development continues to be driven by defense applications, and an estimated \$80 billion in weapons systems use PMCs.²

Commercial Implications

Although the defense industry is the prime contributor to PMC research, heavy military involvement in PMC research is partly responsible for slowing commercial development.³ To prevent foreign adversaries from gaining PMC technology and materials, the U.S. government has imposed tight export controls. These controls hinder a commercial developer's marketing efforts, because orders can be lost before the export approval is given. More importantly, the controls discourage investment in PMC technologies and therefore limit the developer's resources for large-scale testing, which costs substantially more than the initial government research funding. Despite these drawbacks, composite manufacturers have had little success in removing the export controls.

On the other hand, in the construction of commercial and business aircraft, some reports indicate that the volume of PMCs used is about twice that used in military aircraft.⁴ For instance, all of the secondary structure (not flight-critical) and about 3 percent of the structural weight of the Boeing 767 consist of PMCs. Furthermore, two companies, Beechcraft and Avtek, have submitted all-composite aircraft prototypes for business use to the Federal Aviation Administration (FAA) for certification.

2 OTA, 93.

3 "U.S. Loses Edge in Composite Materials," *Wall Street Journal*, December 29, 1989.

4 Richard N. Hadcock, Grumman Aircraft Systems Division, "Status and Viability of Composite Materials in Structures of High Performance Aircraft" (Paper presented to the National Research Council, Aeronautics and Space Engineering Board, Naval Postgraduate School, Monterey, CA, February 10, 1986).

Still, because the performance advantages of PMCs in military applications more than compensate for their high cost, this market is likely to be the fastest growing over the next decade, and research by the various DoD agencies continues, as described in the following paragraphs.

Army

Current figures are not available to indicate what portion of the total DoD funding is allocated to the Army each year. However, one source indicates that the Army budgeted \$13.2 million in 1985, \$8.6 million in 1986, and \$10.4 million in 1987.⁵

PMC research is carried out by several different organizations within the Army, including the Army Ballistic Research Laboratory, Aviation Systems Command, Army Materials Technology Laboratory, and Army Research Office. The Army Research Office conducts more PMC research for the Army than any other organization.

The Army conducts PMC research on a variety of specific topics ranging from the properties and performance of different PMCs to manufacturing techniques. For example, the Army's reported high-dollar projects vary greatly in subject matter. The highest reported funding (\$583,424) is for a project to develop manufacturing techniques for a lightweight, tough composite bridge deck. Another project attempts to develop a new tool for machining of lightweight composite materials by integrating the capabilities of abrasive waterjets and a lathe. The project with the second-highest reported funding seeks to develop a chlorine-resistant material for membrane elements for brackish water and desalination.

DARPA

Fewer than 10 of the PMC research projects identified by this survey are sponsored by DARPA, and total funding figures for DARPA are not available. The most significant DARPA project (funded for \$478,900) uses a real-time in situ dielectric technique to monitor physical and chemical changes of composites during the cure process. Two projects deal with microwave processing of specific composites. Two others involve using composites in thermistors and resistors. One project to construct a sandwich composite of distinct alternating layers of beryllium and graphite epoxy is being conducted with the Navy.

Air Force

Figures for recent years are not available for the total Air Force allotment of DoD PMC research funding. However, one source indicates that in 1985, 1986, and 1987 the Air Force budgeted

5 Committee on the Status and Viability of Composite Materials for Aircraft Structures, *Advanced Organic Composite Materials for Aircraft Structure—Future Programs* (Washington, DC: National Academy Press, 1987), 85.

\$19.8 million, \$20.8 million, and \$26.8 million respectively, in the area of organic composite research and technology programs.⁶

One of the largest contributors to PMC research is the Air Force's Materials Technology Area Plan (MTAP) implemented at Wright-Patterson Air Force Base. The following amounts indicate recent and projected budgeting for PMC research through MTAP under the DoD budget categories of basic research (6.1) and exploratory development (6.2).⁷ Reportedly, the bulk of this research focuses on structures.

<u>Year</u>	<u>Basic Research</u>	<u>Exploratory Development</u>
1988	\$1.44 million	\$5.49 million
1989	\$1.44 million	\$5.67 million
1990	\$1.37 million	\$3.99 million
1991	\$1.39 million	\$4.52 million
1992	\$1.19 million	\$4.20 million
1993	\$1.20 million	\$4.20 million
1994	\$1.21 million	\$4.22 million

MTAP was established in the 1950s to support the application of new materials and processes. It places highest priority on technologies such as corrosion control, failure analysis, composite supportability, and nondestructive inspection techniques; these technologies are essential to the maintainability, reparability, and supportability of Air Force Systems.

MTAP focuses on 10 areas of research, or thrusts, one of which is nonmetallic structural materials. MTAP has included this focus on structural nonmetals, including polymers and the composites made from them, since 1976. This thrust is divided into the following subthrusts:

1. Ordered Polymer-Derived Fiber and Film
2. Molecular Composites
3. Opto-Electronic Materials
4. Innovative Composite Materials Development
5. Thermoplastic Composites
6. Advanced Composite Processing and Producibility
7. Radar-Absorbing Materials/Radar-Absorbing Structures

6 Committee on the Status and Viability of Composite Materials for Aircraft Structures, 85.

7 Dr. Wade Adams, Acting Assistant Division Chief, Integration Operations Division, telephone interview, May 1990.

Results of this program include in situ reinforced composites and the organic matrix composites that are used now in lightweight aerospace structures.

Although funding information for specific projects is limited, the available data indicate a variety of subjects. The project with the highest reported funding (\$936,433) involves developing a first-order model for assessing the coupled ablation/erosion response of composite materials used for nosetips and heatshields on various aircraft. Another reported high-dollar project (\$649,758) is attempting to derive a laminographic nondestructive testing system design for carbon-carbon and filament-wound composite structure applications. Still another project, entitled "Continuous Heated Roll-Forming of Thermoplastic Composite Materials," involves developing a prototype stapling device to improve delamination resistance and reduce damage to in-plane systems.

Navy

Current information on the amount of DoD PMC research funding allocated to the Navy is not available. Funding information for specific Navy projects is also limited. However, several projects were reported with funding of more than \$500,000. One of these projects uses x-ray scattering to detect and size defects in simulated rocket pressure vessels. Two projects involve research with kevlar cord, one to develop methods for saturating the cord completely with a polyurethane resin and the other to identify improved cable configurations and manufacturing techniques to provide reliable sonobuoy cables. Another project is determining appropriate composite materials for anti-submarine rocket launcher components. Finally, an existing portable x-ray residual stress analysis system is being modified and adapted for field use in a Naval aircraft maintenance environment.

The Navy's PMC research is sponsored by various Naval organizations, including the Office of Naval Research (ONR) and Naval Air Development Center. In contrast to the projects previously described, most ONR projects identified deal with the evaluation of the performance of composites under stressful conditions. For example, one project is studying the effects of stress, temperature, and moisture on the mechanical response of PMCs. Another ONR project is determining the role of a polymer's structure, composition, and morphology in the propagation of fatigue cracks in crystalline polymers. Still another project researches the process of damage growth in composite laminates subjected to complex loading states and fatigue.

SDIO

Total yearly funding information for PMC research sponsored by SDIO is not available, nor is it included in the total DoD monies. However, funding data is available for each of the 14 SDIO projects identified in this survey, and these funding amounts total to \$1,750,528. SDIO research is implemented through two separate programs, one within the Army and the other within the Air Force. The most noteworthy projects are for development of ultralightweight high-temperature structural materials for weapons and military rockets (funded at \$547,988) and for the study of fabrication methods and mechanical and electrical properties of high-strength electrical insulation composites (funded at \$416,983).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Total Annual Funding

Within its Aeronautics Research and Technology (R&T) budget, NASA funds a significant amount of research in PMCs. Funding amounts fall under the R&T Base and the Systems Technology Programs. In 1989, as part of its R&T Base, NASA spent approximately \$2 million for basic research on materials and structures technology. R&T funding for basic research on PMCs will continue at this base level (\$2 million per year) at least until 1994. NASA also spent \$1 million in 1989 on PMC research as part of its budget for Advanced High-Temperature Engine Materials Technology, one of its Systems Technology Programs. This level of funding will continue at least until 1994. NASA allocates another \$1.5 million per year toward research in polymers and PMCs as part of its Space R&T budget.

The vast majority of PMC funding occurs, however, through the Advanced Composites Technology (ACT) program, another program within NASA's Systems Technology Programs. Beginning in 1989, NASA budgeted the following amounts for ACT:

- 1989: \$10 million.
- 1990: \$20 million.
- 1991: \$30 million.
- 1992: \$30 million.
- 1993: \$25 million.
- 1994: \$25 million.

These amounts total to \$140 million, to be spent over a period of six years. Data compiled from tables 1 through 3 of this report show that by 1989 NASA had already allocated at least \$93 million of this total. The ACT program is described in more detail below.

The ACT Program

Within NASA, the Materials and Structures Division of the Office of Aeronautics and Space Technology directs the ACT program. The program, managed at the Langley Research Center within the Structures Directorate, encompasses basic research in materials and material forms to improve structural performance (particularly damage tolerance) while reducing processing and fabrication costs. Its principal focus is innovative design and fabrication methodologies within the aircraft industry. The program will emphasize three basic technologies: innovative structural design concepts, cost-effective fabrication techniques, and advanced organic matrix materials.

Although relatively few in number, most current ACT projects reflect a high-dollar level of funding. In 1989, few projects received funding below \$500,000, while the majority received funding above \$1 million. A significant number of these high-dollar projects focus on research for aircraft production. Two projects in particular, each funded at more than \$22 million, target research to develop composite technology for wing structure and pressurized fuselage structure, including innovative structural concepts, structural mechanics, manufacturing technology, and verification. Lockheed and Boeing are each conducting one of the projects. Another project, conducted by McDonnell Douglas, is funded at nearly \$24 million. Its objective is to develop manufacturing technology for heavily loaded (primary) aircraft structures with emphasis on textiles, stitching, thermoplastic forming, and verification. These projects, which address many aspects of advanced composites—from basic materials research to manufacturing processes—may interest DOE because the reduced weight of aerospace structures made from PMCs offers great potential for energy savings.

Origin of ACT

The ACT program emerged from the recommendation of a committee formed by the Aeronautics and Space Engineering Board of the National Research Council at the request of the NASA Office of Aeronautics and Space Technology. Chartered in 1984, the committee's goal was to assess the status and viability of organic composites technology for aircraft structures.

After conducting an assessment of composites technology in the United States from 1985 to 1987, the committee recommended Federally sponsored research and technology development programs that could produce a more rapid and timely translation of the potential of composite materials to production aircraft. It also recommended that the government establish a new program to be jointly sponsored by NASA, DoD, and FAA in cooperation with industry and universities—to develop an integrated, "affordable" composites technology data base.

NASA views technology transfer as essential to its mission.⁸ In keeping with this view, results generated under the program will become a part of the broader NASA-integrated technology base. To further achieve its aim of technology transfer, NASA will work with DoD to ensure the integration of ACT technologies with DoD-developed, cost-effective manufacturing processes. As the technology matures, the FAA will play a major role in determining that requirements for certification are addressed properly. NASA and DoD will also conduct composite program reviews annually to coordinate related research.

Evolution of ACT

The ACT program will evolve in three phases: (I) technology innovation, (II) technology development, and (III) technology verification. Phase I began in 1989, when NASA undertook

8 T. St. Clair, N. J. Johnston, and R. M. Baucom, "High Performance Composites Research at NASA-Langley" (Paper presented at 1988 Society of Automotive Engineers (SAE) International Congress and Exposition, Detroit, Michigan, February 29-March 4, 1988), 6.

15 NASA Research Announcement contracts, as well as in-house research. This phase focuses on new materials and material forms, fabrication processes, innovative structural concepts, and structural mechanics issues. Scheduled to begin in 1991, Phase II will be a significant component test program that utilizes toughened materials, emphasizes cost-effective fabrication methods, and addresses the weight efficiency of advanced structural concepts. This phase will provide test data to substantiate structural mechanics methodology in failure mechanisms, structural response and residual strength predictions, life prediction, and overall structural performance. Though as yet unfunded, Phase III is expected to be an essential element of the total program to establish affordable technology. Phase II should begin by 1995.

NATIONAL SCIENCE FOUNDATION

Total Annual Funding

Between 1985 and 1989, NSF funding for PMC research amounted to more than \$15 million. Many divisions and programs within NSF contribute to this research, including the Mechanical and Structural Systems Division, the Division of Materials Research, the Division of Design and Manufacturing Systems, and the Science and Technology Centers Program. Below are specific funding levels for each of these areas.

Mechanical and Structural Systems Division

NSF's Mechanical and Structural Systems Division, through its programs in Solid and Geomechanics, Structures & Building Systems, and Materials Engineering & Processing/Tribology, funds PMC research. As part of these three research programs, in 1988, NSF spent slightly more than \$800,000 on projects specifically focused on PMC research. The FY89 budget for these three programs, part of which funds PMC research, amounted to nearly \$20 million. In FY90, although the division requested an additional \$1 million, the current plan remained at \$20 million. For FY91, the division plans to submit a budget requesting slightly more than \$21 million for the three programs.

The Materials Engineering & Processing Program supports one project in particular that may interest DOE because of its energy saving potential: development of a superconductive composite wire. The project, performed by Clemson University, incorporates superconductive ceramic particles into a tough polymeric matrix to produce a composite wire that is durable and could provide improved energy efficiency for electrical transmission. In 1988, NSF funded the project with \$59,843.

Division of Materials Research

The Division of Materials Research also supports PMC research. In a recent telephone interview, Dr. Norbert Bikales, Director of Polymers Research, estimated that, taking a broad

view and including work done by the division's groups and centers, total research devoted to PMCs comes to approximately \$1 million each year. Most of this research takes place in the basic sciences that support the actual engineering of PMCs.

Division of Design and Manufacturing Systems

The Division of Design and Manufacturing Systems funds approximately \$250,000 each year in PMC research through its Manufacturing Processes Program. One project supported by this division—development of a new approach to the manufacture of thermoplastic matrix continuous-fiber composite materials—may interest DOE because of its probable initial application: fabrication of aerospace structures. The new process, which will form a flat composite laminate into a complex-shaped component using a machine much smaller than the component itself, will also eliminate the need for fixed dies for forming, thereby reducing costs for manufacturing the lightweight aerospace structures. The project, conducted at Stanford University, received funds of \$403,731 from 1987 to 1990.

Science and Technology Centers Program

NSF's Science and Technology Centers Program, established in 1987, promotes research that requires large-scale equipment, long duration, and special facilities—research which is best undertaken in an environment where collaboration among the university, government, and private sectors can take place. In February 1989, NSF funded 11 research centers located at universities across the country with \$25 million. The centers doubled that amount by raising matching funds from university, state, and private sources. Additional funding is being explored by NSF in conjunction with the National Governor's Association and the Industrial Research Institute.

These academically based, interdisciplinary centers are pursuing a range of research directions. One, the Center for High-Performance Polymeric Adhesives and Composites at VPI&SU, is conducting a five-year, \$8 million program focusing on the creation of new materials, the study of mechanical and molecular behavior on a microscopic level within and between adhesives and composite layers, and the measurement and prediction of large-scale mechanical properties. The center at VPI&SU evolved from the research interests and international reputations of the Polymer Materials and Interfaces Laboratory, the Center for Adhesive and Sealant Science, and the Center for Composite Materials and Structures at the university. Work performed at the center will provide the means to understand, design, and produce high-performance polymeric adhesives and composites.

The creation of the center shows every promise of enhancing the understanding and development of strong, adhesively bonded, lightweight polymeric composite materials that will enhance the United States' competitive edge in this field.

DEPARTMENT OF TRANSPORTATION

Total Annual Funding

Although DOT conducts ongoing research in PMCs, the amount of funding in recent years is well below that for DoD, NASA, and NSF. According to a survey of agency representatives by OTA, DOT budgeted no money for PMC research in 1985. In 1986 and 1987, DOT funds for PMC research were only \$400,000 and \$200,000, respectively.⁹ Furthermore, no DOT funding for new PMC research projects has been identified for the intervening years from 1987 to the present. All current funding is for ongoing projects.

However, some DOT representatives are showing renewed interest in PMC research. In a telephone interview, Eric Munley of the Federal Highway Administration's (FHWA's) Office of Research, Structures Division, reported that he anticipates a major expansion in DOT research in this area during the remaining years in this century. Budget requests for PMC research are being planned for the following amounts: \$6.6 million, 1992; \$6.5 million, 1993; \$6.1 million, 1994; \$6.3 million, 1995; \$5.9 million, 1996; \$5.5 million, 1997; \$3.0 million, 1998; \$2.9 million, 1999; and \$2.3 million, 2000.

Nevertheless, these requests and the funding dollars revealed in the survey represent only one segment of DOT, i.e., FHWA. The literature survey and several telephone interviews with DOT and Transportation Research Board representatives revealed no other DOT agency involved in PMC research.

Research Topics

The majority of research being conducted by DOT (as the tables show) is related to highway construction and marking and bridge construction. Given the increasingly rapid deterioration of the highway infrastructure because of the system's aging and increased traffic loads, this research is timely and valuable. However, its relevance and contribution to achieving DOE goals is questionable.

One project of potential interest to DOE is the construction (by Advanced Structures Technology, Inc.) of a turbine engine for a blade containment system from ceramic tiles and polymer fibers. (A ceramic automobile engine would be 30 to 40 percent more fuel efficient than current models.¹⁰) This project, entitled "Development of An Advanced Fan Blade Containment System," was funded at \$50,000.

Some of the more generally directed research may have implications for a variety of applications. For instance, DOT has sponsored projects to develop or improve nondestructive methods of testing PMCs for defects or flaws. DOT funded \$50,000 for Spire Corporation to

9 OTA, 93.

10 *Wall Street Journal*, December 29, 1989.

study a method that uses gamma-ray scattering, a form of radiometry that can measure the PMC composition, to be used in a portable flaw-detection system. Also, DOT's only reported high-dollar project (\$348,742) is devoted to developing a means of detecting flaws in transportation systems using laser-generated surface acoustic waves. This project is being conducted by American Research Corporation.

The automotive industry has been widely viewed as the industry with the greatest potential for broad use of PMCs in the future. Automobiles constructed from PMCs would be more fuel efficient and corrosion resistant and would have improved ride quality. However, according to OTA, "the application of advanced materials to automotive structures will require: (1) clear evidence of the performance capabilities of the PMC structures, including long-term effects; (2) the development of high-speed, reliable manufacturing and assembly processes with associated quality control; and (3) evidence of economic incentives (which will be sensitively dependent on the manufacturing processes)."¹¹ Although research data and field experience has shown that glass fiber-reinforced PMCs can meet the performance requirements, none of the current manufacturing methods can satisfy all production requirements, and economic justifications for using PMCs in automobiles do not currently exist.

The automotive industry has expended extensive research and development efforts aimed at realizing the potential benefits of PMC structures. PMC body structures have been used in a variety of specialty vehicles for the past three decades. A variety of production methods have been used with two common characteristics: (1) the processes are all slow, perhaps because of the very low production rate of these specialty vehicles and (2) the vehicles have all used some type of steel backbone or chassis, which is designed to absorb most of the load and crash impact. Current vehicles that use high volumes of PMCs have been designed specifically for these materials; therefore, direct comparisons between steel vehicles and PMC vehicles to derive baseline characteristics are not possible.

Automobile manufacturers have had no incentive to accelerate the development of manufacturing process for mass production, and interest in composite industries appears to be waning in Detroit. Edwin Woolard, chairman of Du Pont Company (which has substantial investment in PMCs), warned that this waning interest might allow the Japanese to "steal our thunder" in PMC technology.¹² According to Woolard, "Without any commitment on their [auto manufacturers] part, it's going to take longer to bring the materials to market than we had hoped."

According to OTA, "the advent of composite-intensive vehicles will be evolutionary."¹³ Initial developments would involve pilot programs to evaluate the materials realistically in the field; next, low annual production volumes of a composite-intensive vehicle would be implemented to achieve the manufacturing experience necessary for realistic fabrication guidelines and true

11 OTA, 155.

12 *Wall Street Journal*, December 29, 1989.

13 OTA, 184.

economics. From these programs, the potential for high-volume production could be determined. Although the industry presently is not positioned for PMC-intensive vehicles and current supplies would support only low-volume production, these restrictions can be resolved in time. However, the decisions and financial commitments must be made to implement the necessary changes, and these decisions must be based on significant evidence that PMC vehicles are viable economically and that they will offer customer benefits.

3. SURVEY RESULTS

OVERVIEW

Using computerized literature searches, print research, and personal interviews, followed by a case-by-case screening by subject experts, the survey team identified 773 research projects that meet the survey parameters. Those parameters were as follows:

- ❑ The projects must be Federally sponsored.
- ❑ The projects must concentrate, in whole or in part, on PMCs.
- ❑ The projects must be sponsored by an agency other than DOE, because DOE's objective in authorizing the survey was to assess the research goals of other Federal organizations.
- ❑ The projects must be either ongoing or completed in 1985 or later.

Included in the survey are both contracted research and in-house programs.

Key Contributors

The survey results reveal four key contributors to Federally sponsored PMC research: DoD, NASA, NSF, and DOT. DoD—through the Army, the Navy, the Air Force, SDIO, and DARPA—sponsors 329 projects. NASA and NSF sponsor 228 and 87 projects, respectively. The fourth agency—DOT—is responsible for 43 projects.

Trends in Research

To identify trends in PMC research, the survey team developed a system for categorizing the 778 programs first into broad areas of research, and subsequently into more narrowly defined fields. Based on advice and information gathered during interviews with experts in advanced-composite research at NASA's Langley Research Center and at Wright-Patterson Air Force Base, the team established three areas of research: (1) materials, (2) structures, and (3) manufacturing techniques. Within each of these three broad areas, the survey team further classified projects as follows:

1. Materials: Thermosets, Thermoplastics, or Molecular Composites
2. Structures: Mechanics of Materials, Structural Mechanics, or Structural Concepts
3. Manufacturing: Processes, Joining, or Repair/In-Service Maintenance

With this system in place, subject experts reviewed the projects identified during the survey, categorizing and subcategorizing each of them. The results of their review show that a clear

majority focuses on materials research. As figure 1 illustrates, 52.1 percent of all projects are categorized as materials research, while 29.4 percent focus on structures and 15.0 percent on manufacturing techniques. The remaining 3.5 percent concentrate on two or more areas of research.

Figure 1. Comparison of Areas of Research for Projects Identified in the PMC Survey. Based on a total of 778 projects.

The ratio of materials to structures to manufacturing research within DoD closely parallels the ratios for the full survey. NASA and NSF also sponsor more materials research than structures research, and more structures research than manufacturing research. At NASA, however, the proportion of materials research is greater—and the proportion of manufacturing research smaller—than that indicated for the full survey; NSF survey results indicate less distinction in the amount of effort devoted to the three areas of research.

The fourth key contributor to Federally sponsored research, DOT, is the only agency to break the pattern. DOT focuses first on materials research, second on manufacturing techniques, and third on structures research.

MATERIALS RESEARCH

Survey research classified as "materials" includes those projects that concentrate on developing new PMC materials, or on analyzing or improving existing materials. Common goals include defining mechanical properties, improving curing techniques, and increasing toughness, flexibility, or heat resistance.

Trends in Materials Research

Of the 774 projects identified in the PMC survey, 407 focus exclusively on topics related to materials research. Another 19 projects concentrate on materials research in combination with structures- or manufacturing-oriented goals, or both. The total number of projects focusing on materials, therefore, is 426, or 55 percent of the total.

The proportion of individual research projects dedicated to materials issues by each of the four key contributors to Federally sponsored PMC research—DoD, NASA, NSF, and DOT—parallel the results of the full survey. One hundred sixty-one of the 329 DoD projects included in the survey focus on materials research. Within DoD, the Navy, the Air Force, SDIO, and DARPA all dedicate at least half of all projects initiated to materials research. Only the Army differs from the norm. Of the 92 Army-sponsored projects in the survey, only 28 are materials-related. Structures research accounts for 38 projects and manufacturing for 22. The remaining 4 projects focus on two or more areas.

The survey results indicate that NASA also devotes considerable PMC research effort to materials. Of the 288 NASA projects in the survey, 162 are related to materials research. At NSF, research effort is more evenly distributed among the three areas of research; still, 37 of the identified NSF projects focus on materials, as opposed to 32 in structures and 18 in manufacturing. Finally, 25 of the 43 identified DOT projects focus on materials.

Of the 426 projects focusing on materials, the survey team had sufficient data to more narrowly define 389 projects as concentrating on thermosets, thermoplastics, or molecular composites. More than 90 percent concentrate on thermoset or thermoplastic research.

More specifically, the survey results indicated that 155 out of 426 PMC materials research projects focus on thermoset research. Thermosets, or "thermosetting resins" as they might more accurately be called, include polyesters, vinyl esters, epoxies, bismaleimides, and polyimides. The ability of thermosetting resins to withstand high temperatures, coupled with their resistance to corrosion, has made them viable materials from which to make such products as boat hulls, corrugated sheet, and sporting goods for more than 30 years. These qualities, when combined with recently improved toughness and increased maximum operating temperatures, also make them viable for more advanced uses.

Interestingly, the number of projects—160—in which researchers concentrate on thermoplastics is close to the number categorized as thermoset research. Thermoplastic resins are a promising alternative to thermosets for the future, in part because they offer advantages associated with processing that can make them more appealing to industry. Thermoplastic resins

include polyetherimides, polyamide imides, polyphenylene sulfide, polyether-etherketone (PEEK), liquid crystal polymers, and some polyesters. Unlike thermosets, which go through an irreversible curing process that renders them permanently rigid, processing of thermoplastics is reversible. Thermoplastics are "re-formable"; they can even take on completely new shapes. Thermoplastics currently are inferior to thermosets in terms of high-temperature strength; yet, some recently developed thermoplastic resins, such as PEEK, may rival thermosets in both high-temperature strength and solvent resistance.

Another 45 projects focus on thermosets in combination with thermoplastics. The objective of some cross-categorized projects is to compare the characteristics of specified thermoset and thermoplastic materials. Others seek to find ways to build stronger, more durable materials by combining thermosets and thermoplastics. For instance, the National Technical Information Service reports that the University of Tennessee, under contract to NASA, sought to improve the fracture toughness of PMR-15, a thermosetting polyimide, by co-dissolving it with LaRC-TPI, a thermoplastic resin.

Project Data

Described in table 1, which appears on pages 19-70 of this report, are each of the 426 projects categorized as materials research. The projects are listed in alphabetical order by study title, and each project is numbered. As indicated above, 19 projects classified as materials research also relate to at least one other area of research. A notation follows the title of each of those projects referencing the other table(s) in which the project appears.

Tabular information for every project includes the project sponsor and the performing organization (where applicable). To the extent data is available, the table also provides contract numbers, principal investigators' names, contract duration periods, and funding amounts (or notations of in-house work).

Also included in table 1 are briefly stated project objectives. Following the objective statements is a column that shows not only the subcategory(ies) for each project (thermosets, thermoplastics, or molecular composites), but also the subset(s) of research. Subject experts established at least one subset for each materials project in an effort to clarify the nature of the work taking place. The subsets include the following:

1. Synthesis.
2. Characterization.
3. Resins/Fiber (Interfacial).
4. Mechanical Properties (further subclassified as damage tolerance, fatigue, fracture behavior, and/or environmental effects).
5. Processing.

In the final column, the table indicates the primary data source for each project identified.

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
1. ¹³ C NMR Analysis of the Effects of Electron Radiation on Graphite/Polyetherimide Composites	NASA - DC NCC1-115	M.W. Ferguson Norfolk State College	--	To refine sample preparation techniques; to procure essential equipment; to increase proton signal-to-noise ratio by constructing NMR probe.	Thermoplastics: Characterization/ Mechanical Properties (Environmental Effects)	NTS
2. 371 Degrees Celsius Mechanical Properties of Graphite/Polyimide Composites	NASA	P. Delvige NASA	In-House	To study properties (mechanical) of graphite/polyimide composites.	Thermoplastics: Characterization/ Processing/Mechanical Properties	NTS
3. 700 Degrees Fahrenheit Properties of Autoclave Cured PMR-2 Composites (See also Table 3, Manufacturing, #1.)	NASA - Lewis	R.D. Vannucci, D. Cleri NASA Lewis	In-House	To investigate the processing parameters for autoclaving polyimide composites.	No subcategory established: Characterization/ Processes	NTS
4. Abrasion-Resistant Nonflammable Oxidized Polyacrylonitrile Fabrics	Navy	W. Novis Smith American Hyperform Inc.	\$122,000.00	To improve the abrasion resistance of oxidized polyacrylonitrile fabrics used in composites.	No subcategory established: Processing/Mechanical Properties	FRIP
5. Accelerated Wear Test of Pavement-Marking Materials	DOT-FHW.A	Bryden New York State Department of Transportation	--	To evaluate life and wear characteristics of traffic marking materials by accelerated wear test.	Thermosets/ Thermoplastics: Mechanical Properties (Damage Tolerance/ Environmental Effects)	FRIP
6. Addition Polymers from 1,4,5,8-Tetrahydro-1,4,5,8-Diepoxyanthracene and Bis-Dienest Processable Resins for High Temperature Application	NASA - Lewis	M.A.B. Meador NASA Lewis	In-House	To develop a new addition polymer that is more stable in air at elevated temperatures than in U2 and slows progress as a matrix for composites.	Thermoplastics: Synthesis	NTS
7. Addition-Type Polyimides	Navy - DC	Dept. of the Navy	In-House	To discuss new addition-type bismaleimides for use with polyimides and their cure times.	Thermosets: Synthesis	NTS

Note The data sources have been abbreviated according to the following key: ACT = Advanced Composites Technology; ASC = Proceedings of the American Society for Composites; CA = Chem Abstracts; FRIP = Federal Research in Progress; MCR = Mechanics of Composites Review; NTS = National Technical Information Service; and US/J = U.S./Japan Composites Workshop.

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subsets)	Source
8. Addition-Type Polyimides Demonstrated	Navy - Department of the Navy	Navy Surface Weapons Center	In-House	To discuss addition-type polyimides.	Thermoplastics: Mechanical Properties	NTIS
9. Adhesive Evaluation of LARC-TPI (Langley Research Center Thermoplastic Polyimide) and a Water-Soluble Version of LARC-TPI	NASA - Langley	D.J. Progar NASA Langley	In-House	To evaluate polyimides as high temperature adhesives and determine their mechanical properties.	Thermoplastics: Characterization / Mechanical Properties (Damage Tolerance)	NTIS
10. Adhesive Evaluation of New Polyimides	NASA - Langley	T.L. St. Clair, D.J. Progar NASA Langley	In-House	To synthesize and evaluate polyimides for use as adhesives.	Thermoplastics: Synthesis	NTIS
11. Adsorption of Migrating Chemical Species by Composite Polymer	Air Force	Gary Czupryna Foster-Miller, Inc.	\$59,224.00	To study adsorption of migrating chemical species by composite polymer.	Characterization	FRIP
12. Advanced Composites for Body Armor Applications	Army	R.F. Kovar Foster-Miller Inc.	\$59,963.00	To process hard layered composites containing PBT/SOL-GEL glass film/glass matrix sections.	Thermoplastics: Processing	FRIP
13. Advanced Fiber Placement Studies (See also Table 3, Manufacturing, # 3.)	NASA - Langley NASI-18887	Freeman Hercules	04/06/89 \$1,134,000.00	To study an advanced automated fiber placement process for fabricating in grid and curved panels.	Thermoplastics: Processing/Mechanical Properties (Damage Tolerance)	ACT
14. Advanced Materials and Product Forms	NASA - Langley NASI-18834	J.T. Hartness BASF	04/01/89-05/31/95	To develop improved matrix resins and unique material forms that offer increased performance and improved processability over state-of-the-art structural composite materials.	Thermoplastics: Resin- Fiber (Interfacial) Chemistry-Mechanics	MCR
15. Advanced Ordered Polymer/Glass Microcomposites	Air Force	Richard Lustigna Foster-Miller, Inc.	\$559,942.00	To study advanced ordered polymer/glass microcomposites.	Thermoplastics / Synthesis/Characterization/Mechanical Properties	FRIP
16. Advances in Composites Technology	NASA - Langley	D.R. Tenney, H.B. Dexter NASA Langley	In-House	To discuss advantages in composites such as new matrices and new filament winding technology.	Thermoplastics: Processing	NTIS
17. Amine Terminated Bispartimide Polymer	NASA - Ames	D. Kumar, G.M. Fohlen, J.A. Parker NASA Ames	In-House	To study an Amine-Terminated Bispartimide Polymer.	Thermoplastics: Synthesis	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
18. Analysis of Delamination-Related Fracture Processes in Composites (See also Table 2, Structures, #18.)	NASA	Erian A. Armanios Georgia Institute of Technology	—	To develop mid-plane and transverse crack tip delamination analysis for interlaminar damage prediction in uniform laminates, and to construct simple models for the delamination analysis of tapered laminated composites in order to use them for the preliminary design of composite rotor hubs.	Thermosets	NASA
19. Analysis of Thermal and Shock Reduction of Graphite Fiber Reinforced	DARPA	Li-Chen Hsu Macromolecular Material Inc.	\$50,000.00	To evaluate the mechanical properties relevant to thermal and shock reductions of a certain graphite fiber/polyimide composite.	Thermoplastics: Mechanical Properties (Fatigue)	FRIP
20. Analysis of Interlaminar Fracture in Composites Under Combined Loading	NASA-Langley NAG-1-637	Erian A. Armanios Georgia Institute of Technology	10/01/89-09/30/90	To extend an existing sublaminate analysis method to model tapered ply-drop configurations under bending and combined tension-bending loads (analyses for use on personal-class computers).	Molecular Composites/Mechanical Properties/Fracture Behavior	MCR
21. Application of Optical Image Analysis to Quantitative Micro-structure Characterization of Composite Materials	Army - Army Materials Tech. Lab.	J.F. Kelly National Bureau of Standards (NIST)	—	To use optical image analysis to characterize microstructure.	No subcategory established: Characterization	NTS
22. Assessment of Computed Tomography as an Improved Quantitative Nondestructive Evaluation Tool for Low Temperature Composites	Air Force	William H. Pfeiffer PDA Engineering	\$149,965.00	To determine surface energy components of polyaramid fibers.	Thermoplastics: Resin-Fiber (Interfacial) Chemistry-Mechanics	FRIP
23. Atmospheric Effects on Fiber Reinforced Plastic Materials	Navy	Joseph J. Sessler Structural Composites Inc.	\$49,964.00	To examine potential fiber-reinforced plastics atmospheric effects.	Thermoplastics: Characterization/ Mechanical Properties (Environmental Effect)	FRIP
24. Automated Evaluation of Composite Materials (See also Table 3, Manufacturing, #8.)	Army	C.L. Hagnauer, S.G.W. Dunn U.S. Army Research Materials Tech. Labs	In-House	To increase laboratory productivity and improve the quality of test information needed to evaluate fiber-reinforced polymeric matrix composite materials and guide their specification, design, and manufacture.	Molecular Composites: Characterization	MCR

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
25. The Biodegradation of Fluorosilicone	Air Force	Gall Bowers-Irons Technical Research Assoc.	\$55,000.00	To effect nondestructive inspection of composites using gamma ray scattering counting.	Thermosets/ Thermoplastics: Characterization	FRIP
26. Bond of Epoxy-Coated Prestressing Strand	DOT	Johnston North Carolina State University	-	To evaluate the transfer and development lengths for epoxy-coated prestressing strand under various loading and environmental conditions.	Thermosets: Characterization/ Mechanical Properties (Fatigue/Environmental Effects)	FRIP
27. Bridge Deck Restoration Methods and Procedures - Phase II (Experimental Construction)	DOT	Stewart California Dept. of Transportation	-	To determine the durability of bridge installations such as deck membranes, latex modified overlays, sealants, etc.	Thermosets/ Thermoplastics: Characterization/ Mechanical Properties (Damage Tolerance/ Fatigue/Environmental Effect)	FRIP
28. Buckling After Impact Response of Laminated Composites	Air Force	S. Owens; B. Peterson; G. Law General Dynamics/R. Worth	-	To study impact damage resistance and damage tolerance on several composites.	Thermosets/ Thermoplastics: Mechanical Properties (Damage Tolerance)	ASC
29. CT Data Imaging of Sub-Pixel Features	Air Force	Donald R. Jones Failure Analysis Assoc.	\$49,035.00	To develop techniques for using CT data to detect and assess sub-pixel features.	Thermosets: Characterization	FRIP
30. CT Inter/Intra Pixel Mensuration and Imaging of Non-Destructive Evaluation	Air Force	James E. Youngberg Perceptics Corp.	\$55,898.00	To develop improved imaging techniques to characterize nozzle CT interface geometry.	No subcategory established: Characterization	FRIP
31. Cellular Thermosetting Fluoropolymers and Process for Making Them	NASA - Goddard	S.Y. Lee NASA Goddard	In-House	To study the synthesis of cellular thermosetting fluoropolymers.	Thermosets: Synthesis/ Processing	NTIS
32. Characterization Methods for the Mechanical Behavior of Thermoplastic Composites	NASA	R. Falabella Hexcel Corporation	-	To develop a characterization method for mechanical behavior of commercially available thermoplastic composites and compare the results to that for thermoset composites.	Thermoplastics: Characterization	ASC

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
33. Characterization and Cold Compaction of Poly (Ether Ether Ketone) Powders	Navy	J.J. Reilly, I.L. Kamel Naval Air Development Center	In-House	To characterize compaction of PEEK powders.	Thermoplastics: Characterization	CA
34. Characterization of Elastic-Plastic Properties of ASA/APC-2 Thermoplastic Composite	NASA - DC	C.T. Sun; K.J. Yoon Purdue University	—	To characterize the elastic and inelastic properties of ASA/APC-2 composites.	Thermoplastics: Mechanical Properties (Damage Tolerance)	NTIS
35. Characterization of Mode 1 and Mode 2 Delamination Growth and Thresholds in Graphite/PEEK Composites	NASA - Langley DA Proj. ILJ-61102-AH-45-C	R.H. Martin; G.B. Murri NASA Langley	In-House	To study the delamination of PEEK/Graphite composites by characterizing Mode I and Mode II delamination growth.	Thermoplastics: Characterization	NTIS
36. Characterization of Rigid-Rod Molecular Composites by Photothermal and Ultrasonic Imaging	Air Force AFOSR-87-4020; 2302-A3	J.W. Madachian; M. Madey; R.K. Eby; W.W. Adams Computer Sciences Corp.	—	To use photothermal and ultrasonic imaging in characterization of a molecular composite.	Molecular Composites: Characterization	NTIS
37. Characterization of Viscoplastic Behavior of ASA/PEEK Thermoplastic Composite	NASA	C.T. Sun Purdue University	—	To develop constitutive models capable of describing the orthotropic elastic-viscoplastic behavior of ASA/PEEK thermoplastic composite at various temperatures under both monotonic and cyclic loading.	Thermoplastics: Characterization/ Processing/Mechanical Properties	NASA
38. Characterization of a Thermoplastic Polyimidesulfone	NASA - Langley	J.F. Dezen; P.R. Young NASA Langley	In-House	To discuss the synthesis and characterization of the chemistry and adhesive of polyimidesulfone.	Thermoplastics: Synthesis/ Characterization	NTIS
39. Characterization of the Relationship of the Cure Cycle Chemistry to Cure Cycle Processing Properties (See also Table 3, Manufacturing #12.)	NASA NAG1-237	D.E. Kranbuehl College of William and Mary	—	To study the use of dynamic dielectric analysis used to examine the curing of polymer systems and thermoplastics.	Thermoplastics: Characterization	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subsets(s)	Source
40. Chem. Modif. of Matrix Resin Networks with Engr. Thermoplastics III. Synthesis & Prop. of Epoxy Networks Mod. w/ Amine-Terminated Poly (Aryl Ether Sulfone) Oligomers	Navy N00014-78-C-0629	J.L. Hedrick; M.J. Jurk; I. Yilgor; J.E. McGrath Virginia Tech	—	To study the modification of networks with amine-terminated thermoplastics.	Thermosets: Synthesis	NTS
41. Chemical Control of Nadimide Cure Temperature and Rate	NASA - Langley	R.W. Laurer NASA Langley	In-House	To study cure time of polyimide networks cured by use of maleimide and nadimide-terminated monomers and oligomers.	Thermosets: Synthesis	NTS
42. Chemical Modification of Matrix Resin Networks with Engineering Thermoplastics 1. Phenolic Hydroxyl Terminated Poly (Aryl Ether Sulfone) Epoxy Systems	Navy N00014-78-C-0629	J.L. Hedrick; I. Yilgor; C.L. Wilkes; J.E. McGrath Virginia Tech	—	To study modification of epoxy network by hydroxyl terminated thermoplastics	Thermosets: Synthesis	NTS
43. Chemoviscosity Modeling for Thermosetting Resins, Part 4	NASA - DC NAS1-18000	T.H. Hou; J.Y.Z. Huang PRC Kentron, Inc.	—	To conduct and analyze an experimental study on the changes of chemorheological properties on commercial Hercules 3501-6 resin system cured under several conditions between 375 and 435K.	Thermosets: Characterization	NTS
44. Chemoviscosity Modeling for Reverse-Setting Resins, Part 1	NASA - DC NAG1-569	S.N. Tiwari; T.H. Hou; J.M. Bai Old Dominion University	—	To study chemoviscosity modeling for thermosetting resins	Thermosets: Characterization	NTS
45. Chemoviscosity Modeling for Thermosetting Resins, Part 2	NASA - DC NAS-18000	T.H. Hou PRC Kentron, Inc.	—	To develop an analytical model of chemoviscosity thermosets.	Thermosets: Characterization/ Processing	NTS
46. Chemoviscosity Modeling for Thermosetting Resins, Part 3	NASA-DC NAS1-18000	T.H. Hou; J.M. Bai PRC Systems Services Co.	—	To use modified WLF theory to describe chemoviscosity increases of cured materials.	Thermosets: Characterization/ Processing	NTS
47. Chlorine-Resistant Hollow-Fiber Reverse-Osmosis Membrane Elements	Army	Walter C. Babcock Bend Research Inc.	\$547,958.00	To develop chlorine-resistant membrane elements for brackish water & desalination.	Molecular Composites: Synthesis	FRIP
48. Comparative Evaluation of Epoxy Sealers and Their Polymer Concrete Overlays	DOT	M. Sprinkel Virginia Dept. of Highways and Transportation	—	To measure water proofing and permeability characteristics of epoxy sealers and their polymer concrete overlays.	Thermosets: Characterization/ Mechanical Properties (Environmental Effects)	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
49. Comparison of Flexural Properties of Aramid-Reinforced Pultrusions Having Varied Matrices, Pretreatments and Postures	NASA - Langley	M.L. Wilson; G.S. Johnson; J.O. Macconochie NASA Langley	In-House	To compare flexural properties of aramid-reinforced pultrusions.	Thermoplastics: Resin-Fiber (Interfacial) Chemistry-Mechanics	NTIS
50. Comparison of Notch Strength between Gr/PEEK (APC-1 and APC-2) and Gr/Epoxy Composite Materials and Elevated Temperature	Air Force - Wright-Patterson	Joe E. Ramsey, Jr. Wright-Patterson AFB	In-House	To study delamination growth in composite materials.	Thermoplastics: Characterization/ Mechanical Properties	NTIS
51. Composite Material Systems for High Temperature Applications	NASA - DC	E.R. Thompson United Technologies Research Center	-	To develop composite materials that will meet the demands of high temperature structural applications and to develop multilayer coating approaches that depend upon silicon nitride as the primary oxidation barrier.	Characterization: Processing	NTIS
52. Composite Materials Interface Mechanics	Air Force AFOSR-MIPR-89-0022	Zvi Hashin The University of Pennsylvania	03/01/89-02/28/91	To assess the effects of realistic interface conditions due to elastic, inelastic, and damaged interphase on the thermoelastic properties and failure of composite materials.	Molecular Composites: Mechanical Properties (Damage Tolerance)	MCR
53. Composite Materials for Intermediate Protective Clothing	Air Force	Richard W. Baker Membrane Technology and Research	\$401,712.00	To develop a new composite fabric material that will provide protection to Air Force workers exposed to hazardous environments.	Thermoplastics/Thermoplastics: Synthesis/ Characterization/ Processing/Resin/Mechanical Properties	FRIP
54. Computed Tomograph: Sensor for Intelligent Carbon-Carbon Processing	DARPA	James H. Stanley Advanced Research & Applications	\$63,445.00	To evaluate x-ray computer tomography to provide local measurement of material properties.	No subcategory established: Characterization	FRIP
55. Computer Simulation of the Motion of Defects and its Influence on Flow and Molecular Orientation in Liquid Crystal Polymers	NSF 880637	R. Ryskin Northwestern University	09/01/88-02/28/90 \$114,890.00	To study motion of defects in liquid crystal polymers modeled theoretically and numerically.	Molecular Composites: Resin-Fiber (Interfacial) Chemistry-Mechanics	FRIP
56. Conductive Polymer Blends	Navy - Naval Air Development Center N62769-86-C-0274	A.L. Barrier; K.A. Montoya Martin Marietta Labs	-	To study conductive polymer blends.	Thermoplastics: Characterization/ Processing	NTIS

TABLE 1
PMC RESEARCH MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
57. Conductivity Meter for Graphite Epoxy	Navy	Herbert Blenner MSI Electronics Inc.	\$49,171.00	To develop an efficient usable method of measuring the conductivity of graphite epoxy composite materials.	Thermoplastics Characterization	FRIP
58. Continuous Forming of Carbon/Thermoplastics Composite Beams	NASA - DC	Y. Sakatani, Y. Yamaguchi, M. Yashida Joint Publications Research Service	-	To develop a continuous forming method of thin, long structural elements with a view to applications for future large-sized space structures.	Thermoplastics Processing	NTS
59. Copolyimides with Flexibility Groups: Copolymers Have Improved Flexibility, Processability, and Melt-Flow Characteristics	NASA - DC	NASA DC	In-House	To discuss the synthesis of flowable polyimides.	Thermoplastics Synthesis	NTS
60. Copolyimides with a Combination of Flexibility Groups	NASA - Langley	T.L. St. Clair; H.D. Burke; D.J. Progar NASA Langley	In-House	To prepare a copolyimide of improved flexibility, processability and melt-flow characteristics.	Thermoplastics Synthesis/ Characterization/ Processing	NTS
61. Correlation Between Dielectric and Structural Properties During Epoxy Cure	Navy N00014-84-K-0274	W.W. Bidstrup; S.A. Bidstrup; S.D. Senturia Massachusetts Institute of Technology	-	To report on the relationship between dielectric properties and molecular structure of epoxies.	Thermosets Characterization	NTS
62. Correlation of Low-Velocity Impact Resistance of Graphite-Fiber-Reinforced Composites with Matrix Properties	NASA - Lewis	K.J. Bowles NASA Lewis	In-House	To study impact resistance of glass fiber-reinforced reinforced composites correlated with polymer matrix properties.	Thermoplastics Characterization/ Mechanical Properties	NTS
63. Correlation of Polyimide Resin Mechanical Properties With Polymeric Physical Properties	Air Force	Terry Brewer Brewer Science Inc.	\$124,557.00	To study the effects of polymeric physical properties on resin mechanical properties.	Thermosets: Synthesis/ Characterization	FRIP
64. Correlations of Norbornenyl Crosslinked Polyimide Resin Structures with Resin Thermo-Oxidative Stability Resin Glass Transition and Composite Initial Mechanical Properties	NASA - Lewis	W.B. Alston NASA Lewis	In-House	To study the correlation of crosslinked polyimide structure with that of glass transition and initial mechanical properties.	Thermosets Characterization/ Mechanical Properties	NTS

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PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
65. Corrosion Protection of Prestressing Systems in Concrete Bridges	DOT-FHWA	J. Pracek Wiles, Jenner, Elsner Associates	-	To develop corrosion resistant prestressing and post tensioning strands and bars using epoxy resins.	Thermosets: Processing	FRP
66. Crystallization of Tough Thermoplastic Resins in the Presence of Carbon Fibers. Semiannual Progress Report November 1, 1985-May 1, 1986	NASA - DC NAG1-525	M.H. Thell North Carolina State University	-	To study crystallization kinetics of PPS and PEEK in the presence and absence of carbon fibers.	Thermosets: Characterization	NTIS
67. Crystallization of Tough Thermoplastic Resins in the Presence of Carbon Fibers. Technical Report, Year Ending December 31, 1986.	NASA - DC	M.H. Thell North Carolina State University	-	To study the rate of isothermal crystallization as a function of amount of carbon fibers for thermoplastic composites.	Thermoplastics: Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics	NTIS
68. Cure and Properties of Cure and Properties of Thermosetting Polymers	Army - Army Research Office DAA029-84-K-0037	K. Gilham Princeton University	03/01/84-08/31/87	To study time-temperature transformation relationships of thermosets.	Thermosets: Characterization	NTIS
69. Cure Characterization of an Epoxy Network by Fluorescence Behavior of Trans-Diaminostilbene	Army - Army Research Office DAA029-85-K-0055	C.S. Sung; R. Maribon University of Connecticut	-	To mimic the reactivities of the curing agent in cure reactions using an approach based on labelling with reactive dyes.	Characterization: Processing	NTIS
70. Cure Monitoring of Epoxy Resins by Fluorescence Spectroscopy	Army-Army Research Office MIPR-ARO-111-84; MIPR-ARO-113-85 NIST	F.W. Wang; R.E. Lowry; R.M. Fasconi NIST	-	To monitor epoxy curing by fluorescence spectroscopy.	Thermosets: Characterization	NTIS
71. Cure Monitoring for Polymer Matrix Composites	NIST	B. Fancost; F. Wang; D. Hunston; F. Morsak NIST	In-House	To develop suitable means of process monitoring and control for improved processing.	Thermosets: Characterization/ Processing	NTIS
72. Cure and Properties of Thermosetting Systems	Navy N00014-84-K-0021	J.K. Gilham Princeton University	-	To understand the processes such as cure, properties, and degradation of the time-temperature-transformation diagrams.	Thermosets: Characterization	NTIS
73. Curing	Army - Army Research Office DAA029-84-K-0037	J.K. Gilham Princeton University	-	To describe the relationships between cure, properties, and thermal degradation for thermosetting systems during curing.	Thermosets: Processing	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subset(s)	Source
74. Curing	Navy N00014-84-X-0021	John K. Gillham Princeton University	-	To study curing of thermosets.	Thermosets: Processing	NTS
75. Curing Reaction-Processing- Structure Relationships of Thermosetting Polyester Resins	NSF 8517707	CD Han Polytechnic University	07/01/86-12/31/89 \$222,599.00	To study polymerization and compression molding through mathematical models.	Thermosets/ Thermoplastics: Synthesis/Character- ization/Processing/ Mechanical Properties	FRIP
76. Curing of Low Shrinkage Unsaturated Polyester Resins in Reactive Processing	NSF 8520674, 8820674	L. Lee Ohio State University	03/01/89-02/28/90 \$75,591.00	To improve surface quality and cycle time of unsaturated polyester resins by understanding the reaction mechanisms: 3d molecular structure.	Thermosets: Characterization/ Processing	FRIP
77. Damage Accumulation in a Gradient Stress Field in Graphite/Epoxy Laminates.	NASA	P.A. Lagace and C.E. Wolfe Technology Lab for Advanced Composites	-	To perform an experimental and analytical study on the progression of damage in gradient stress fields in graphite/epoxy systems.	Thermosets: Resin-Fiber (Interfacial) Chemistry- Mechanics/Mechanical Properties	ASC
78. Damage Characteristics of Laminates With a Hole	NASA	W.S. Chan Center for Composite Materials	-	To study damage characteristics of graphite/epoxy laminates with a hole.	Thermosets: Mechanical Properties (Damage Tolerance)	ASC
79. Damage Detection and Active Control Systems for Smart Aerospace	Air Force	Steve F. Stone Mission Research Corp.	\$50,159.00	To develop methods for sensing fiber damage in fiber reinforced epoxy composites.	Thermosets: Mechanical Properties (Damage Tolerance)	FRIP
80. Damage Tolerance Sensitivity/Durability (See also Table 2, Structures, #56.)	NASA - Langley NAS1-18778	Poe Stanford University	12/16/88 \$450,000.00	To model impact damage and develop damage tolerance sensitivity criteria.	Thermosets: Mechanical Properties (Damage Tolerance)	ACT
81. Damage Tolerance of Composites	Air Force Wright-Patterson AFB	E. Demuts Wright-Patterson AFB	In-House	To provide technical data and recommendations for damage tolerance for low velocity impact in advanced composites.	Thermosets: Mechanical Properties (Damage Tolerance)	ASC
82. Deteriorology-Creep-Fatigue Interaction in Composite Laminates	Air Force	R. Ostroff; W.W. Stinchcomb; K.L. Reisfelder Virginia Tech	-	To evaluate the magnitude of creep-fatigue interaction in composite laminates.	No subcategories established Mechanical Properties (Damage Tolerance/Fatigue)	ASC

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subject(s)	Source
83. Delamination Growth in Composite Materials	NASA - DC NAG1-475	J.W. Gillespie, L.A. Carlson; R.B. Pipes University of Delaware	-	To study delamination growth in composite materials.	Thermosets/ Thermoplastics/ Characterization/ Mechanical Properties	NTIS
84. Demonstration Project 60 - Epoxy Thermoplastic (EIT) Pavement Marking Material	DOT	K.R. Agent Kentucky University (Trans. Res. Prog.)	-	To evaluate by comparison the field performance of the epoxy thermoplastic pavement marking material.	Thermoplastics/ Characterization/ Mechanical Properties (Environmental Effects)	FRIP
85. Dependence of Interfacial Shear Strength on Matrix and Interphase Properties	Air Force	V. Rao; L.T. Drzal Michigan State University	-	To study the interfacial shear strength as a function of matrix and interphase properties.	Thermosets: Mechanical Properties	ASC
86. Design and Manufacturing Plan for a Composite Low-Altitude Dispenser (LAD)	Air Force	David Maas Advanced Composite Products	\$678,997.00	To manufacture epoxy composites for low-altitude dispenser.	Thermosets: Processing	FRIP
87. Design of a Stiffened Composite Plate with a Hole	NASA	S. Nagendra; R.T. Haftka; Z. Gurdal Virginia Tech	-	To describe the design of a centrally loaded hole in a stiffened composite plate.	No subcategory established. Mechanical Properties	ASC
88. Detection of Impact Damage in Composite Laminates by Acousto-Ultrasonic Technique	Navy	S.M. Moon; H.T. Hahn; K.L. Jerina Washington University	-	To use acousto-ultrasonic technique to locate damage and evaluate its extent in graphite/epoxy laminates.	Thermosets/ Characterization/ Mechanical Properties (Damage Tolerance)	US/I
89. Determination of the Viscosity Number of Thermoplastics in Dilute Solution; Polyimides(pa)	NASA - DC	NASA DC	In-House	To develop a method for determination of viscosity of polyimides.	Thermoplastics/ Characterization	NTIS
90. Development of Composite Structures with Enhanced Damage Tolerance	NASA	Janice Malden Textile Technologies Inc.	\$56,995.00	To develop advanced weaving designs of reinforcing fabric to give composites with enhanced mechanical properties.	Thermosets/ Processing/ Mechanical Properties (Damage Tolerance)	FRIP
91. Development of Covalent Bonding Processes for Thermoplastic Composites	NSF	John E. McDonald PDA Engineering	\$40,000.00	To study plasma treatment of fibers for improved interfacial resin adhesion.	Thermoplastics: Resin- Fiber (Interfacial) Chemistry-Mechanics	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
92. Development of Novel Curing Techniques for Thermosetting Polymers	Army	Bernard Baum Springborn Materials Science	\$49,510.00	To determine the feasibility of developing a thermosetting polymeric adhesive and curing method that will not require cure cycles in an oven or a press at elevated temperatures and pressures.	Thermosets: Synthesis	FRIP
93. Development of a Controlled Interfacial Bond Strength Process For Carbon-Phenolic and Carbon-Carbon Composites	NASA	H.M. Stoller ITDA Engineering	\$50,000.00	To increase fiber/resin adhesion by water and ammonia plasma treatment.	Thermosets: Resin/Fiber (Interfacial) Chemistry-Mechanics/Mechanical Properties (Environmental Effects)	FRIP
94. Development of a Heterogeneous Laminating Resin System	NASA - DC NAS1-16798	T.F. Biermann; L.C. Hopper Narmco Materials, Inc.	-	To evaluate composite properties as the formulation of the matrix is varied.	Thermosets: Processing/Mechanical Properties	NTIS
95. Development of a Polyimide Matrix for Filament Winding with Improved Extensibility and Fracture Toughness for Permanent Use at 200 Degrees Celsius	NASA - DC	H. Stenzenberger; M. Herzog; N. Frang; F. Seibacher Technochemie G.M.G.H.	-	To obtain high strength fibers using filament winding of bismaleimides.	Thermosets: Processing	NTIS
96. Development of an Asbestos Free Insulant for Rocket Motors	NASA - DC	D. Sureshchagrin; G. Couture Defense Res. Est. Valcaurtes	-	To replace asbestos in the rocket motor insulant designated RF/B.	Thermosets/Thermoplastics: Processing/Mechanical Properties	NTIS
97. Development of an Impact-and Solvent-Resistant Thermoplastic Composite Matrix, Phase 4.	NASA - DC NAS1-16808	C.B. Delano AccuresCorp/ Aerotherm	-	To discuss the synthesis and characterization of solvent-resistant polyimides.	Thermoplastics: Synthesis/Characterization	NTIS
98. Development of an Impact-and Solvent-Resistant Thermoplastic Composite Matrix, Phase 3.	NASA - DC NAS1-16808	C.B. Delano; C.J. Kleckas Accures Corp/ Aerotherm	-	To study polyimides to prepare void-free composite at low molding temperatures.	Thermoplastics: Synthesis/Processing	NTIS
99. Dielectric Analysis of Thermoset Cure	Navy N00014-84-K-0274	S.D. Senturia; N.F. Sheppard, Jr. Massachusetts Institute of Technology	5/1/84-10/7/85	To study measurement of dielectric analysis in curing thermosets.	Thermosets: Characterization	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
100. Dielectric Analysis of the Cure of Thermosetting Epoxy/Amine Systems	Navy N00014-84-K-0274	N.F. Sheppard, Jr.; S.D. Senturia Massachusetts Institute of Technology	5/00/85-8/00/86	To study the dielectric analysis of the cure of thermosetting epoxy/amine systems.	Thermosets: Characterization/ Processing	NTIS
101. Differential Scanning Calorimetry as a Quality Control Method For Epoxy Resin Prepreg	Army	M.F. Pleszar Benet Lab.	--	To study DSC as quality control for epoxy resin prepregs.	Thermosets: Characterization	CA
102. Diffraction Efficiency of Photothermoplastic Layers for the Recording of Discrete Holograms	NASA - DC	S.N. Koreshev; Y.A. Cherkasov; T.L. Kislinsky NASA DC	In-House	To determine the dependence of eta of a digital phase Fourier hologram of a point object on the amount of deformation delta and to detail the discrete-structure parameters that represent the hologram.	No subcategory established: No subset established	NTIS
103. Donor Acceptor Polymerization Chemistry as a Vehicle to Low Energy Cure of Matrix Resins: Evolution of the 2-Tg Concept to Produce High Tg Polymers at Ambient Temperatures	Air Force - Wright-Patterson F33615-85-C-5093; 2419/01	K.B. Wagener; G.B. Butler; C.H. Do; M. Johnson; M.A. Smith University of Florida	--	To synthesize the necessary donor and acceptor monomers and to examine a variety of synthetic approaches to create these compounds.	Thermosets: Synthesis/ Characterization	NTIS
104. Double-Pulsed CCD Phase-Sampled Laser Speckle Interferometric Methodology for NDT/E	NASA	Robert K. McMahan, Jr. McMahan Electro-Optics Inc.	\$43,110.00	To establish use of double-pulsed CCD phase-sampled laser speckle interferometric methodology for nondestructive testing.	No subcategory established: Characterization	FRIP
105. Durability and Damage Tolerance of Bismaleimide Composites, Volume 2: Appendix of Crack Growth & Low-Velocity Impact Data.	Air Force - Wright Aeronautical Labs F33615-85-C-3212; 2401/01	S.T. Tyahla; P.S. McClellan McDonnell Aircraft Co.	--	To evaluate durability and damage tolerance of bismaleimide (BMI) composites.	Thermosets: Mechanical Properties (Damage Tolerance)	NTIS
106. Durability of Reinforced Concrete Beams Strengthened by Epoxy-Bonded Steel Plates	DOT	R. Jones Sheffield University (England)	--	To evaluate the durability of epoxy-bonded steel plates as a strengthening system for reinforced concrete structures.	Thermosets: Mechanical Properties (Environmental Effects)	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
107. Dynamic Matrix Cracking and Delamination in Composite Laminates Subjected to Impact Loading	Navy - Office of Naval Research N00014-84-K-0554	C.T. Sun Purdue University	07/01/84-10/31/91	To investigate the propagation of damage in composite laminates due to impact loading conditions using theoretical and experimental techniques.	Molecular Composites: Mechanical Properties (Damage Tolerance)	MCR
108. Eddy Current Inspection of Graphite-Epoxy Composites	Navy	T.A.O. Gross Gross T.A.O. Inc.	\$457,724.00	To test structural integrity of graphite-epoxy composites by eddy current.	Thermosets: Characterization	FRUP
109. Eddy Current Inspection of Graphite/Epoxy Laminates	Navy	S.S. Lane; R.H. Moore; G.V. Candhe; and O.H. Griffin, Jr. Virginia Tech	-	To present a tutorial review on the fundamentals of eddy current in the laminates.	Thermosets	ASC
110. Effect of Annealing History on Free Volume in Thermoplastics	NASA - Langley	J.J. Singh; T.L. St. Clair NASA Langley	In-House	To study the effects of thermal annealing on thermoplastic glassy polymers.	Thermoplastics	NTIS
111. Effect of Counterface Material Type and Its Topography on the Tribological Properties of Polyimide Composites	NASA - Lewis	R.L. Fusaro NASA Lewis	In-House	To discuss tribological properties and wear rate of polyimides.	Thermoplastics: Characterization	NTIS
112. Effect of Substituted Phenyladimides on Processing and Properties of PMR (Polymerization of Monomeric Reactants) Polyimide Composites	NASA - Lewis	W.B. Alston; R.W. Lauver NASA Lewis	In-House	To investigate the curing of polyimides with nitronadimides and non-nitronadimides.	Thermosets: Synthesis/ Characterization	NTIS
113. Effects of Cure Pressure on Resin Flow, Voids, and Mechanical Properties	Air Force - Wright-Patterson F33615-84-C-5049; 2419-01	G.S. Springer; J.M. Tang; W.I. Heu Stanford University	-	To study mechanical property and voids as a function of cure pressure.	Thermosets: Characterization/ Mechanical Properties	NTIS
114. Effects of Ionizing Radiation on Epoxies, Graphite Fiber and Heir Components	Army	J.S. Park; K.S. Seo; R.E. Fornes; R.D. Gilbert North Carolina State University	-	To investigate the effect of high-energy radiation on epoxy composite interfaces.	Thermosets: Mechanical Properties (Damage Tolerance/Fatigue)	CA
115. Effects of Long-Term Thermal Aging on Coated Cellon/Larc-160 Composites	NASA - Langley	J.R. Nelson NASA Langley	In-House	To study thermal aging of polyimides over long periods with coated Cellon to see weight loss effects.	Thermoplastics: Mechanical Properties (Environmental Effects)	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
116. Effects of Moisture Loss and Elevated Temperature Upon the Material Damping of Fiber Reinforced Polymer Matrix Composites	NASA-DC	W.D. Morrison Toronto University	—	To investigate the effects of moisture loss and high temperature on the mechanical properties of composites.	Thermoplastics: Characterization/ Mechanical Properties	NTIS
117. Effects of Ply Dropoffs on the Tensile Behavior of Graphite/Epoxy Laminates	Air Force	P.A. Lagace; R.K. Cannon Massachusetts Institute of Technology	—	To study the effects of ply dropoffs on the mechanical and fracture behavior of graphite/epoxy laminates	Thermosets: Characterization/ Mechanical Properties	US/I
118. Effects of Simulated Space Environmental Parameters on Six Commercially Available Composite Materials	NASA - Langley	J.G. Frunk; G.F. Sykes NASA Langley	In-House	To determine the effects of simulated space environmental parameters on microdamage induced by the environment in a series of commercially available graphite fiber-reinforced composite materials.	Thermoplastics/ Thermosets: Mechanical Properties (Environmental Effects)	NTIS
119. Effects of Solvents on Craze Initiation and Crack Propagation in Transparent Polymers	Army	J.J. Vanselow; A.J. Heich; J.H. Brown; J.L. Stevens Army Materials Technology Lab	In-House	To evaluate transparent polymers that are being considered for use in Army systems for resistance to crack and craze growth in a chemical environment.	Thermoplastics: Mechanical Properties (Environmental Effects)	NTIS
120. Effects of Thermal Cycling on Composite Materials for Space Structures	NASA - Langley	S.S. Tompkins NASA Langley	In-House	To describe the effects of thermal cycling on the thermal and mechanical properties of composite materials.	No subcategory established: Mechanical Properties (Environmental Effects)	NTIS
121. Effects of Thickness on Notched Laminated Composites Under Uniaxial Compression	Navy	A.J. Vizzini and N.L. Mueller University of Maryland	—	To study the effects of thickness of the laminates on stress-strain and fracture mode under uniaxial compression.	Thermosets: Mechanical Properties (Damage Tolerance)	ASC
122. Elastomer Encapsulant for Solar-Cell Arrays: Liquid Encapsulant Polymerizes to a Transparent, Protective Rubberlike Coat	NASA - DC	NASA DC	In-House	To discuss the use and curing of butylacrylate syrup for potting compounds in photovoltaic cells.	Thermosets: Synthesis	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
123. Elastomer Toughened Polyimide Adhesives	NASA - Langley	A.K. St. Clair; T.L. St. Clair NASA Langley	In-House	To synthesize rubber toughened polyimides.	Thermoplastics: Synthesis	NTIS
124. Electrochemical Behavior of Graphite Fiber Polymer Composites	Army - Army Research Office DAA029-82-K-0053	G.E. Stoner; G.L. Caher University of Virginia	-	To measure electrical properties and surface functional groups of thermosets.	Thermosets: Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics	NTIS
125. Electromagnetic (Microwave) Processing of High-Performance Polymeric Matrix Resins for Composite Structures	DARPA	J.C. Hedrick; D.A. Lewis; G.D. Lyle; T.C. Ward and J.E. McGrath Virginia Tech	-	To develop electromagnetic (microwave) processing that is extended from simple epoxies to toughened epoxies and toughened maleimides.	Thermosets/ Thermoplastics: Processing/Mechanical Properties (Fatigue)	ASC
126. Electron Beam Imageable Polyimides	NSF	Perry Brewer Brewer Science, Inc.	\$226,208.00	To develop polyimide precursors which can be imaged by electron beams.	Thermoplastics: Synthesis	FRIP
127. Electronic and Ionic Transport in Polymers	Navy N00014-86-K-0769	M. Pomerantz; J.R. Reynolds; K. Rajeshwar; D.S. Marynick; T.D. Shaifer University of Texas	-	To study a bimolecular phase transfer catalyzed polythioetherification, and to prepare and study new salen monomers containing terminal alkyl units and unsaturation.	Thermoplastics: Synthesis/ Characterization	NTIS
128. Emulsion Polymerization Kinetics	NSF	G.W. Fochlein Georgia Institute of Technology	12/01/87-05/31/89 \$66,734.00	To study emulsion polymerization kinetics.	Thermoplastics: Synthesis	FRIP
129. Engineering Research Equipment Grant: In-Plane Biaxial Servo-Hydraulic Fatigue Testing Machine	NSF	M. Cornthou University of Michigan	\$75,000.00	To study interfacial shear and biaxial interfacial fatigue of an aluminum-epoxy bimaterial.	Thermosets: Mechanical Properties	FRIP
130. Environmental Effects and Environmental Damage in Composites	Navy - Office of Naval Research N00014-82-K-0562	Y. Wetsman Texas A&M University	10/01/84-09/30/90	To research the effects of stress, temperature, and moisture on the mechanical response of polymer composites. Environmentally induced damage growth and its effect on composite response will be investigated.	Molecular Composites: Mechanical Properties (Environmental Effects)	MCR
131. Environmental Stress Cracking and Cracking of Transparent Polymers	Army	A.J. Heich, J.J. Varelzow Army Materials Technology Lab	In-House	To evaluate the resistance to crack and growth in polycarbonate and poly (methyl methacrylate).	Thermoplastic: Characterization/ Environmental	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
132. Epoxy Network Structure: 4. A Neutron Scattering Study of Epoxies Swollen in a Deuteriated Solvent	NIST	W.L. Wu; D.L. Hunston; H. Yang; R.S. Stein NIST	In-House	To study the network characterization of epoxies using neutron scattering using deuteriated acetone as contrast.	Thermosets: Characterization	NTIS
133. Epoxy Thermoplastic Demonstration	DOT	D. Griffin Colorado Department of Highways	-	To evaluate the cost and effectiveness of epoxy thermoplastic (ETP) pavement marking.	Thermoplastics: Characterization/ Mechanical Properties	FRIP
134. Epoxy Thermoplastic Pavement-Marking Materials Demonstration Project 60	DOT-FHWA	J.A. Wagner Florida Dept. of Transportation	-	To evaluate epoxy thermoplastic pavement-marking materials.	Thermoplastics: Characterization	FRIP
135. Epoxy-System Overlay for Concrete Bridge Decks	DOT-FHWA	M. Rasoulian Louisiana Dept. of Transportation	-	To evaluate cost - effective performance of various epoxy system overlays for concrete bridge decks.	Thermosets: Characterization	FRIP
136. Ethynyl-Containing Phthaloyl Halides	Air Force	R.C. Evers; G.J. Moore Air Force	In-House	To investigate the synthesis of polyimides through intramolecular cyclization.	Thermoplastics: Synthesis	NTIS
137. Ethynylated Aromatics at High Temperature Matrix Resins	NASA - Lewis	F.I. Hurwitz NASA Lewis	In-House	To study the synthesis and curing of acetylene terminated polymers and review mechanical properties.	Thermosets: Synthesis/ Characterization/ Mechanical Properties	NTIS
138. Evaluation of Epoxy-Coated Reinforcing Steel	DOT-FHWA	W.T. McKee, Jr. Virginia Dept. of Highways & Transportation	-	To evaluate the performance of epoxy-coated reinforcing steel in bridge decks.	Thermosets: Characterization/ Mechanical Properties	FRIP
139. Evaluation of Epoxy-Coated Reinforcing Steel in Bridge Decks	DOT-FHWA	L. Ku Maryland Dept. of Transportation	-	To evaluate the performance of epoxy-coated reinforcing steel in bridge decks.	Thermosets: Characterization/ Mechanical Properties	FRIP
140. Evaluation of Extruded Thermoplastics as Lane Delineation	DOT - FHWA	K.R. Agent; J.C. Piggman Kentucky Transportation Research Program	-	To evaluate the performance of thermoplastics as lane delineation and to compare the performance of hydrocarbon versus alkylid formulations.	Thermoplastics: Characterization	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
141. Evaluation of Thin Epoxy System Overlays for Concrete Bridge Decks	DOT - FHWA	M. Rasolian Louisiana Dept. of Transportation	-	To evaluate application and properties of thin epoxy system overlays for concrete bridge decks.	Thermosets: Characterization / Processing	FRIP
142. Evaluation of TI-6Al-4V Surface Treatments for Use with a Polyphenylquinoxaline Adhesive	NASA - Langley	D.J. Progar NASA Langley	In-House	To evaluate three surface treatments for TI-6Al-4V using a thermoplastic polymer MEPTQ.	Thermoplastics: Mechanical Properties	NTIS
143. Evaluation of a Thermoplastic Polyimide (422) for Bonding Gr/pt Composite	NASA	D.J. Progar NASA Langley	In-House	To study the mechanical properties of hot melt processable polyimides.	Thermoplastics: Mechanical Properties	NTIS
144. Evolution Mechanics	Air Force AFOSR-89-0216	K.L. Reifelder Virginia Tech	12/01/88-11/30/91	To develop methods for predicting the long term behavior of composite materials, especially their remaining strength and life after periods of service which includes exposure to time-variable thermo-mechanical and chemical loading.	Molecular Composites: Mechanical Properties (Fatigue)	MCR
145. Experimental Construction of a Bridge Slab with Epoxy Resin-Coated Reinforcing Bars	DOT	Japan Highway Public Administration (Japan)	-	To evaluate corrosion resistance of bridge slab with epoxy coated reinforcing bars due to deicing chemicals.	Thermosets: Mechanical Properties (Environmental Effects)	FRIP
146. Experimental Epoxy Traffic Stripes	DOT-FHWA	C. Younger New Jersey Dept. of Transportation	-	To establish the superior performance of epoxy resin pavement systems over conventional traffic paint.	Thermosets: Characterization	FRIP
147. Fabrication and Testing of Fire Resistant Graphite Composite Panels	NASA - DC NAS2-12039	W.D. Roper Hercules, Inc.	-	To fabricate and test fire-resistant graphite composite panels.	Thermosets: Processing	NTIS
148. Failure Behavior of PEEK and Its Short-Fiber Composite System	Army - Army Research Office DAA/G29-85-K-0042	J.M. Schultz University of Delaware	-	To study the development of microstructure in PEEK and its short-fiber composites and the effects of microstructure on mechanical failure.	Thermoplastics: Processing/Mechanical Properties	NTIS
149. Failure of Thick Composite Laminates	Navy - Office of Naval Research N00014-88-F-0044	R.M. Christensen Lawrence Livermore National Lab (DOE)	02/01/88-01/31/90	To research the mechanics of failure of composite material, with emphasis on physically based failure criteria for thick composite laminates.	Molecular Composites: Mechanical Properties (Fatigue)	MCR

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
150. Fatigue Crack Propagation in Crystalline Polymers and Composites	Navy N00014-77-C-0633	John A. Manson; R.W. Hertzberg Lehigh University	-	To determine the role of polymer structure, composition, and morphology on the kinetics, energetics, and mechanisms of FCP in typical crystalline polymers, as well as the effects of external variables such as frequency and stress range.	Thermoplastics: Mechanical Properties (Fatigue)	NTIS
151. Fatigue Damage Development of Various CFRP (Carbon Fiber Reinforced Plastic)-Laminates	NASA - DC NASW-4307	K. Schulte; C. Baron NASA DC	In-House	To investigate fatigue behavior of polymer composites by varying the type of weave of the fibers.	Thermoplastics: Mechanical Properties (Fatigue)	NTIS
152. Filament Winding Thermoplastic Composites	NSF 8814593	G. Springer Stanford University	12/01/88-05/31/90 \$101,309.00	To develop methodologies required to filament point thin and thick structural elements made of thermoplastic matrix composites.	Thermoplastics: Mechanical Properties	FRIP
153. Fire Characteristics of Composite Materials--A Review of the Literature	Navy - Naval Sea Systems Command	J.E. Brown; J.I. Lofthus; R.A. Dipert NIST	-	To study fire characteristics of composite materials for use in U.S. Navy shipboard structures.	Thermosets/ Thermoplastics: Mechanical Properties	NTIS
154. Flammability Smoke and Toxicity Characterization of Thermoplastic Elastomers	Navy	Douglas Hoon Advanced Composite Products Inc.	\$73,228.00	To assess lightweight structural composite materials with greatly improved flammability, smoke generation, and toxic fume generation properties.	Thermoplastics: Characterization/ Mechanical Properties (Environmental Effects)	FRIP
155. Formation and Properties of Thermosetting and High Tg Polymeric Materials	Navy N00014-84-K-0021	J.K. Gillham Princeton University	-	To study the synthesis of high Tg thermosetting polymeric materials.	Thermosets: Synthesis	NTIS
156. Fractography of Composite Materials	Air Force Wright-Patterson	S.S. Saliba; D.R. Askins; James A. Said University of Dayton	-	To characterize failure modes and examine fracture surfaces of glass reinforced polypropylene composites.	Thermoplastics: Characterization/ Mechanical Properties (Damage Tolerance)	US/J
157. Fractography of Composites	Air Force - Wright-Patterson F33615-82-C-5039; 2421, 03	P.L. Stumpff; J.A. Said University of Dayton	-	To develop a fractography handbook for composite materials.	Thermosets: Characterization	NTIS
158. Fracture Characterization of Injection Molded Thermoplastic Elastomers	NSF	B.H. Kim University of Massachusetts	\$68,100.00	To examine fracture characterization of injection molded thermoplastic elastomers.	Thermoplastics: Mechanical Properties (Fracture Behavior)	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
159. Fracture Mechanics of Interfacial Zones in Bonded Materials	Navy - Office of Naval Research N00014-89-J-3188	F. Erdogan Lehigh University	09/01/89-08/31/91	To study the micromechanics aspects of failure of composites, accounting for realistic interfacial zones. Models will be established for crack propagation in interfacial regions with continuously varying mechanical properties.	Thermosets: Resin-Fiber (Interfacial) Chemistry-Mechanics/Mechanical Properties	MCR
160. Fracture Mechanics, Laminate Failure Mechanics (See also Table 2, Structures, #106.)	NASA - Langley NAS1-18833	Grews University of Utah	12/08/88 \$179,000.00	To develop laminate failure mechanisms using fracture mechanics.	Thermosets: Mechanical Properties	ACT
161. Fracture Surface Analysis in Composite and Titanium Bonding	NASA - DC NAG1-343	T.A. Devilbiss; J.P. Wightman Virginia Tech	-	To study fracture surface analysis of composite materials.	Molecular Composites: Characterization	NTIS
162. Fracture/Fatigue: Textiles Failure Response (See also Table 2, Structures, #108.)	NASA - Langley NAS1-18840	Whitcomb Rockwell	03/31/89- \$433,000.00	To develop the micromechanics of fatigue failure in composites made from textile preforms.	Thermosets: Mechanical Properties (Fatigue)	ACT
163. Free Radical Cure of the Bismaleimide of Dimer Diamine	Navy	E.C. Martin; A.A. De Frisco Department of the Navy	In-House	To discuss the free radical curing of bismaleimide.	Thermosets: Synthesis	NTIS
164. Graphite/PMR Polyimide Composites With Improved Toughness	NASA - Lewis	R.D. Vannucci, K.J. Bowles NASA Lewis	In-House	To study the toughness of polyimides modified with flexible links.	Thermoplastics: Synthesis / Characterization / Processing	NTIS
165. Hardened Lightweight Air Cover Design (See also Table 2, Structures, #110.)	Air Force	P.S. Spangler Sunol Sciences Corp.	\$53,187.00	To define crucial air cover design parameters for meeting the higher nuclear hardness and survivability requirements of advanced re-entry vehicles.	Thermoplastics: No subset established	FRIP
166. Heat Resistant Matrix Materials	NASA - DC	O. Dickman Forsvarets Forskningsanstalt	-	To study heat resistant matrix materials.	Thermoplastics: Processing	NTIS
167. Heterogeneous Characterization of Composite Materials with Progressive Damage	Air Force AFOSR-88-0724	Isaac M. Daniel Northwestern University	02/01/88-01/31/91	To develop constitutive and failure models for composite materials based on observed damage mechanisms and damage development. The study will include organic matrix composite materials such as graphite/epoxy, as well as high-temperature composites, such as ceramic matrix/ceramic fiber composites.	Thermosets: Mechanical Properties (Damage Tolerance)	MCR

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subsets(s)	Source
168. High Char Yield Polymer Matrix Composites	Navy	E.L. Paquette Refractory Composites Inc.	\$49,885.00	To study new high char yield resins to achieve structurally sound, low cost carbon-carbon composites.	Thermosets: Processing/Resin-Fiber (Interface) Chemistry- Mechanics	FRIP
169. High Molecular Weight Polyphenylquinoxalines with Increased Solvent Resistance	Air Force - Wright-Patterson	P.M. Lindley; B.A. Reinhardt; F.A. Arnold Wright Aeronautical Labs	In-House	To increase solvent resistance of high molecular-weight polyphenylquinoxalines.	Thermoplastics: Synthesis/Mechanical Properties (Environmental Effects)	NTIS
170. High Performance Composites Research at NASA-Langley	NASA - Langley	T.L. St. Clair; N.J. Johnston; K.M. Baucom NASA Langley	In-House	To examine the use and processing of thermoplastics and thermosets for use as advanced composites.	Thermosets/ Thermoplastics: Processing	NTIS
171. High Performance Mixed Bismide Resins and Composites Based Thereon	NASA - Ames	J.A. Parker; A.H. Heimbach; M.T.S. Hsu; T.S. Chen NASA Ames	In-House	To study high performance mixed bismide resin and composites based thereon.	Thermoplastics: Characterization/ Mechanical Properties	NTIS
172. High Performance Thermoplastics: A Review of Neat Resin and Composite Properties	NASA	N.J. Johnston; P.M. Hergenrother NASA Langley	In-House	To review neat polymer properties and the resulting composite.	Thermoplastics: Processing	NTIS
173. High Strength/High Modulus Aromatic Heterocyclic ABA Block Copolymers	Air Force - Wright-Patterson	T.T. Tsai; F.E. Arnold Wright Aeronautical Labs	In-House	To discuss research on the synthesis and properties of ABA block copolymers composed of a rigid-rod block for reinforcement and a flexible coil block as the matrix.	Molecular Composites: Synthesis/ Characterization	NTIS
174. High Temperature Composites Using Schiff's Base Pyropolymer Matrices	Navy - Naval Air Development Center RSMAS3	S.J. Thomann; L.J. Buckley Naval Air Development Center	In-House	To evaluate two acetylene functional Schiff's base pyropolymers as matrix materials for fiber reinforced composite materials.	Thermosets: Synthesis/ Characterization/ Mechanical Properties	NTIS
175. High Temperature Polyimide Film Laminates and Process for Preparation Thereof	NASA - Langley	A.K. St. Clair; T.L. St. Clair NASA Langley	In-House	To study preparation process for high temperature polyimide film laminates.	Thermoplastics: Processing	NTIS
176. High Temperature Polymer Matrix Composites	NASA - Lewis	M.A. Meador NASA Lewis	In-House	To examine the use and future for high temperature composites for aircrafts.	Thermoplastics: No subsets established	NTIS

TABLE 1
PMC RESEARCH MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subset(s)	Source
177. High Temperature Rigid-Rod Polymers	Air Force	Dr. Neil Hendricks Maxdem Inc.	\$71,611.00	To design and synthesize some derivatives of a new rigid rod polymer.	Thermoplastics: Synthesis	FRIP
178. High Temperature Zero Coefficient of Thermal Expansion Space	SDIO	Richard E. Engdahl Synterials	\$49,887.00	To study the feasibility of deliberately biodegrading fluorosilicone elastomers.	Thermosets/ Thermoplastics: Characterization/ Mechanical Properties (Environmental Effects)	FRIP
179. High-Performance Electrical Insulators for Space Power Applications	SDIO	Ward D. Halverson Spire Corp.	\$74,721.00	To assess efficiency and reliability of vacuum cast epoxies for high-voltage insulators in vacuum.	Thermosets: Characterization	FRIP
180. High-Sensitivity One-Sided X-Ray Inspection Systems	Navy	Harold Berger Industrial Quality, Inc.	\$545,000.00	To detect and size defects in simulated rocket pressure vessels using x-ray scattering.	Thermosets: Characterization	FRIP
181. High-Temperature Copolyimide Adhesive; Thermoplastic Copolyimide Polymer Is Made from Inexpensive Commercially Available Materials	NASA - DC	NASA DC	In-House	To synthesize high-temperature copolyimides from inexpensive available materials.	Thermoplastics: Synthesis	NTIS
182. High-Temperature Thermosets Derived from the Diels-Alder Polymerization of Bisbenzocyclobutenes and Bismaleimides	Air Force - Wright Patterson	L.S. Tan; E.J. Soloski; F.E. Arnold Wright Aeronautical Lab.	In-House	To study high-temperature thermosets made by curing bisbenzocyclobutenes and bismaleimides.	Thermosets: Synthesis	NTIS
183. Homogeneous Polymer Salt Composites	NSF 8722245	J. Smid State University of New York	04/01/88-09/30/90 \$187,300.00	To synthesize and study solid-state properties of homogeneous ion-conducting polymer-electrolyte complexes.	Molecular Composites: Synthesis/ Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics	FRIP
184. Homogenization Study of Matrix Behavior in a Composite Material	NASA - DC DRET-86-34-001	J. Renard, L. Anquez Office National d'Etudes et de Recherches Aerospaciales (France)	—	To study transversal cracks in composite materials and to describe local degradation by the matrix homogenization method using a square elementary cell and a hexagonal one.	Thermosets: Mechanical Properties	NTIS

TABLE 1
PMC RESEARCH MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
185. Hugonots of M-30 Propellant and an Inert Simulator of M-30	Army - Army Ballistic Research Lab 1L162618A:180	V.M. Boyle Army Ballistic Research Lab	In-House	To examine hugonots of M-30 propellant and an inert simulator of M-30	Thermoplastics: Mechanical Properties/Damage Tolerance/Fracture Behavior	NTS
186. Hygrothermal Influence on the Edge Delamination in Composites	NASA	E.A. Armanios and A.M. Badir Georgia Institute of Technology	—	To develop a theory on shear deformation to calculate interlaminar stresses and edge delamination in graphite/epoxy laminates.	Thermosets: Mechanical Properties (Damage Tolerance)	ASC
187. Impact Damage Characterization of Carbon-Carbon Satellite Materials	Navy	Kent W. Buecking Materials Sciences Corp.	\$50,000.00	To evaluate the effects of impact damage upon the structural behavior of carbon-carbon satellite materials	No subcategories established: Characterization	FRP
188. Impact Damage Development in Damaged Composite Materials	NASA	J.C. Duke, Jr., M.T. Klerman Virginia Tech	—	To predict impact damage development in composites based on acousto-ultrasonic techniques.	Thermosets: Characterization/Mechanical Properties (Damage Tolerance)	US/J
189. Impact Resistance of Cross-Piled Polyphenylene Sulfide Composites	Navy	Murali Vedula and Michael J. Koczak Drexel University	—	To study the impact resistance and residual strength of polyphenylene sulfide composites with regard to laminate configurations.	Thermoplastics: Characterization/Mechanical Properties (Damage Tolerance)	US/J
190. Impact Response and Damage in Three-Dimensional Braided Graphite Fiber Composites	NASA - Langley	C.C. Poe, Jr. NASA Langley	10/01/87-10/31/90 In-House	To characterize damage in three-dimensional braided composites subjected to hard-object impact at low-energy levels.	Thermosets: Mechanical Properties (Damage Tolerance)	MCR
191. Impact Response and Damage in Three-Dimensional Braided Graphite Fiber Composites (See also Table 2, Structures, #122.)	NASA	Bhavani V. Sankar University of Florida	—	To evaluate the impact damage resistance of graphite fiber braided composites and to compare their performance with that of laminated composites.	Thermosets: No subcategory established	NASA
192. Impact Response and Damage of Braided Graphite/Epoxy Composites	NASA	J.C. Gang and B.V. Sankar University of Florida	—	To study damage and impact response of 3-D braided graphite/epoxy composites.	Thermosets: Mechanical Properties (Damage Tolerance)	ASC
193. Improved Synthesis of Poly(Benzobisthiazole) Polymers	Air Force	Robert F. Kovar Foster-Miller Inc.	\$243,177.00	To develop better synthesis of PBT.	Molecular Composites: Synthesis	FRP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory/ Subset(s)	Source
194. In Situ Fiber Optic Sensor for FTIR Monitoring of Composite Cure Cycles	NASA	John McCoy Foster Miller Inc.	\$544,951.00	To observe degree of cure of thermosetting composites with in situ FTIR Fiber Optic System.	Thermosets Characterization	FRP
195. In Situ Monitoring of Chemical and Rheological Changes During Fabrication of Advanced Fiber Architecture Composites	NASA	David Kornbluth College of William and Mary	—	To develop automated cost-effective fabrication methods for Resin Transfer Molding (RTM) of resin/3-D advanced fiber architectural materials using Frequency Dependent Electromagnetic Sensors (FDEMS).	Thermosets Characterization/ Processing	NASA
196. In-Situ Formation of Reinforced Thermoplastic Composites	NSF	D.G. Baird; T. Sun; D.S. Dore, and G.L. Wilkes Virginia Tech	—	To process in-situ formation of LCP reinforced thermoplastic composites.	Thermoplastics Processing	ASC
197. Industrial Process Profiles for Environmental Use. Chapter 10a. The Plastics and Resins Processing Industry.	EPA EPA-68-02-3994	Radian Corp.	—	To study the conversion of organic chemicals into solid or liquid polymers.	Thermoplastics Synthesis	NTIS
198. Industry-University Cooperative Research: Flow of Polymers in Complex Geometries	NSF 8819660	W.W. Graessley Princeton University	02/15/89-07/31/91; \$122,792.00	To study polymer-flow in the formation of composites.	Thermosets; Resin-Fiber (Interfacial) Chemistry- Mechanics	FRP
199. Influence of Particle Properties on the Room Temperature Compaction of Polyester-Ether Ketone (PEEK) Powders	Navy - Naval Air Development Center	J.J. Reilly, L.L. Kamel Naval Air Development Center	In-House	To study cold compaction of PEEK.	Thermoplastics Processing	NTIS
200. Injection Compression for Short Fiber Reinforced Plastics	NASA - DC	J.M. Sainteuchandelin Societe Nationale Industrielle Aerospatiale	—	To study the injection compression of thermoset moldings with short fibers.	Thermosets; Processing	NTIS
201. Injection-Molded Thermoplastic Electronic Enclosures	Air Force-Dept. of the Air Force	—	—	To establish manufacturing processes for injection molding of thermoplastic electronic enclosures.	Thermoplastics Processing	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subject(s)	Source
202. Innovative Concepts, Structural Mechanics, Verification (See also Table 2, Structures, #130 and Table 3, Manufacturing, #64.)	NASA - Langley NASI-18888	Stuart Lockheed	04/78/89- \$22,526,000.00	To develop composite technology for wing structure and pressurized fuselage structure including innovative structural concepts, structural mechanics, manufacturing technology, and verification.	Thermosets/ Thermoplastics/ Synthesis/ Characterization/ Processing/ Mechanical Properties/ Damage Tolerance/ Fatigue	ACT
203. Interface Modified Glass Fiber/Thermoplastic Matrix Composites	Navy N00014-88-C-0725	R.F. Kowar, R.W. Lusignea Foster Miller, Inc	-	To apply a proprietary interface modification process to improve the interaction between glass fibers and thermoplastic resin composites matrices.	Thermoplastics/ Resin/ Fiber (Interfacial) Chemistry-Mechanics	NTIS
204. Interfacial Adhesion of Carbon Fiber. Final Report, November 1984-October 1986.	NASA - DC	W.D. Rescom Hercules, Inc.	-	To examine the interfacial adhesion of carbon fiber.	Thermoplastics/ Processing	NTIS
205. Interfacial Adsorption and Crystallization of Polycarbonate in Carbon Fiber Composites	Navy N00014-88-K-0224	R.S. Porter, R.L. Brady University of Massachusetts	-	To examine a polycarbonate/carbon fiber composite system with regard to interfacial adsorption and crystallization by altering times and temperature of annealing.	Thermoplastics/ Resin/ Fiber (Interfacial) Chemistry-Mechanics/ Mechanical Properties	NTIS
206. Interfacial Shear Strength in Fiberglass Composites	Navy - Office of Naval Research	D.W. Dwight, P.J. Sabat, H.F. Britton Lehigh University	-	To compare short beam shear strength and the corresponding interfacial shear strength of single fiber specimens.	Thermosets/ Characterization/ Resin/ Fiber (Interfacial) Chemistry-Mechanics	ASC
207. Interfacial Strength Development in Thermoplastic Resins and Fiber-Reinforced Thermoplastic Composites	NASA - Langley NASA-NAG1-343	J.C. Howes, A.C. Loos Virginia Tech	-	To investigate an experimental approach to developing test methods for interfacial strength.	Thermoplastics/ Mechanical Properties	NTIS
208. Interlaminar Compression of a Thick Composite	NASA	D. Post, J. Morton, Y. Wang and F. Dai Virginia Tech	-	To study surface deformations and interlaminar compression studies using Moiré interferometry.	Thermosets/ Mechanical Properties (Damage Tolerance)	ASC
209. Interlaminar Fracture Toughness Testing of Composites	NASA - Langley	T. Kevin O'Brien NASA Langley	In-House	To develop standard tests for measuring interlaminar fracture toughness of composites.	Thermosets/ Thermoplastics/ Mechanical Properties	MCR

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
210. Interlaminar Fracture Toughness of Thermoplastic Composites	NASA - Langley	J.A. Hinkley; N.J. Johnston; T.K. O'Brien NASA Langley	In-House	To study delamination and fracture toughness of thermoplastic composites.	Thermoplastics: Characterization / Resin-Fiber (Interfacial) Chemistry / Mechanics	NTS
211. Interlaminar Shear Fracture Toughness (See also Table 2, Structures, #134.)	NASA - Langley	Gretchen B. Murri NASA Langley	05/31/89-09/30/90 In-House	To measure the mode II strain energy release rate of two materials in fatigue using cyclic end-notched flexure tests.	Thermoplastics: Mechanical Properties	MCR
212. Interlaminar Shear Fracture Toughness and Fatigue Thresholds for Composite Materials	NASA - Langley DA proj. ILL-61102-AH-45c	T.K. O'Brien; G.B. Murri; S.A. Salpekar NASA Langley	In-House	To examine fracture toughness and interlaminar shear fracture of composites.	Thermoplastics: Mechanical Properties	NTS
213. Interlaminar Shear Fracture of Laminated Composites	NIST	H. Chai Polymers Division NIST	In-House	To study Mode I and Mode II interlaminar fracture behavior of laminated composites using beam type specimens and SEM.	No subcategory established: Mechanical Properties	ASC
214. Interphase Technology	NASA - Langley NASI-18883	Hinkley University of Utah	03/28/90- \$847,900.00	To develop resin fiber interphase technology emphasizing influence of interphase properties on compression properties.	Thermoplastics / Resin-Fiber (Interfacial) Chemistry - Mechanics / Mechanical Properties	ACT
215. Investigation of Composite Materials for Marik in Skeletal Components, Small Business Innovation. Research Phase I	Air Force - Wright-Patterson F33615-87-C-0544; 7231; 36	C. Van Ingen; J.W. Colman Sumula, Inc.	-	To analyze 50th percentile Hybrid III and human femoral bone properties for designing a composite femur, and to conduct a comprehensive testing study to compare their strength.	No subcategory established: Characterization / Mechanical Properties	NTS
216. Investigation of Deformation Path-Independence of Mechanical Work in Fiber-Reinforced Plastics	Air Force	M.J. Lamborn and R.A. Schapery Texas A & M University	-	To experimentally verify the prediction that mechanical work is a potential function during damage-growth process in graphite/epoxy composites.	Thermoplastics: Characterization / Mechanical Properties (Damage Tolerance)	US/I
217. Investigation of Fiber-Reinforced Thermoplastic Materials For Use in Aircraft	Army 009102	Joseph W. Colman Sumula Inc.	\$49,970.00	To investigate fiber-reinforced thermoplastic materials for use in air craft.	Thermoplastics: Mechanical Properties (Damage Tolerance)	FRIP
218. Investigation of Physical Properties of Thermoplastic Polyimides	NASA - Langley	J.J. Singh; D.M. Soakley NASA Langley	In-House	To investigate the mechanical properties of polyimides.	Thermoplastics: Characterization	NTS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
219. Investigation of the Effects of Cobalt Ions on Epoxy Properties	NASA - Langley	J.J. Singh; D.M. Stokley NASA Langley	In-House	To investigate the effects of cobalt ions on epoxy properties.	Thermosets: Synthesis/ Characterization	NTIS
220. Investigation of the Temperature Dependence of the Ultrasonic Properties of ASA/lexan and XAS/lexan Composites	NASA - DC NAG1-431	B.T. Smith Christopher Newport College	-	To investigate the temperature dependence of the ultrasonic properties of ASA/lexan and XAS/lexan composites.	Thermoplastics: Mechanical Properties	NTIS
221. Japan (ISPS) Postdoctoral Program: Design Methodology of Upper Stage Composite Rocket Motor Cases	NSF 8903099	K. Gramoll Memphis State University	\$19,200.00	To design a procedure to increase the efficiency of upper stage rocket motors with casings made of fiber reinforced plastic materials.	Thermosets: Processing/Resin-Fiber (Interfacial) Chemistry- Mechanics	FRIP
222. Laboratory Development of Rubber-Enhanced And Hybrid Fiber-Reinforced Resin Matrix Systems	SDIO	Steven F. Stone Mission Research Corp.	\$50,013.00	To incorporate high-temperature curing low shrinkage matrix into a composite by use of a rubber.	Thermosets: Synthesis/ Characterization/ Processing/Mechanical Properties	FRIP
223. Laminate Comprising Fibers Embedded in Cured Amline Terminated Bis-Imide	NASA - Ames	D. Kumar; C.M. Fohlen; J.A. Parker NASA Ames	In-House	To discuss laminate comprising fibers embedded in cured amline-terminated bis-imide.	Thermoplastics: Synthesis/ Characterization/ Processing	NTIS
224. Life Prediction Methods for Notched Composite Laminates	Air Force	K.L. Reifsnider Virginia Tech	-	To develop model for life predictions of notched composite laminates.	Thermosets: Characterization/ Mechanical Properties (Damage Tolerance)	US/J
225. Light Weight Polymer Matrix Composites Material	NASA - Lewis	K.J. Bowles; C.E. Lowell NASA Lewis	In-House	NA (Patent Application)	No subcategory established: Processing/Mechanical Properties (Environmental Effects)	NTIS
226. Light-Weight Fire Resistant Graphite Composites (Patent)	NASA - Ames	D.A. Kourtidis; J.A. Parker; M.T.S. Hsu NASA Ames	In-House	To evaluate fire retardant polymers based upon bismaleimides and carbon fibers for use in structures for aircraft.	Thermosets: Synthesis	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory/ Subset(s)	Source
227. Local Orientation Studies in a Semicrystalline Thermoplastic Composite Matrix Material: I.	NSF	J.T. Mueller; J.W. Hellge; G.L. Wilkes Virginia Tech	-	To perform spectroscopic studies on a semicrystalline composite matrix.	Thermoplastics Characterization	ASC
228. Long-Term Thermal Aging of Celcon/V378a Composite Materials	NASA - Langley	J.B. Nelson NASA Langley	In-House	To study mechanical properties of graphite/bismaleimide composites aged in air at different temperatures.	Thermosets: Mechanical Properties (Fatigue)	NTS
229. Low Contraction Additives for Polyester Resins	NASA - DC	M.A. Arso Construccion Aeronautica S.A. (Spain)	-	To study thermoplastic additives in glass fiber reinforced polyesters.	Thermoplastics Processing/Mechanical Properties	NTS
230. Low Glass Transition Temperature Aromatic Polyamides	Air Force - DC	T. Abraham Dept. of the Air Force	In-House	To develop thermoplastic polymers to act as matrices for rod-like polymers in the molecular composites that are soluble and chemically stable in strongly acidic mediums such as methane-sulfonic acid.	Thermoplastics Synthesis	NTS
231. Low Temperature Thermal Conductivity of Composites: Alumina Fiber/Epoxy and Alumina Fiber/PEEK	NASA - Ames	D.L. Rule; L.L. Sparks NIST	-	To determine the effects of thermal conductivities of poly-ether-ketone (PEEK), of alumina fiber in a matrix of epoxy, along with the effects of fiber orientation and thermal cycling.	Thermosets/ Thermoplastics Mechanical Properties	NTS
232. MRL Minority Research Supplement	NSF 8819885; 8819885	G.C. Farrington The University of Pennsylvania	04/01/89-07/31/90 \$3,350,000.00	To design and synthesize advanced polymers and ceramics.	No subcategory established: Synthesis	FRIP
233. Main-Chain Liquid Crystals and Model Compounds with Conventional Thermoplastics and Ionomers	NSF	R.B. Blumstein University of Lowell	01/15/88-06/30/91 \$14,650.00	To examine main-chain liquid crystals and model compounds with conventional thermoplastics and ionomers.	Thermoplastics: Synthesis/ Characterization	FRIP
234. Manufacturing Thermoplastic Matrix Composite	Air Force - Wright-Patterson F33615-84-C-5049; 2419; 01	G.S. Springer Stanford University	-	To develop and test a model of the steps involved in the manufacturing process of semicrystalline thermoplastic matrix composites.	Thermoplastics: Processing/Mechanical Properties	NTS
235. Material Trends in Advanced Composites	Air Force AAMRL-TR-89-008	Diana Carlin Wright Aeronautical Labs	-	To determine historical trends of composite materials and anticipated improvements.	Thermosets/ Thermoplastic	CA

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
236. Materials and Structures Research and Technology (See also Table 2, Structures, #146.)	NASA 506-43-00	Jozan M. Moacanin California Institute of Technology	-	To investigate new methods for predicting structure-property relations in spacecraft materials.	Thermoplastics: Characterization	FRIP
237. Materials and Structures Research and Technology	NASA	Samuel L. Verner NASA DC	In-House	To investigate properties of future airframe materials.	No subcategory established: Characterization/ Mechanical Properties/ (Damage Tolerance/ Fatigue/Environmental Effects)	FRIP
238. Mathematical Sciences: Crack Propagation in Linear and Nonlinear Viscoelastic Material	NSF	J.R. Walton Texas A & M University	06/01/89-05/31/91 \$71,575.00	To analyze various mathematical models of propagating cracks in linear and nonlinear viscoelastic material.	No subcategory established: Mechanical Properties	FRIP
239. Matrix Resin Effects in Composite Delamination: Mode I Fracture Aspects	NASA - Langley	D.L. Hunston; R.J. Moulton; N.J. Johnston; W.D. Bascom NIST	-	To examine the correlation between matrix and interlaminar strain energy.	Thermoplastics: Characterization/ Mechanical Properties/ (Damage Tolerance)	NTIS
240. Matrix and Microstructural Influences on Composite Compression Strength	NASA	S.W. Yurgartis; S.S. Sternstein Clarkson University	-	To develop a measurement of thermoplastic compression strength as a function of temperature, keeping the microstructural variables constant, while varying the matrix properties.	Thermoplastics: Mechanical Properties (Damage Tolerance)	ASC
241. Mechanical Behavior of Particle Filled Thermoplastics	NASA - DC	P.H.T. Vollenberg Eindhoven (Netherlands)	-	To study mechanical properties of thermoplastic while varying the filler particles.	Thermoplastics: Mechanical Properties	NTIS
242. Mechanical Characterization of Whisker-Reinforced Continuous-Fiber Composites	Navy	J.M. Alper; S.J. Thoman Naval Air Development Center	In-House	To evaluate the effect of adding whiskers to continuous fiber composites on mechanical properties.	Thermoplastics: Characterization/ Mechanical Properties	ASC
243. Mechanical Damping Characterization of Carbon-Carbon Composites	SDIO	Stephen M. Biddle Fiber Materials Inc.	\$49,956.00	To determine damping characteristics of carbon-carbon composites.	Thermoplastics: Mechanical Properties	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
244. Mechanical Properties of Carbon Fiber Reinforced Thermoplastics for Cryogenic Applications	NASA	K. Ahlborn Kernforschungszentrum Karlsruhe (W. Germany)	—	To study mechanical properties like strength, stiffness, and fatigue of carbon reinforced thermoplastic matrix systems at cryogenic temperatures.	Thermoplastics: Mechanical Properties (Environmental Effects)	NTIS
245. Mechanical Properties of Carbon Fiber Reinforced Thermoplastics	NASA - DC	Y. Noguchi National Aerospace Lab (Japan)	—	To investigate the mechanical properties of carbon fiber reinforced thermoplastics.	Thermoplastics: Characterization / Mechanical Properties	NTIS
246. Mechanical Properties of Neat Polymer Matrix Materials and Their Unidirectional Carbon Fiber-Reinforced Composites	NASA NAG1-277	Donald F. Adams; R.S. Zimmerman University of Wyoming	—	To evaluate the potential of various candidate polymer matrix materials for use in high-performance composites. The mechanical and physical properties of these polymers in neat (unreinforced) form were measured, along with those of carbon fiber-reinforced unidirectional composites incorporating these matrix materials.	Thermosets/ Thermoplastics: Mechanical Properties	NASA
247. Mechanical Properties of Several Neat Polymer Matrix Materials and Unidirectional Carbon Fiber-Reinforced Composites	NASA - DC NAG1-277	S. L. Cogswell, D. F. Adams Wyoming University	—	To determine experimentally the mechanical and physical properties of three neat matrix materials and twelve unidirectional carbon fiber composites incorporating matrix materials characterized in this or earlier studies.	Thermosets/ Thermoplastics: Mechanical Properties	NTIS
248. Mechanical Properties of Steel-to-Steel Adhesive Bonds	DOT-FHWA	N. Gasparini Case Western Reserve University	—	To evaluate the mechanical properties of steel-to-steel adhesive bonds using modified acrylic and epoxy adhesives.	Thermosets/ Thermoplastics: Characterization / Mechanical Properties	FRIP
249. Mechanical-Vibrational Spectroscopic Studies of Thermoplastic Elastomers	NSF	S. Hsu University of Massachusetts	02/15/88-07/31/90 \$46,800.00	To review mechanical-vibrational spectroscopic studies of thermoplastic elastomers.	Thermoplastics: Characterization	FRIP
250. Mechanics Framework for a Progressive Failure Methodology for Laminated Composites	NASA	C.E. Harris; D.H. Allen; D.C. Lo NASA Mechanics of Materials Branch	In-House	To present a mechanics framework and a global-local strategy for predicting strength and life.	No subcategory established: Mechanical Properties (Damage Tolerance)	ASC
251. Mechanics of Composites: Review of Experiments of Moire Interferometry	NASA	J. Morton; D. Post Virginia Tech	—	To review the applications of Moire Interferometry on composite materials.	Thermosets: Characterization / Mechanical Properties (Damage Tolerance)	ASC

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
252. Mechanics of Interface Cracks	Navy - Office of Naval Research N00014-88-K-0119	C.F. Shih Brown University	11/01/87-09/30/91	To provide a fundamental understanding of the behavior of interface cracks in bimaterial elastic-plastic systems.	Thermoplastics: Resin-Fiber (Interfacial) Chemistry-Mechanics	MCR
253. The Mechanism of Halogen Attack on Composite Reverse-Osmosis Membranes	NSF	R.J. Ray, S.B. McCray Bend Research, Inc.	\$250,000.00	To evaluate and verify the mechanisms of halogen attack on polyamide and polyurea composite membranes.	Thermoplastics: Characterization/ Damage Tolerance	FRIP
254. Mesomechanical Model for Fibre Composites: The Role of the Interface	Air Force AFOSR-89-0365	M.R. Piggott University of Toronto (Canada)	06/01/89-05/31/92	To establish the relationship between the interface/interphase parameters and the composite properties. Particular attention is paid to the role of interphase failure.	Molecular Composites: Resin-Fiber (Interfacial) Chemistry-Mechanics/ Mechanical Properties (Fatigue)	MCR
255. Metallic Inhibition/Protection System for Carbon-Carbon Composites	Air Force	George H. Reynolds MSNW, Inc.	\$48,860.00	To develop improved metallic inhibition/protection systems for carbon-carbon composites.	No subcategory established: Processing	FRIP
256. Method of Controlling a Resin Curing Process	NASA - Johnson	C.N. Webster, R.O. Scott NASA Johnson	In-House	To use an analytical process to control curing of composites.	Thermosets: Processing	NTIS
257. Micro and Macro Approaches to Tough Polymers for Composites Progress Report, September 25, 1986-September 25, 1987	NASA - DC NAG1-607	A.F. Yee, D.S. Parker, K.A. McGrady, J. Iho Michigan University	-	To develop methods to toughen polymers by both micro and macro seals.	Thermoplastics: Characterization/ Mechanical Properties	NTIS
258. Microcrack Density Damage Parameter as a Function of Normal and Shear Strains of a Fiber Reinforced Composite Material.	Air Force	C.R. Corleto, W.L. Bradley Texas A & M University	-	To develop an approach to quantify microcracking of the matrix material that develops ahead of a crack tip of a fiber-reinforced resin.	Thermosets: Resin-Fiber (Interfacial) Chemistry-Mechanics	ASC
259. Micrograded Polymer Concrete Coating System for Steel Bridges	DOT	M. Guseckman Sekar Enterprises	\$50,000.00	To design micrograded polymer concrete mixes which are highly corrosion resistant for steel coating.	Thermosets: Synthesis/Processing	FRIP
260. Micrographic Study of Bending Failure in Five Thermoplastic/Carbon Fiber Composite Laminates	NASA - DC NAG1-253	S.W. Yurgartis, S.S. Sternstein Rensselaer Polytechnic Institute	-	To observe the microscopically local deformation and failure sequences of five thermoplastic matrix composites.	Thermoplastics: Characterization/ Mechanical Properties	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
261. Micromechanical Deformation	NSF	J.C. Li University of Rochester	12/15/88-05/31/90 \$117,500.00	To develop a mechanical test technique capable of measuring the mechanical properties (such as yield strength and fracture toughness) of micron-size volumes.	No subcategory established: Mechanical Properties (Fatigue)	FRIP
262. Microscopic Aspect of Fiber & Fracture in Cross-Ply Fiber-Reinforced Composite Laminates (See also Table 2, Structures, #166.)	Army	S. Bandyopadhyay; E.P. Cellent; V.M. Silva, J.H. Underwood Army Armament Research	In-House	To study the micromechanisms of tensile fracture and interlaminar mode I delamination failure.	Thermosets: Mechanical Properties	NTIS
263. Microwave Processing of Unidirectional Carbon Fiber/Epoxy Composite Laminates Using a Resonant Cavity Technique	DARPA	G.L. Vogel; J. Jow; J.D. DeLong; M.C. Hawley Michigan State University	-	To do microwave processing of unidirectional carbon fiber/epoxy composites using a resonant cavity technique.	Thermosets: Processing	CA
264. Miscibility in Poly-p-Phenylene Terephthalamide/Nylon 6 and Nylon 66 Molecular Composites	Army - Army Research Office DAAAC29-85-K-0219	T. Kyu; T.I. Chen; H.S. Park; J.L. White Akron University	-	To investigate the apparent crystallinity of nylon 6 and nylon 66 in molecular composites.	Thermoplastics/ Molecular Composites: Characterization	NTIS
265. Modeling the Deformation Processing of Solid Thermoplastics	NSF	G. Eggert Rensselaer Polytechnic Institute	10/15/88-03/31/91 \$7,000.00	To model the deformation processing of solid thermoplastics.	Thermoplastics: Mechanical Properties	FRIP
266. Model Describing the Steady-State Gasification of Bubble-Forming Thermoplastics in Response to an Incident Heat Flux	NIST	J.S. Wichman NIST	In-House	To study radiation effects on high performance polymer matrix materials.	Molecular Composites	NTIS
267. Modeling High Viscosity Melt-Phase Polycondensation Reactors Using Direct Inclusion of Experimental Mixing Data	NSF	K.J. Sampson Ohio University	06/15/88-11/30/90 \$61,467.00	To gain a fundamental understanding of the reaction kinetics, mixing, and mass transfer that occur in the manufacture of high viscosity condensation polymers using melt-phase processes.	Thermoplastics: Synthesis/Processing	FRIP
268. Modeling of the Impact Response of Fiber-Reinforced Composites	Air Force AFOSR-87-0129	John Harding; C. Ruiz Oxford University (England)	11/15/86-11/14/89	To characterize the mechanical behavior and failure mechanisms of carbon/epoxy, Kevlar/epoxy, and hybrid composites under tensile impact loading using specially designed split Hopkinson bar equipment.	Thermosets: Mechanical Properties (Damage Tolerance)	MCR

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
269. Molecular Composites Processing and Properties I	Air Force F33615-84-C-5020; 2419: 08	C.C. Lee; T.E. Helmink; H. Chuah University of Dayton	-	To study the coagulation of PBT/Nylon 66 into pressurized molds to form void free molecular composites.	Molecular Composites: Processing	NTS
270. Molecular Composites from Phase Separation at Low Temperatures of Kevlar and Diaminophenylindane Polyimide in Sulfuric Acid	Navy N00014-86-K-0772	M.A. Alonso; M.T. Shaw University of Connecticut	-	To serve a program to develop critical advanced composite technology in the areas of physical properties, structural concept and analysis, manufacturing, reliability, and life predictions.	Thermoplastics / Molecular Composites: Characterization / Mechanical Properties	NTS
271. Molecular Composites: Processing, Post-Treatment and Mechanics	Air Force - Wright-Patterson F33615-83-K-5001; 2419: 01	M.F. Malone; C.F. Hwang; C.A. Gabriel; O.A. Nehme; K.J. Farris University of Massachusetts	-	To discuss the properties and processing of molecular composites.	Molecular Composites: Processing	NTS
272. Molecular Sensor Technique for Crosslinked Polymers	NSF 8703908	C. Sung University of Connecticut	04/15/88-09/30/90 \$239,700.00	To study cure composition, kinetics, mechanism, molecular mobility and mechanical properties of crosslinked polymers characterized by molecular sensors.	No subcategory established: Characterization/Resin- Fiber (Interfacial) Chemistry: Mechanics	FRIP
273. Monitoring Delamination Progression in Composites through Acoustic Emission During Fatigue Loading	Navy	J. Cohen; J. Averbuch Drexel University	-	To use acoustic emission data to monitor delamination progression in graphite/epoxy laminates during fatigue loading.	Thermosets: Characterization / Mechanical Properties (Damage Tolerance / Fatigue)	US/J
274. Monitoring the Cure of a Composite Matrix Resin with Microelectrometry	Navy	W.W. Bidstrup; S.D. Senturia Massachusetts Institute of Technology	-	To monitor the cure of a composite matrix resin with microelectrometry.	Thermosets: Characterization / Processing	NTS
275. Morphology and Properties of Amine Terminated Poly (Arylene Ether Ketone) and Poly (Arylene Ether Sulfone) Modified Epoxy Resin Systems	NASA - DC	J.A. Cecore; J.L. Hedrick; J.E. McGrath Virginia Tech	-	To study the use of amine terminated thermoplastics to modify an epoxy network.	Thermosets: Synthesis	NTS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
276. Multiple Melting Peaks of Polyether	NIST	S.S. Chang NIST	In-House	To determine the thermal characterization of PEEK samples.	Thermoplastics: Characterization	NTIS
277. Net Shape Tubular Structures From Ordered Polymers	SDIO	Richard W. Lusignea Foster-Miller Inc.	\$65,592.00	To use poly(p-phenylene terephthalazone) as a tubular structure.	Molecular Composites: Characterization/ Processing/Mechanical Properties	FRIP
278. Network Structure in Epoxides: 5. Deformation Mechanism in Epoxides	NIST	W.L. Wu; B.J. Bauer NIST	In-House	To investigate the response of epoxy network molecules to large strain deformation using small-angle neutron scattering.	Thermosets: Characterization/ Mechanical Properties	NTIS
279. Network Structure of Epoxides: 1. A Neutron Scattering Study	NIST	W. Wu; B.J. Bauer NIST	In-House	To study the network structure of epoxides using elastic neutron scattering.	Thermosets: Synthesis/ Characterization	NTIS
280. Network Structure of Epoxides: 2. A Neutron Scattering Study	NIST	W. Wu; B.J. Bauer NIST	In-House	To study the network structure of epoxides using neutron scattering.	Thermosets: Characterization	NTIS
281. New Improved Dental Composites	HHS	Bernard C. Marker Greenmark Inc.	\$50,000.00	To develop filled resins for dental composites.	Thermosets: Characterization/ Processing/Mechanical Properties (Fatigue/ Environmental Effects)	FRIP
282. New Preparative Techniques for Carbon/Carbon Composites	DARPA	Jorge Soto Maidem Inc.	\$61,389.00	To synthesize materials for use in composite brake systems.	Thermoplastics: Synthesis/ Characterization/ Mechanical Properties	FRIP
283. New Readily Processable Polyimide	NASA - Langley	F.W. Harris; M.W. Beltz; P.M. Hergenrother NASA Langley	In-House	To develop a new processable polyimide with tough solvent resistance.	Thermoplastics: Synthesis/Processing	NTIS
284. New Restorative Dental Resins	HHS	Ronald W. Gumbs Gumbs Associates	\$37,000.00	To develop new low shrinkage crosslinkable dental resins.	Thermosets: Synthesis/ Characterization/ Processing/Mechanical Properties (Environmental Effects)	FRIP
285. Nondestructive Determination of Resin in Graphite Composites	Air Force	Gerald Entine Radiation Monitoring Devices	\$71,456.00	To find resin content in composites using nuclear methods.	Thermosets: Characterization	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subsets(s)	Source
286. Nondestructive Evaluation and Damage Accumulation of Composites	Navy - Office of Naval Research N00014-87-K-0159	I.M. Daniel Northwestern University	04/01/87-12/31/91	To research the process of damage growth in composite laminates subjected to complex loading states and fatigue.	Molecular Composites: Mechanical Properties (Fatigue)	MCR
287. Novel Conducting Ceramic/Polymer Composite PTC Thermistors	DARPA	In-Myung Chung Matronix Inc.	\$50,000.00	To make ceramic/polymer composite thermistors.	Thermoplastics	FRIP
288. Novel High Temperature Metal/Plastics Composites For Sealing	Air Force	Donald E. Hudgin P.P.L. (Composite Systems Div.)	\$48,461.00	To blend molten thermoplastics with metals.	Thermoplastics: Resin-Fiber (Interfacial) Chemistry-Mechanics	FRIP
289. Novel Matrix Resins with Improved Processability and Properties for Primary Aircraft Structures	NASA - Langley NASA-18841	E.P. Woo Dow Chemical Company	04/01/89-04/30/92	To develop new high-performance thermoset resins with improved durability, toughness, and processability.	Thermosets: Synthesis	MCR
290. Novel Thermoplastic Composite Material Forms for Primary Aircraft	Army	David Maass Advanced Composite Product	\$96,580.00	To fabricate a primary structural component using a mixture of graphite and thermoplastic filaments and characterize it.	Thermoplastics: Characterization/Processing	FRIP
291. Ordered Polymer Films For Scientific Research Balloons	NASA	Richard W. Lustig Foster-Miller Inc.	\$519,591.00	To use poly(p-phenylene benzobisthiazole) as balloon film.	Thermoplastics: Characterization/Processing/Mechanical Properties (Damage Tolerance/Environmental Effects)	FRIP
292. Ordered Polymer High Performance Matrix for Aircraft Structural Materials	Air Force	Ted Kirchner Foster-Miller Inc.	\$69,761.00	To process rigid rod matrix graphite fiber reinforced composites into structural materials without interlaminar delamination.	Thermoplastics: Processing	FRIP
293. Ordered Staple Manufacturing Technology See also Table 3, Manufacturing #97.)	NASA - Langley NASA-18758	Jegley University of Delaware	09/30/88- \$251,000.00	To develop manufacturing technology utilizing ordered staple goods such as long discontinuous fiber (LDF) mats.	Thermoplastics: Processing/Mechanical Properties (Damage Tolerance)	ACT

TABLE 1
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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory/ Subsets(s)	Source
294. Organic Matrix Composite Materials for Cryogenic Service	Air Force	Matthew Liu Advanced Material Systems, Inc.	\$49,867.00	The use of amorphous copolymers and polymer alloys as resin matrix for fabrication of composites: their behavior at cryogenic environments.	Thermoplastics: Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics/ Mechanical Properties (Environmental Effects)	FRP
295. PMR Polyimide Compositions for Improved Performance at 371 Degrees Celsius	NASA - Lewis	Raymond D. Vannucci NASA Lewis	In-House	To identify matrix resins useful at 371 degrees Celsius using PMR methodology.	Thermoplastics: Mechanical Properties	NTS
296. Patching and Grouting Materials for Portland Cement Concrete	DOT-FHWA	J.C. Jenkins Oregon Department of Transportation	-	To evaluate patching and grouting materials for repair of pavement defects.	Thermosets/ Thermoplastics: No subsets established	FRP
297. Pavement-Marking Materials	DOT-FHWA	G.R. Korfhage Minnesota Department of Transportation	-	To measure the reflectivity of traffic marking materials.	Thermosets/ Thermoplastics: Characterization	FRP
298. Performance of Thermoplastic Pavement Markings	DOT-FHWA	J.E. Bryden; G.F. Gurney New York State Dept. of Transportation	-	To evaluate thermoplastic polymers as highway markers.	Thermoplastics: Mechanical Properties (Damage Tolerance)	NTS
299. Phenox Resins Containing Pendant Ethynyl Groups and Cured Resins Obtained Therefrom	NASA - Langley	P.M. Hergenrother NASA Langley	In-House	To prepare phenox resins with pendant ethynyl groups and to crosslink ethynyl groups to form networks.	Thermosets: Synthesis	NTS
300. Phenox Resins Containing Pendant Ethynyl Groups: Cured Resins Show Greatly Improved Resistance to Heat and Solvents	NASA - DC	NASA DC	In-House	To study phenox resins containing pendant ethynyl groups.	Thermoplastics: Synthesis/ Characterization/ Processing	NTS
301. Physical Aging of Polymer Composite Matrices	NIST	A. Lee; G.B. McKenna NIST	In-House	To study physical aging in glass/epoxy composites using linear and non-linear viscoelastic responses.	Thermosets: Characterization/ Mechanical Properties (Environmental Effects)	US/J

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
302. Physical and Mechanical Properties of American Cyanamid's Acetylene-Terminated Prepreg System: T-300/CATB-44	Air Force - Wright-Patterson	D.B. Curiles Wright Aeronautical Lab	In-House	To compare results of the physical and mechanical properties of the cured composite T-300/CATB-44 with the first generation T-300/V378A carbon-fiber-reinforced bismaleimide composite.	Thermosets/ Thermoplastics: Characterization/ Processing/Mechanical Properties	NTIS
303. Place for Thermoplastic Composites in Structural Components	Nuclear Regulatory Commission MDA 903-86-K-0720	National Materials Advisory Board - NRC	In-House	To review the role of thermoplastics in composites.	Thermoplastics: No subjects established	NTIS
304. Plasma Treatment Optimization of Polyaramid Filaments to Improve Performance of Kevlar/Epoxy Composites	Army	Nicholas J. DeBolis PDA Engineering/ Sharnet Inc.	\$266,649.00	To investigate the effect of plasma treatment of polyaramid to improve performance of Kevlar/epoxy composites.	Thermosets: Resin-Fiber (Interfacial) Chemistry- Mechanics	FRIP
305. Plastics and Rubber in Different Chemical Environments: A Survey of Their Resistance To Corrosion	NASA - DC	G. Bergman Korrosionsinstitut (Sweden)	-	To study corrosion properties of some plastics and rubbers.	Thermosets/ Thermoplastics: Mechanical Properties (Environmental Effects)	NTIS
306. Polyarylene Ethers with Improved Properties	NASA - Langley	P.M. Hergenrother, B.J. Jensen, S.J. Havens NASA Langley	In-House	To study novel polyarylene ethers with improved properties	Thermosets Synthesis/Mechanical Properties	NTIS
307. Polyimide Quartz Multilayer Board	Navy	Louis M. Leung A.I. Technology Inc.	\$51,014.00	To study thermoplastic polyimide for use in low TEC quartz filled circuits.	Thermoplastics: Synthesis/ Characterization/ Processing/Mechanical Properties (Environmental Effects)	FRIP
308. Polyimides	NASA	D. Wilson; H.D. Stenzenberger; Chapman and Hall	-	To review polyimides including synthesis, characterization, processing, and advanced composites.	Thermosets/ Thermoplastics: Synthesis/ Characterization/ Processing	CA

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory/ Subset(s)	Source
309. Polyisimide for In-Situ Rigid Rod Molecular Composites	Air Force- Wright-Patterson F33615-87-C-5241; 2419-01	S.I. Wang; J.A. Bai; C.L. Webster; T.E. Benner; Hillmink University of Dayton	—	To explore rigid rod molecular composite applications from a new material concept using in-situ rod formation from a coil like poly (tetramethyl isimide).	Molecular Composites/ Processing/Mechanical Properties	NTIS
310. Polymer Blends: New Materials from Old	Army - Army Research Office DAAC29-84-K-0138	D.R. Paul University of Texas at Austin	—	To discuss compatibility of two polymers.	Thermoplastics/ Characterization/ Mechanical Properties	NTIS
311. Polymer Matrix and Graphite Fiber Interface Study	NASA - DC NAS2-11612	D.F. Adams; R.S. Zimmerman; E.M. Odum Wyoming University	—	To study composites with different carbon fibers and matrices at different conditions to determine the effect of fiber sizing on properties.	Thermosets/ Characterization/Resin/ Fiber (Interfacial) Chemistry/Mechanics/ Mechanical Properties (Environmental Effects)	NTIS
312. Polymer Powder Prepregging/ Scoping Study (Abstract only)	NASA - DC	J.L. Throne Akron University	—	To study polymer powder prepregging.	Thermosets/ Thermoplastics/ Processing	NTIS
313. Polyphenylquinolines via Aromatic Nucleophilic Displacement	NASA - Langley	P.M. Hergenrother; J.W. Connell NASA Langley	In-House	To produce polyphenylquinolines by an aromatic nucleophilic displacement reaction involving an activated aromatic dihalide with an appropriate quinoline monomer.	Thermoplastics/ Synthesis/ Characterization	NTIS
314. Polysulfone Modified Thermoplastic Polyimide Segmented Copolymer Matrix Resin Systems	NSF	D.L. Wilkens; C.A. Arnold; M.J. Jurek; M.E. Rogers; J.E. McGrath Virginia Tech	—	To investigate synthesis and characterization of polyimide segmented copolymer system for thermoplastic matrix systems.	Thermoplastics/ Synthesis/ Characterization	ASC
315. Postbuckling Analysis of Graphite/Epoxy Laminates	NASA - Langley	Manuel Stein NASA Langley	10/01/80-09/30/90 In-House	To develop accurate analyses for the postbuckling response of graphite/epoxy laminates and to determine the parameters that govern postbuckling behavior.	Thermosets: Mechanical Properties (Fatigue)	MCR
316. Powdered Tow, Coningled, Thermoplastics (See also Table 3, Manufacturing, #101.)	NASA - Langley NAS1-18634	N.J. Johnston BASF	04/13/89 \$1,771,000.00	To develop powdered and coningled tow from thermoplastics and thermosets.	Thermosets/ Thermoplastics/ Characterization/ Processing/Mechanical Properties (Damage Tolerance)	ACT

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
317. Precision-Segmented Reflectors	NASA - Langley	NASA Langley	In-House	To develop the technology needed for the large lightweight precision reflectors for space applications.	Thermosets: Processing	FRIP
318. Prediction and Control of Processing-Induced Residual Stresses in Composites	Air Force AFOSR-87-0242	H. Thomas Hahn The University of Pennsylvania	06/01/87-05/31/89	To identify the mechanisms underlying the introduction of residual stresses during processing of polymer matrix composites, and to develop a prediction methodology as well as a procedure for controlling these stresses through optimization of the process cycle.	Molecular Composites: Processing	MCR
319. Prediction of Residual Stresses in Advanced Composite Materials During the Curing Process	Air Force	H.G. Rai; R.A. Brockman University of Dayton	-	To predict residual stresses in polymer composites during cure using a heat transfer model.	Thermosets: Characterization / Processing	US/I
320. Predictive Model for Failure Properties of Thermoset Resins	NASA - Lewis NAC3-599	J.M. Caruthers; K.J. Rowles NASA Lewis	In-House	To develop a predictive model for the three-dimensional failure behavior of engineering polymers.	Thermosets: Mechanical Properties	NTIS
321. Preliminary Investigations Into the Microcracking of PMR-15/Graphite Composites Part 1: Effect of Cure Temperature	NASA - DC	D. Wilson; J.K. Wells; J.N. Hay; D. Lind; G.A. Owens Rolls-Royce, Ltd	-	To examine micro-cracking of PMR-15/Graphite Composites.	Thermosets: Mechanical Properties	NTIS
322. Presidential Young Investigator Award	NSF 8657215	J.M. Howe Carnegie-Mellon University	07/01/87-12/31/90 \$187,500.00	To study interfacial properties of composite materials.	Thermosets / Thermoplastics: Resin-Fiber (Interfacial) Chemistry; Mechanics	FRIP
323. Presidential Young Investigator Award (Supplemental Funding for Women Engineering Research Assistants)	NSF	D.D. Denton University of Wisconsin	\$201,531.00	To develop polyimide based relative humidity sensors and characterize mechanical properties in hostile environments.	Thermoplastics: Characterization / Mechanical Properties (Environmental Effects)	FRIP
324. Presidential Young Investigator Award: Structure Development in Polymer Processing	NSF 8888303	M. Calmak University of Akron	\$87,500.00	To study characterization as well as different properties of polymers: optical, substrate surface, and forging.	No subcategory established: Synthesis / Characterization	FRIP

TABLE 1
PMC RESEARCH MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory/ Subset(s)	Source
367. Study of Failure Characteristics in Thermoplastic Composite Material	Air Force - Wright Patterson	R.J. Martin Air Force Institute of Technology	In-House	To study the fracture toughness of PEEK/Graphite composites.	Thermoplastics: Mechanical Properties	NTIS
368. Study of Failure Characteristics in a Thermoplastic Composite Material at High Temperature	Air Force - Wright-Patterson	J.M. Fisher Air Force Institute of Technology	In-House	To study the failure characteristics of the thermoplastic composite Graphite/Polyetheretherketone (G./PEEK) at 250 degrees Fahrenheit.	Thermoplastics: Mechanical Properties	NTIS
369. Study of Thermal Transitions in a New Semicrystalline Thermoplastic Polyimide	NASA - Langley NAS1-18000; NAS1-18599	J.R. Pratt; T.L. St. Clair; M.K. Gerber; C.R. Gauthreaux NASA Langley	In-House	To prepare and characterize by differential scanning calorimetry (DSC) and wide angle X-ray scattering (WAXS) a polyimide derived from 4,4'-isophthaloyl diphenyl ether (IDPA) and 1,3-bis(4-aminophenoxy) 4'-benzoyl benzene (1,3-BABBB) having semicrystalline behavior.	Thermoplastics: Synthesis/ Characterization	NTIS
370. Study of the Application of Automation to Composites Manufacture	Army - Army Materials Technology Lab DAAAG46-85-K-0001	S.M. Krolewski Massachusetts Institute of Technology	-	To evaluate effect of direct labor savings, quality improvements and process flexibility on manufacturing cost to identify desirable characteristics for new equipment.	No subcategory or subset established	NTIS
371. Study of the Effects of Oxygen Transport and Temperature History of the Chemistry of PMMA Pyrolysis	NIST NANB - 400086	E.M. Samberg; V. Dalal; T. Kelly Brown University	-	To study thermal degradation and thermal oxidation degradation of PMMA.	Thermoplastics: Characterization	NTIS
372. Styrene-Terminated Polysulfone Oligomers as Matrix Material for Graphite Reinforced Composites: An Initial Study	NASA - Lewis	D. Garcia; K.J. Bowles; R.D. Vannucci NASA Lewis	In-House	To study the synthesis and curing of styrene-terminated polysulfone.	Thermosets: Synthesis	NTIS
373. Surface Characterization and High-Temperature Adhesive Bonding on Carbon Fiber-Polyimide Matrix Composites	NASA	D.J.D. Moyer; J.P. Wightman Virginia Tech	-	To study the surface of pretreated composites before and after bonding with high temperature adhesives.	No subcategory established: Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics/ Mechanical Properties (Environmental Effects)	ASC

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
374. Surface Chemical Modification of Graphite Filaments to Improve Graphite/Thermoplastic Composites	NASA	Ronald E. Alired PDA Engineering	\$250,000.00	To develop high performance, high temperature thermoset and thermoplastics composites with improved interfacial adhesion characteristics.	Thermosets/ Thermoplastics Processing	FRUP
375. Surface Fluorinated Composite Materials For Use In Space	SDIO	Th Houng Loh Tekmal Corp.	\$49,517.00	To study surface modification of fluoropolymer composites.	Thermoplastics Processing	FRUP
376. Surface Properties of Carbon Fibers and Their Adhesion to Organic Polymers	NASA - DC NAS1-17918	W.D. Bascom; L.T. Drzal Hercules, Inc.	-	To study the surface of carbon fibers and the adhesion of the polymer's matrix.	Thermoplastics: Resin- Fiber (Interfacial) Chemistry: Mechanics	NTIS
377. Surface Treatment Problems Found In New Aircraft Designed Using Structural Composites	NASA-DC	G. Heiland Societe Nationale Industrielle Aerospatiale (France)	-	To study surface treatment problems in structural composites used on aircraft.	No subcategory established: Resin-Fiber (Interfacial) Chemistry: Mechanics	NTIS
378. Surface and Interfacial Aspects of Carbon Fibers (I) and Fractography of Composite Delamination (II)	NASA	Willard D. Bascom University of Utah	-	To characterize surface properties of carbon fibers especially as they relate to adhesion to thermoplastics and to experimentally determine the micromechanisms of delamination using conventional metallographic techniques.	Thermoplastics: Resin-Fiber (Interfacial) Chemistry: Mechanics/ Mechanical Properties	NASA
379. Survey of Poly-Ether-Ether-Ketone and Its Advanced Composites	NASA - DC FMV-FRL-82250-86- 69-25-001	S. Nilsson Aeronautical Research Institute of Sweden (Sweden)	-	To review the suitability of poly (ether-ether-ketone) PEEK for aircraft structures.	Thermoplastics: Characterization/ Mechanical Properties	NTIS
380. Synthesis and Characterization of Copolyimides with Varying Flexibilizing Groups	NASA - Langley	H.D. Burks; T.L. St. Clair; D.J. Progar NASA Langley	In-House	To study the synthesis of polyimides with flexible groups in back bone to change rheological and adhesive properties.	Thermoplastics: Synthesis/Processing	NTIS
381. Synthesis and Characterization of Processable Polyimides with Enhanced Thermal Stability	NASA	Frank W. Harris University of Akron	-	Primary: To synthesize and characterize of processable polyimides with outstanding thermal and mechanical properties. Secondary: To develop relationships between the polymers' structures and their properties.	Thermoplastics Synthesis	NASA
382. Synthesis and Characterization of Protective Coatings for Aerospace Materials	NASA	Judy S. Ruffie Mencor Inc.	\$518,614.00	To synthesize and characterize thermally stable coating materials that would protect against atomic oxygen bombardment.	Thermoplastics: Synthesis/ Characterization	FRUP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
383. Synthesis and Properties of Arylethersulfone Thermoset System.	Air Force - Wright-Patterson	P.M. Lindley; L.G. Ficklesmer; B. Evans; J.J. Kane; F.E. Arnold Wright Aeronautical Labs	In-House	To develop acetylene terminated arylethersulfones with varying degrees of polymers cured to give a network Tg dependent upon molecular weight of the starting polymer.	Thermosets: Synthesis/ Characterization	NTIS
384. Synthesis and Structure Property Studies of Toughened Epoxy Resins-Via Functionalized Polysiloxanes	Navy N00014-78-0629	J.S. Riffle; E.M. Yorkgits; C. Tran; I. Yilgor; J.L. Hedrick Virginia Tech	-	To evaluate the synthesis of toughened epoxies by functionalized polysiloxanes and properties.	Thermosets: Synthesis	NTIS
385. Synthesis and Thermal Properties of Aryl and Aryloxyethyl Monomers for Thermoset Resins of Reduced Crosslink Density	Air Force - Wright-Patterson	M.R. Unroe; B.A. Reinhardt; F.E. Arnold Wright Aeronautical Labs	In-House	To investigate a series of thermoset matrix materials with phenylethynyl and phenoxyphenylethynyl end groups to assess the extent of crosslinking in the cured resins by thermo-analytical and thermomechanical methods.	Synthesis: Characterization/ Mechanical Properties	NTIS
386. Synthesis of New High Stability Polymers	Air Force	L. Ananthasubramanian Cambridge Isotope Labs	\$41,662.00	To incorporate deuterium into PBT, PBO, and BBB for composite matrix.	Thermoplastics: Synthesis/ Characterization	FRIP
387. Synthesis of Polymers and Oligomers for Nonlinear Optical Activity	NSF 8815508	L.R. Dalton University of Southern California	12/15/88-11/30/89 \$92,400.00	To develop polymers and composites for enhanced non-linear optical activity.	Thermoplastics: Synthesis/ Characterization	FRIP
388. Tension, Torsion, and Compression of Composite Tubes	NASA	O.O. Ochoe and P.N. Roachke Texas A & M University	-	To study elastic moduli and stress-strain distribution under torsion and tension loads.	No subcategory established: Resin-Fiber (Interfacial) Chemistry-Mechanics/ Mechanical Properties (Fatigue)	ASC
389. Textiles, RTM, VIM, Stitching, Verification (See also Table 2, Structures, #226 and Table 3, Manufacturing, #117.)	NASA - Langley NASI-18862	McDonnell Douglas	03/31/89 \$23,750,000.00	To develop manufacturing technology for primary aircraft structure with emphasis on textiles, RTM, stitching, thermoplastic forming, and verification.	Thermosets/ Thermoplastics: Processing/Mechanical Properties (Damage Tolerance)	ACT

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
390. The New Matrix System: 1. Blended Composite Materials Comprising Simple Bismaleimide and Maleimide Functional Poly(arylene ether) Ketone Thermoplastic Modifiers	NSF	J.S. Senger, G. York, D. Chen, K. Ung, and J.E. McGrath Virginia Tech	-	To perform studies on blended composite materials (BMI with PEEK-MI systems) for military vehicle needs.	Thermoplastics Processing/Mechanical Properties	ASC
391. Thermoplastic Composites for Long Term Space Applications	SDIO	David Maas Advanced Composite Products Inc.	\$92,378.00	To study new thermoplastic composites for longliveliness.	Thermoplastics Characterization/Resin- Fiber (Interfacial) Chemistry/Mechanics	FRIP
392. Therm-X Tooling Methods (See also Table 2, Structures, #228 and Table 3, Manufacturing, #119.)	NASA - Langley NASA1-18799	Deaton Sikorsky Helicopter	05/09/89. \$1,059,000.00	To develop Therm-X processing for advanced composite fuselage structures.	Thermosets Processing/Mechanical Properties (Damage Tolerance/Fatigue)	ACT
393. Thermal Cycling and Mechanical Property Assessment of Carbon Fiber Reinforced PMR-15 Polyimide Laminates	NASA	G.A. Owens, S.E. Schofield Rolls Royce LTD (England)	-	To study the effects on carbon fiber/PMR-15 polyimide mechanical properties of prolonged thermal cycling representative of a specific component application, and the resulting crack distribution within the laminate.	Thermoplastics Mechanical Properties	NTIS
394. Thermal Deformation and Strength of Composite Materials at High Temperatures (Abstract Only)	NASA - DC	G.N. Tretyachenko; L.I. Gnatcheva Joint Publications Research Service	-	To examine the thermodynamic relationships between specific heat and thermal expansion.	Thermoplastics Characterization	NTIS
395. Thermal Expansion of Selected Graphite Reinforced Polyimide-Epoxy, and Glass-Matrix Composite	NASA - Langley	S.S. Tompkins NASA Langley	In-House	To measure and compare the thermal expansion of composites, compared to the values from classical laminate theory with good agreement.	Thermosets Characterization	NTIS
396. Thermal Stress Analysis in PMR-15 Carbon Fiber Laminates	NASA - DC	D.A. Elmes, D.G. Gilbert British Petroleum Co. Ltd (England)	-	To determine the mechanical property data and analysis required to accurately assess thermal stresses in PMR-15/carbon fiber laminates.	Thermosets: Processing	NTIS
397. A Thermal-Electrical Model for Microwave Processing of Polymer Matrix Composites	NSF 8948569	C.H. Stern Virginia Tech	\$69,799.00	To produce a model to determine temperature and electric fields during microwave processing of polymer matrix composites.	Thermosets: Processing	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
398. Thermally Modified Polymer Matrix Composite Material With Structural Integrity to 371 Degrees Celsius	NASA - Lewis	K.J. Bowles NASA Lewis	In-House	To study the potential for using surface coatings to inhibit the thermal oxidation of polymer matrix composites.	Thermosets/ Thermoplastics: Characterization/Resin-Fiber (Interfacial) Chemistry-Mechanics/Mechanical Properties (Damage Tolerance)	NTIS
399. Thermomechanical Characterization of Prepreg by Torsion Impregnated Cloth Analysis (TICA)	NASA	H.L. Price Promatec, Inc.	-	To discuss a dynamic mechanical technique that is useful in characterizing prepregs.	Thermoplastics: Characterization	ASC
400. Thermoplastic Adhesives Based on 4,4'-Isophthaloyldipthalic Anhydride (IDPA)	NASA - Langley	D.J. Progar; T.L. Sklar; J.R. Pratt NASA Langley	In-House	To prepare and evaluate thermoplastic polyimides as adhesives.	Thermoplastics: Synthesis/Resin-Fiber (Interfacial) Chemistry-Mechanics/Mechanical Properties	NTIS
401. Thermoplastic Coating of Carbon Fibers	NASA	D.D. Edle; G.C. Liddfield Clemson University	-	To develop a continuous process for producing a flexible fiber prepreg using thermoplastic polymers, such as La RC-TP1, which exhibit time-dependent melt viscosities.	Thermoplastics: Processing/Resin-Fiber (Interfacial) Chemistry-Mechanics	NASA
402. Thermoplastic Coating of Carbon Fibers. Annual Report, 1987-1988.	NASA - DC	D.D. Edle; G.C. Liddfield, M.J. Drews; M.S. Ellison; L.E. Allen Clemson University	-	To test prepreg fibers to ensure the coating process fibers.	Thermoplastics: Processing/Resin-Fiber (Interfacial) Chemistry-Mechanics/Mechanical Properties	NTIS
403. Thermoplastic Matrix Composite Processing Model	NASA - DC NAG1-343	P.H. Darr; A.C. Loos Virginia Tech	-	To assess the effects that processing parameters have on graphite fiber-reinforced thermoplastic matrix composites.	Thermoplastics: Characterization	NTIS
404. Thermoplastic Matrix For Composite Primary Structures Improvement	Army	Ronald W. Gumbel Gumbel Associates Inc.	\$93,060.00	To synthesize, characterize, and crosslink a novel crystallizable thermoplastic material.	Thermosets: Synthesis/ Characterization	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subject(s)	Source
405. Thermoset High-Temperature System Based on the Homolytic Polymerization of Benzocyclobutene Aromatic Imide Monomers and Oligomers	Air Force - Wright Patterson	L.S. Tan; F.E. Arnold Air Force Wright Aeronautical Labs	In-House	To discuss the synthesis and characterization of a new series of bisbenzocyclobutene terminated polyimides.	Thermosets: Synthesis/ Characterization	NTIS
406. Thermosetting Arylether Compounds and Their Synthesis	Air Force	B.A. Reinhardt; F.E. Arnold; M.R. Unroe Dept. of the Air Force	In-House	To study the process of thermosetting arylether compounds.	Thermosets: Synthesis/Processing	NTIS
407. Time-Temperature-Transformation (TTT) Cure Diagram of Thermosetting Systems	Navy N00014-84-K-0021	Marc T. Aroshime; John K. Gillham Princeton University	-	To study the development of a time-temperature-transformation cure diagram of thermosetting systems.	Thermosets: Characterization/ Processing	NTIS
408. Tough High-Modulus Epoxy Casting Materials	Navy	Ronald W. Gumbs Gumbs Associates Inc.	\$292,045.00	To determine the effect of thermoplastic modifiers on processing and mechanical properties of epoxy network.	Thermosets/ Thermoplastics: Processing/Mechanical Properties	FRIP
409. Toughened Thermosets, RTM Systems	NASA - Langley NAS1-18641	P.M. Hergenrother DOW	04/11/89. \$5,993,000.00	To develop toughened thermosets and resin transfer molding (RTM) systems.	Thermosets: Synthesis/ Characterization/ Processing/Mechanical Properties (Damage Tolerance)	ACT
410. Toughening Mechanisms in Elastomer-Modified Epoxies. Part 3. The Effect of Crosslink Density.	NASA DC	R.A. Pearson; A.F. Yee University of Michigan	-	To determine the effect of crosslink density on the toughen-ability and toughening mechanism of elastomer-modified epoxies.	Thermosets: Characterization/ Environmental	CA
411. Toughening of Bismaleimide Resins: Synthesis and Characterization of Maleimide Terminated Poly (Arylene Ether) Oligomers and Polymers. Final Report	NASA-DC NCCI-63	J.E. McGrath; C.D. Lytle; M.J. Jurek; D. Mohanty; J.C. Hedrick Virginia Tech	-	To study toughening of Bismaleimide by incorporation of maleimide terminated thermoplastic.	Thermosets: Synthesis	NTIS
412. Toughening of Unique Modified Larc-13 Polyimide Blends by Compositional Quenching	Air Force	Milton L. Evans High Technology Services Inc.	\$50,000.00	To disperse LARC TPI with other high performance polymers and use in composite field.	Thermoplastics: Characterization/ Processing/Mechanical Properties	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
413. Tougher Addition Polyimides Containing Siloxane: Laminates Show Increased Impact Resistance and Other Desirable Mechanical Properties	NASA - DC	NTIS Tech Notes NASA	In-House	To develop aromatic addition polyimides as both matrix and adhesive resins for applications on future aircraft and spacecraft.	Thermosets: Synthesis/Character- ization	NTIS
414. Transient Moisture Effects in Fibers and Composite Materials	Navy - Office of Naval Research	J.Z. Wang; M.P. Wolkoff; F.A. Kamke; D.A. Dillard Virginia Tech	-	To study moisture effects (mechanosorptive) on aramid fibers and epoxy composites.	Thermosets/ Thermoplastics: Mechanical Properties/ Environmental	ASC
415. Trapped Radiation	NASA - DC	A.L. Vampola; W.K. Stuckey Aerospace Corp.	-	To study the effects of trapped radiation on organic polymers.	No subcategory established: Mechanical Properties (Environmental Effects)	NTIS
416. Two-Phase Elastomer Toughening of Blasmaletimide Resins	Air Force	Ming-Ta Hsu; Timothy Chen HC Chem Research & Service Corp.	\$58,436.00	To improve toughness of BMI with elastomers.	Thermosets: Processing/Mechanical Properties	FRIP
417. Ultra High Stiffness Net-Shape Tubular Space Structures	NASA	Ted E. Kirchner Foster-Miller Inc.	\$50,000.00	To co-extrude PBT tubes combined with compatible polymer materials to form a lightweight tube with ultra high stiffness.	Thermosets: Processing	FRIP
418. Ultra Lightweight Heat Temperatur: Structural Materials	SDIO	R.H. Tuffias Ultramet	\$547,988.00	To develop ultra lightweight, high temperature structural materials for KKV weapons and military rockets.	No subcategory established: Synthesis/Processing	FRIP
419. Ultrasonic NDE of Nonlinear Viscoelastic Media	NSF	J.H. Williams Massachusetts Institute of Technology	09/01/88-02/28/90 \$23,635.00	To explore the use of the ultrasonic nondestructive evaluation (NDE) technique for determining the nonlinear viscoelastic properties of thermoplastics.	Thermoplastics: Mechanical Properties (Fatigue)	FRIP
420. Unique Class of Electroactive Polymers Developed	Navy - DC	Dept. of the Navy	In-House	To discuss new electroactive polymers and their uses	Thermosets: Synthesis	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subsets(s)	Source
421. Use of Adhesives to Replace Welded Connections	DOT - FHWA	P. Albrecht Blunt and Evans	-	To establish feasibility of the use of adhesives for fabrication of secondary structural members in bridges.	Thermosets/ Thermoplastics/ Molecular Composites/ Characterization/ Mechanical Properties	FRIP
422. Viscoelastic Behavior of a Polyetheretherketone (PEEK) Composite	Air Force - Wright Patterson	R.P. Lockwood Air Force Institute of Technology	In-House	To examine the mechanical properties of PEEK along with a development viscoelastic response of PEEK components.	Thermoplastics: Characterization	NTIS
423. Waterproofing of Concrete Bridges	DOT	Y. Colldin Nat'l Swedish Road & Traffic Res. Inst. (Sweden)	-	To work out test methods and quality criteria for water-proofing bridge courses.	Thermosets: Mechanical Properties (Environmental Effects)	FRIP
424. Wide-Angle X-Ray Diffraction Investigations of Orientation of Chopped Fibers in Fabricated Thermoplastic Parts	Army - Army Research Office DAA/G29-85-K-0219	S. Lim, T. Kikutani; J.L. White, T. Kyu Aeron University	-	To devise a method of determining fiber orientation in composites using wide-angle x-ray diffraction.	Thermoplastics: Characterization/ Processing	NTIS
425. Winding of Continuous Filaments Impregnated with Thermoplastic Resins	NASA - DC	J.L. Tsine Societe Nationale Indust. Aerospatiale (France)	-	To study the winding of continuous filaments impregnated with thermoplastic resins.	Thermosets/ Thermoplastics: Mechanical Properties	NTIS
426. World of Polycarbonates	NIIST	S.K. Sikdar NIIST	In-House	To discuss new developments in polycarbonates, including uses and drawbacks.	Thermoplastics: Synthesis	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
325. Presidential Young Investigator Award: Transport Phenomena and Fluid Flow of Polymeric and Colloidal Liquids	NSF 8451446	G.G. Fuller Stanford University	07/01/85-02/28/91 \$312,500.00	To develop an optical technique by which the individual components of polydisperse polymeric liquids can be studied during a flow process.	Thermoplastics: Characterization/ Processing	FRIP
326. Presidential Young Investigator Award: Double-Diffusive and Buoyancy/Surface Tension Natural Convection	NSF	T.L. Bergman University of Texas	\$143,552.00	To study double diffusive natural convection in layered salt systems.	No subcategory established: Characterization	FRIP
327. Pressurized Structures, Structural Mechanics, Verification (See also Table 2, Structures, #193, and Table 3, Manufacturing, #103.)	NASA - Langley NAS1-18889	Freeman Boeing	05/12/89- \$22,647,000.00	To develop composite technology for pressurized fuselage structure including innovative structural concepts, structural mechanics, manufacturing technology and verification.	Thermosets: Mechanical Properties (Damage Tolerance/Fatigue)	ACT
328. Procedure for the Numerical Description of the Moisture Dependent Material Behavior	NASA - DC	S. Kraemer Technische Hochschule Aachen (Germany)	-	To present numerical descriptions of the behavior of polymers under the influence of environmental humidity.	Thermosets: Mechanical Properties (Environmental Effects)	NTIS
329. Process for Crosslinking and Extending Conjugated Diene-Containing Polymers	NASA - Langley	V.L. Bell; S.J. Havens NASA Langley	In-House	To discuss a process for crosslinking and extending conjugated diene-containing polymers.	Thermoplastics: Synthesis/ Characterization/ Processing/Mechanical Properties	NTIS
330. Process for Curing Bismaleimide Resins	NASA - Ames	J.A. Parker; A.H. Neimich; M.T.S. Hsu; T.S. Chen NASA Ames	In-House	To discuss process for curing bismaleimide resins.	Thermoplastics: Processing	NTIS
331. Processable Polyimide Adhesives and Matrix Composite Resins	NASA - Langley	T.L. St. Clair; D.J. Progar; J.R. Pratt NASA Langley	In-House	To synthesize processable thermoplastic polyimides.	Thermoplastics: Synthesis/ Characterization/ Processing	NTIS
332. Processing and Properties of Poly(p-Phenylene Benzobisthiazole/Bisbenzocyclobutene Molecular Composites	Air Force - Wright-Patterson F33615-87-C-5241,23 63: Q3	H.H. Chuah; L.S. Tan; F.E. Arnold University of Dayton	-	To investigate the reinforcement of thermoset systems at the molecular level by rigid-rod polymers.	Thermosets/Molecular Composites: Synthesis/Characterization	NTIS

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory: Subset(s)	Source
333. Processing of Fiber-Reinforced Materials by Injection Molding	NASA - DC	V. Woelfel Technische Hochschule Aachen (Germany)	-	To develop computer programs for computer-aided design of molded parts made from short glass fiber thermoplastics.	Thermoplastics Processing	NTS
334. Pultrusion Die Assembly	NASA - Langley	M.L. Wilson; G.S. Johnson; M.W. Frye; C.E. Stanfield	-	To look at an invention that relates generally to pultrusion die assemblies, and to use particularly to a pultrusion die assembly that incorporates a plurality of functions to produce a continuous thin composite fiber reinforced thermoplastic material.	Thermoplastics Processing	NTS
335. Quantum Yield of Vinylidene (3) 132) From the Vacuum UV Photolysis of Acetylene and Ethylene	NIST	Final Report NIST	In-House	To study Yield of Vinylidene 3(2) from Vacuum UV Photolysis of Acetylene & Ethylene.	Thermoplastics Synthesis	NTS
336. RV Boundary Layer Plasma	Air Force	Clark H. Lewis VRAP	\$578,892.00	To study the viscous hypersonic reentry flows at moderate angles of attack in a carbon-air system.	Thermosets/ Thermoplastics Characterization	FRIP
337. RV Composite Material/Payload NH&S Interaction Investigation	DNA	Nicholas J. Dispenzere Technology Development Assoc.	\$121,400.00	To develop graphite/epoxy composites for use in reentry vehicles.	Thermosets/ Processing/Mechanical Properties	FRIP
338. Radiation Effects on High Performance Polymers	NASA - DC NAG1-593	R.A. Orwoll College of William and Mary	-	To study the effect of radiation on high-performance polymers.	Thermoplastics Mechanical Properties (Environmental Effects)	NTS
339. Radiothermoluminescence Studies of Polymers Solids	Army - Army Research Office DAA C29-85-0203	C. Buckley Northwestern University	-	To characterize polymeric solids by radiothermoluminescence.	Thermosets/ Thermoplastics Characterization/ Mechanical Properties (Environmental Effects)	NTS
340. Rapid Nondestructive Determination of Resin/Fiber Content	Army	Gerald Entine Radiation Monitoring Devices	\$458,406.00	To apply a nondestructive nuclear measurement to fiberglass reinforced plastics.	Thermoplastics Characterization	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subset(s)	Source
341. Real Time In Situ Dielectric Monitoring of Advanced Composite	DARPA	L. Brian Keller Programmed Composites Inc.	\$478,900.00	To monitor physical and chemical changes in the cure process of composites using the Res-Cap technique.	Thermoplastics/ Characterization/ Processing	FRIP
342. Reduced Damage Accumulation Through Shrinkage Control	Army	Lynn Penn Strategic University Resources	\$49,830.00	To improve epoxy resin shrinkage in composites.	Thermosets/ Characterization/ Processing/Resin-Fiber (Interfacial) Chemistry/ Mechanics/Mechanical Properties (Damage Tolerance)	FRIP
343. Reducing Free Edge Effect on Laminar Strength by Edge Modification	Navy	C.T. and G.D. Chu School of Aeronautics and Astronautics	-	To investigate methods to reduce free edge interlaminar stresses in quasi-isotropic graphite/epoxy laminates.	No subcategory established: Characterization/ Mechanical Properties (Damage Tolerance)	US/J
344. Reinforcing of Thermoplastic Polycarbonate and Polysulfone with Carbon Fibers: Production and Characteristics of Un-Compound Objects	NASA - DC NASW-4307	E. Fitzer, H. Jaeger NASA DC	In-House	To investigate the production and mechanical properties of pre-pregs of polycarbonate.	Thermoplastics/ Characterization/Resin- Fiber (Interfacial) Chemistry-Mechanics	NTIS
345. Replacement of Precious Metal Thick Film Inks Using New Conductive Polymer Technology	DARPA	Al Zeinaki Metech Inc.	\$317,895.00	To evaluate substitution of metals with conductive polymers in thick film conductors and resistors.	Thermoplastics/ Characterization/ Processing	FRIP
346. Report on the 1986 Gordon Research Conference on Elastomers Held in New Hampshire in 1986	Army - Army Research Office, DAA103-86-G-0090	J.E. Mark Rhode Island University	-	To report on the 1986 Gordon Research Conference on Elastomers.	Thermosets/ Thermoplastics/ Synthesis/ Characterization/ Processing/Mechanical Properties	NTIS
347. Research Experience For Undergraduates (REU): Preparation And Properties of Electronic Materials	NSF 8901019	NLM Hagel University of California at Los Angeles	\$19,000.00	To determine characterization of conducting polymers.	No subcategory established: Characterization	FRIP
348. Research Initiation Award: Intermolecular Reactions In Flexible Polymer Solutions	NSF 8908995	B. O'Shaughnessy Columbia University	\$60,000.00	To derive a model for reaction rate in high viscosity melts where functional groups are diluted.	No subcategory established: Synthesis	FRIP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subset(s)	Source
349. Research Initiation: Thin-Gel Composite Membranes for the Separation of Biological Molecules	NSF 8808986	T.A. Barbert Johns Hopkins University	06/01/88-11/30/90 \$65,000.00	To develop thin-gel composite membranes for application in gel chromatography for bioseparations.	Molecular Composites: Synthesis	FRP
350. Resin Transfer Molding Process Modeling	NASA	Alfred C. Loos Virginia Tech	—	To develop and verify a processing model for resin transfer molding (RTM) of textile composites.	Thermoplastics: Processing/Resin-Fiber Interfacial Chemistry- Mechanics	NASA
351. Review of Thermal Properties of Graphite-Composite Materials	NASA - Ames	D.A. Kourtidis NASA Ames	In-House	To study flammability, thermal, and mechanical properties of graphite reinforced epoxides.	Thermosets: Characterization/ Mechanical Properties	NTS
352. STPI/LARC: A 200 Deg. C Polyimide Adhesive	NASA - Langley	D.J. Progar, T.L. St. Clair NASA Langley	In-House	To study synthesis of polyimide polymers and the processability and adhesive properties.	Thermoplastics: Synthesis/Mechanical Properties (Damage Tolerance)	NTS
353. Semi-2 Interpenetrating Networks of High Temperature Systems	NASA - Langley	A.O. Egli, T.L. St. Clair NASA Langley	In-House	To discuss interpenetrating network of the same repeat unit.	Thermosets: Synthesis	NTS
354. Semi-Interpenetrating Polymer Networks of Polyimides: Fracture Toughness (Abstract only)	NASA - DC	M.G. Hansen University of Tennessee	—	To improve the fracture toughness of the PMR-15 thermosetting polyimide by co-dissolving LaRC-ITP, a thermoplastic polyimide.	Thermosets/ Thermoplastics: Mechanical Properties	NTS
355. Silicon Nitride Whisker Reinforced Glass Matrix Composites	Air Force - Department of the Air Force	G.K. Layden; K.M. Prewo Air Force	In-House	NA (Patent Application)	No subcategory established: No subjects established	NTS
356. The Solid Phase Processing of Polymer Materials - A Computer Aided Engineering Approach	NSF	D. Lee Rensselaer Polytechnic Institute	09/01/80-08/31/89 \$319,825.00	To use a computer-aided engineering approach to study solid phase processing of polymer materials.	Thermoplastics: No subjects established	FRP
357. Solid State Digital X-Ray Imaging System for Improved NDI/E Techniques	Air Force	John D. Cox General Imaging Corp.	\$49,708.00	To develop non-destructive inspection using solid-state digital x-ray imaging system.	Thermosets: Processing	FRP

TABLE 1
PMC RESEARCH: MATERIALS

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory- Subject(s)	Source
358. Solvent Assisted Delamination: Crack Growth Behavior of Amorphous Thermoplastic Materials	Army	A.J. Hsieh; J.L. Vanselow Army Materials Technology Lab	In-House	To implement crack growth studies with ox/yone in an amorphous thermoplastic polyethimide (PEI), via a static desweight wading apparatus. The three systems evaluated were the best resin, composite, and adhesively bonded composite.	Thermoplastics: Environmental	NTS
359. Space Environmental Effects on Polymeric Materials. Semi-Annual Progress Report.	NASA - DC NAG1-678	R.L. Kleffer; R.A. Orwell College of William and Mary	-	To evaluate the use of polymer matrices as orbiting structures.	Thermosets: No subset established	NTS
360. Specifications for Painting Structural Steel	DOT-FHWA	B.R. Appleman Steel Structures Painting Council	-	To formulate specifications for painting structural steel.	Thermosets/ Thermoplastics: Processing	FRP
361. Strain Energy Release Rates for Cracked Uniaxial Fiber-Reinforced Composites	Air Force	W.K. Bindenda; F. Dedals; A.S.D. Wang Drexel University	-	To mathematically compute strain energy release rates for cracked uniaxial fiber-reinforced composites.	Thermosets: Characterization/ Mechanical Properties (Damage Tolerance)	US/I
362. Structural Characterization and Mechanics of Chopped Fiber and Molecular Composites	Army - Army Research Office DAA629-85-K-0219	J.L. White; T. Kyu Akron University	-	To investigate the phenomenon of phase segregation and its kinetic for PPTA/amorphous nylon mixtures and to evaluate the melt rheology and mechanical behavior of PPTA/nylon 6 and 66 molecular and particulate composites.	Thermoplastics/ Molecular Composites: Processing/Mechanical Properties	NTS
363. Structural Design Painting	DOT	Doris-Medina D.C. Department of Public Works	-	To evaluate the cost-effectiveness of these materials and degree of surface preparation before paint application.	Thermosets: No subset established	FRP
364. Structure Property Relationships in Polymeric Matrix Materials	Navy N00014-76-C-0200	J.K. Gillham Princeton University	-	To present results of thermoset matrix material.	Thermosets: Synthesis/ Characterization	NTS
365. Studies on Deformation and Fracture of Viscoclastic Composite Materials	Air Force AFOSR-87-0257	Richard A. Schapery Texas A&M University	07/01/87-06/30/89	To develop and verify mathematical models of deformation and delamination of viscoelastic composites with distributed microdamages.	Molecular Composites: Mechanical Properties	MCR
366. Study of Damage Tolerance of Thermoplastic Composites	NASA - Langley	C.C. Poe, Jr. NASA Langley	12/01/88-12/31/92 In-House	To develop an analysis that can also be used as a design tool for predicting the complete damage state during and after impact and the residual properties in thermoplastic and thermoset matrices.	Thermosets/ Thermoplastics: Mechanical Properties (Damage Tolerance)	MCR

STRUCTURES RESEARCH

"Structures" research includes those surveyed projects that concentrate on the development and use of structural components made from PMC materials. As demonstrated by table 2, which lists the structures research projects included in the survey, typical goals for structures research include testing the effectiveness of composite structural components, the development of structural models, and assessments of the benefits of weight reduction that results from the use of PMC components. A significant amount of research focuses on the use of composites in constructing wings and other aircraft components.

Trends in Structures Research

Structures research accounts for 246 of the 778 projects identified in the survey. Of this number, 229 focus exclusively on structures research, while 17 projects combine structures research with materials research, manufacturing research, or both. Except for DOT, where only 7 out of 43 sponsored projects focus on structures research, the proportion of research dedicated to structures by all key Federal agencies roughly parallels that shown for the full survey.

NASA's keen interest in developing aircraft constructed in whole or in part of components made from advanced composites is a driving force behind its leadership in the area of structures research. Through the ACT program, NASA has issued several contracts to leaders in the U.S. aircraft industry, each designed to achieve advances that will promote the use of advanced composites in building both commercial and government aircraft. An ultimate goal is to achieve weight reductions in aircraft that will improve performance and save energy. Sample ACT projects include "Innovative Composite Fuselage Structures," a \$22 million contract awarded in 1989 to Lockheed. The objective of that contract is to develop composite technology for wing structures and pressurized fuselage structures, including innovative structural concepts, structural mechanics, manufacturing technology, and verification. Another example, titled "Innovative Wing Concepts, Commingled, RTM, Verification," is a \$2.7 million award to Grumman made in 1989. Here, the main objective was to develop innovative wing concepts for high-speed aircraft.

About one-third of DoD's PMC research effort concentrates on structures research. Product-specific research focuses on a variety of products, from aircraft to conventional weapons. For instance, the "Lightweight Howitzer Project" is an in-house (U.S. Army Laboratory Command) project established to demonstrate the use of composite materials to build towed artillery, thus reducing the weight of the artillery.

To define applicable fields of research more specifically, all structures research projects included in the survey have been subcategorized into one or more of the following areas: mechanics of materials, structural mechanics, and structural concepts or verification. Distribution among the subcategories was relatively even, with 89 projects subcategorized as mechanics of materials, 63 as structural mechanics, and 64 as structural concepts. Thirty projects have been cross-categorized as belonging to two or more subcategories.

Project Data

Described in table 2, which appears on pages 73-102 of this report, are each of the 246 projects categorized as structures research. The projects are listed in alphabetical order by study title, and each project is numbered. As indicated above, 17 projects classified as structures research also relate to at least one other area of research. A notation follows the title of each of those projects referencing the other table(s) in which it appears.

Tabular information for every project includes the project sponsor and the performing organization (where applicable). To the extent data is available, the table also provides contract numbers, principal investigators' names, contract duration periods, and funding amounts (or notations of in-house work).

Also included in table 2 are briefly stated project objectives. Following the objective statements is a column that shows the subcategory(ies) assigned to each project (mechanics of materials, structural mechanics, or structural concepts/verification).

In the final column, the table indicates the primary data source for each project identified.

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
1. 3-D Synchrotron X-Ray Micro-radiography for Composites	Navy - Office of Naval Research N00014-89-C-0076	A.S. Krieger Radiation Science, Inc.	04/01/89-03/31/90	To assess the internal structure and defects in composite materials and composite interfaces using three-dimensional synchrotron x-ray microtomography.	Structural Concepts- Verification	MCR
2. A 3-D Numerical Model for Ultrasonic Phenomena	NSF	R. Ludwig Worcester Polytechnic Institute	02/01/88-07/31/90 \$1.00	To develop a general purpose finite element code to solve the underlying equation of motion for two-dimensional plane-strain situations.	Mechanics of Materials	FRIP
3. Adhesive Bond Evaluation by Nondestructive Testing Techniques	NSF	C. Brent Fagan Engineering Data Management	\$40,000.00	To evaluate the feasibility of using multiple-variable NDE methods to provide fast, cost-effective, reliable determination of the strength of adhesive bonds through the use of the impact sonic wavespectral analysis method.	Structural Concepts- Verification	FRIP
4. Advanced Composite Fabrication and Testing	NASA - Langley NAS1-18954	Anthony Falcone Boeing Aerospace	08/01/89-08/31/94	To process and test experimental composite materials and state-of-the-art systems including woven, braided, knitted, and stitched fiber forms.	Structural Mechanics	MCR
5. Advanced Composite Laminates for Rotorcraft	Army	R.J. Diefendorff, O.A. Bauchau, S.J. Winkler Rensselaer Polytechnic University	-	To develop new two- and three-dimensional composite concepts that promise advanced elastic tailoring, improved load transfer, and/or reduced fabrication costs using analytical modeling, fabrication, and testing research.	Structural Mechanics/ Structural Concepts- Verification	MCR
6. Advanced Composite Materials for Ultra-High Precision Reflector Honeycomb Panels	NASA - Langley	Stephen S. Tompkins NASA Langley	10/01/88-09/30/91 In-House	To develop advanced structural composite materials that are dimensionally stable and durable in the LEO and GEO space environments.	Structural Mechanics	MCR

Note The data sources have been abbreviated according to the following key: ACT = Advanced Composites Technology; ASC = Proceedings of the American Society for Composites; CA = Chem Abstracts; FRIP = Federal Research in Progress; MCR = Mechanics of Composites Review; NTIS = National Technical Information Service; and US/J = U.S./Japan Composites Workshop.

TABLE 7.
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
7. Advanced Composite Structural Concepts	NASA - Langley NASI-18888	James H. Starnes, Jr. Mail Stop 190 NASA Langley	10/01/84-09/30/92 In-House	To develop composite structural concepts and design technology needed to realize the improved performance, structural efficiency, and lower-cost advantage offered by new material systems and manufacturing methods for advanced aircraft structures.	Structural Concepts- Verification	MCR
8. Advanced Composite Structural Concepts and Material Technologies for Primary Aircraft Structures	NASA - Langley NASI-18888	A. Jackson Lockheed Aeronautical Systems Company	04/01/89-05/31/95	To develop and verify innovative structural concepts such as geodesic stiffening, sandwich construction, and pultruded stiffness.	Structural Concepts- Verification	MCR
9. Advanced Composite Structural Design Technology for Commercial Transport Aircraft	NASA - Langley NASI-15943	R.E. Barrie Lockheed Aeronautical Systems Company	09/24/79-03/23/90	To design, analyze, fabricate, and test generic advanced-composite structural components for transport aircraft applications in order to develop verified design technology.	Structural Concepts- Verification	MCR
10. Advanced Composite Structures Technology Program	NASA - Langley	C.P. Blankenship NASA Langley	In-House	To perform advanced concept development analysis, fabrication, testing, and demonstration programs in structures and materials with emphasis on primary structure for aircraft applications.	Structural Concepts- Verification	FRIP
11. Advanced Composites	Air Force WUD 45	James M. Whitney Materials Lab. Wright Res. & Dev. Ctr.	10/01/88-10/31/89 In-House	To evaluate deformation and failure in composite laminates.	Structural Mechanics	MCR
12. Advanced Concepts for Composite Helicopter Fuselage Structures	NASA - Langley	Donald J. Baker NASA Langley	04/01/83-01/01/92 In-House	To investigate new design concepts for composite materials on lightly loaded helicopter fuselage structures.	Structural Concepts- Verification	MCR
13. Advanced Mechanical Design of High-Performance Articulating Robotic Systems	Army	M.V. Gandhi; B.S. Thompson Michigan State University	-	To develop a new generation of high-performance lightweight robot arms fabricated in advanced composite materials.	Structural Mechanics	MCR
14. Advantages of Fiber Placement Versus Conventional Filament Winding for a Marine Structure	NASA	R.L. Anderson Hercules, Inc.	-	To discuss the advantages of a new process of fiber placement for a marine structure over the convent filament method.	Structural Mechanics/ Structural Concepts- Verification	ASC
15. Aerelastic Tailoring Technology	NASA - Langley NASI-18754	Lopez University of California at Davis	01/04/89 \$212,000.00	To develop aerelastic tailoring for technology.	Structural Mechanics/ Structural Concepts- Verification	ACT

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
16. Analysis and Design of Composite Fuelage Frames	Army	O.A. Bacheu Kensseler Polytechnic Institute	-	To develop a model that will allow the accurate analysis and design of helicopter fuelage frame components using composite materials.	Structural Concepts- Verification	MCR
17. Analysis of 2-D and 3-D Reinforced Composites	NASA - Langley NAS1-18000	Raymond L. Foye PRC Kentron, Inc.	03/01/87-09/30/90	To develop analytical methods to predict the elastic and strength response of 2-D and 3-D reinforced composite materials.	Mechanics of Materials	MCR
18. Analysis of Delamination-Related Fracture Processes in Composites (See also Table 1, Materials, #18.)	NASA	Erian A. Armanios Georgia Institute of Technology	-	To develop mid-plane and transverse crack tip delamination analysis for interlaminar damage prediction in uniform laminates, and to construct simple models for the delamination analysis of tapered laminated composites in order to use them for the preliminary design of composite rotor hubs.	Mechanics of Materials	NASA
19. Analysis of Effects of Microstructure and Geometry	Navy	Saileendra N. Chatterjee Materials Sciences Corp.	\$30,000.00	To develop analytical methods for probing mechanized models of composite structures.	Structural Concepts- Verification	FRIP
20. Analysis of Shear Band Development Incorporating Heat Conduction	Army - Army Research Office DAA/G29-85-K-0003	J. Le Monds; A. Needleman Brown University	-	To incorporate the effects of material temperature sensitivity and heat conduction into an infinite bond type analysis of shear localization.	Structural Mechanics	NTIS
21. Analytical Modeling of Composite Interface Mechanics	Navy - Naval Air Development Center	Lee W. Cause Naval Air Development Center	09/01/85-10/31/8 In-House	To understand how interface failure mechanisms develop and influence the properties of resin matrix composites and devise nonlinear micromechanics models to describe the behavior at the interface region.	Structural Mechanics	MCR
22. Analytical and Experimental Characterization of Damage Processes in Composite Laminates	Air Force-Bolling AFB AFOSR-84-0366; 2302; B2	G.J. Dvorak; N. Laws Kensseler Polytechnic Institute	-	To study damage development in metal and polymer matrix composite laminates.	Structural Mechanics	NTIS
23. Angular Weaving Techniques for Turbin Components Assessment	Air Force	Janice R. Malden Textile Technologies Inc.	\$33,845.00	To develop new weave techniques of composites.	Structural Concepts- Verification	FRIP

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
24. Anisotropic Shell Analysis	NASA - Langley NAG-1-901	Michael W. Hyer Virginia Tech	10/01/88-09/30/90	To develop accurate analyses for the response of anisotropic composite shell structures.	Structural Concepts- Verification	MCR
25. Assessment of a Fiber-Reinforced Plastic Weapon Storage Structure	Navy	Thierry Deegan Deegan Research GP Inc.	\$49,162.00	To investigate the feasibility and suitability of applying a fiber-reinforced plastic composite structure to house and support torpedo tube launched weapons in submarines.	Structural Mechanics	FRIP
26. Ballistic Survivability of Generic Composite Main Rotor Hub Flexbeams	Army - Army Aviations Systems Command	E. Robeson; K. Saitka U.S. Army ARTA (AVSCOM)	In-House	To quantify the ballistic survivability of typical composite main rotor hub flexbeams.	Structural Mechanics	MCR
27. Basic Research in Structure	Army - Army Aviations Systems Command	T.K. O'Brien; R.L. Bainott; G.L. Farley; M.W. Nixon U.S. Army ARTA	In-House	To investigate and explore structures technologies that exploit advanced materials for improved structural performance, develop superior analyses for composites design, and devise automated processes for inspecting and manufacturing rotorcraft structures.	Structural Mechanics	MCR
28. Basic Research into Static and Dynamic Properties of Composite Blades with Structural Couplings	Army	John Dugundji Massachusetts Institute of Technology	-	To study analytically and experimentally the static and dynamic behavior of helicopter rotor blades made of composite materials.	Mechanics of Materials	MCR
29. Behavior of Composites Subjected to Underwater Explosive Loading	Navy	Erik Rasmussen Navy	01/01/87-09/30/90 In-House	To develop the analytical and experimental techniques required to assess the dynamic capabilities of proposed composite submarine pressure hull structural and material concepts.	Mechanics of Materials/ Structural Concepts- Verification	MCR
30. Buckling and Strength of Thick-Walled Composite Cylinders	NASA - Langley	Dawn C. Jegley NASA Langley	10/01/86-09/30/90 In-House	To develop accurate analyses for the buckling and strength predictions of thick-walled composite cylinders.	Mechanics of Materials	MCR
31. Characterizing the Fracture Toughness of Advanced Composite Structures	NASA - Langley NASI-18833	John A. Nairn University of Utah	04/01/89-05/31/95	To develop fracture mechanics analyses for predicting matrix microcracks and microcrack-induced delaminations.	Structural Mechanics	MCR
32. Collapse and Failure Modes in Advanced Composite Structures	NASA - Langley NSC-1483	Wolfgang G. Knauss California Institute of Technology	01/15/78-01/14/90	To experimentally and analytically study time-dependent effects on buckling and failure of composite structures with discontinuities.	Mechanics of Materials	MCR

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
33. Combined Two-Dimensional Parameter and Function Estimation in Heat Transfer	NSF 8813263	J.V. Beck Michigan State University	09/15/88-02/28/91 \$55,010.00	To analyze two-dimensional experiments for measurement of directional thermal conductivities of fiber filled epoxy materials.	Mechanics of Materials	FRIP
34. Compaction Study of Conductive Polyether Ether Ketone (PEEK) and Nickel Powder Composites	Navy	J.J. Reilly; I.L. Kanel Naval Air Development Center	In-House	To perform compaction studies of PEEK of different coarse guides with Nickel Powder correlation with strength.	Mechanics of Materials	NTIS
35. Composite Airframe Design for Weapons Interface	Army - Army Aviations Systems Command	J. Moffatt U.S. Army ARTA (AVSCOM)	In-House	To investigate the effect of 20-30mm weapon firing in close proximity to composite airframe.	Mechanics of Materials	MCR
36. Composite Erosion Test and Model Development	Air Force	Lowell D. McMillen Sparta Inc.	\$936,433	To develop a first-order model for assessing coupled ablation/erosion response of composite materials used for nosetips and heatshields on various vehicles.	Structural Concepts- Verification	FRIP
37. Composite Fuselage Technology	NASA - Langley NAC-1-982	P.A. Lagace Massachusetts Institute of Technology	04/07/89-04/07/90	To conduct experimental and analytical studies of pressurized composite fuselage shells subjected to damage.	Structural Concepts- Verification	MCR
38. Composite Hull for Light Infantry Fighting Vehicle	Army	E. Weerth PMC Corp.	-	To demonstrate the application of thick composites technology to armored vehicles for the purpose of weight reduction.	Structural Concepts- Verification	MCR
39. A Composite Improved Mau-12 Bomb Ejector Rack Assembly Development	Air Force	David Maass Advanced Composite Products	\$82,651.00	To develop thermoplastic composite bomb ejector rack assembly.	Structural Mechanics	FRIP
40. Composite Materials for Manikin Skeletal Components KP 358-86	Air Force	Eli Rubinstein Ketrion, Inc.	\$49,937.00	To demonstrate the feasibility of improving the biofidelity of a modern manikin such as hybrid III by replacing the existing metal bones with stronger, lighter weight composite material structural members which incorporate appropriate ballasting features.	Structural Mechanics	FRIP

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
41. Composite Pressure Hull Penetration and Joint Design	Navy	M. Brown David Taylor Research Center	06/01/88-09/30/90 In-House	To develop structurally efficient joint, penetration, and rein forcement concepts for composite pressure hulls.	Structural Concepts- Verification	MCR
42. Composite Structural Materials. Annual Progress Report No. 50, May 1, 1986 - April 30, 1987	NASA - DC	R.G. Loewy; S.E. Wilberley Rensselaer Polytechnic Institute	-	To review the use of composites as structural materials in aircraft.	Structural Concepts- Verification	NTS
43. Composite Structures	Army	W.H. Drysdale AMC LABCOM Ballistic Research Lab.	In-House	To develop failure criteria, architecture transition technology, and optimum design technology for thick ballistic structures.	Mechanics of Materials	MCR
44. Composite Structures for Surface Ships	Navy	M. Critchfield David Taylor Research Center	10/01/85-09/30/93 In-House	To develop the basic technology to support the applications of composites to naval ship structures including design and analytic methods in structural joints and attachments, and to demonstrate the feasibility of using FRP composites for surface ship structural applications.	Structural Mechanics	MCR
45. Composites Characterization Work Breakdown Structure	NASA - Langley	Joseph S. Heyman IRD Nondestruct. Measurement Science Br.	-	To develop quantitative measurement and technology to characterize properties of composites nondestructively and link physical properties thus measured to engineering properties needed for materials and structures certification.	Mechanics of Materials	MCR
46. Compression Failure Mechanisms of Composite Structures	NASA - DC NAGI-295	H.T. Hahn; M. Sohi; S. Moon Washington University	-	To study the compression failure mechanisms of composite structures.	Mechanics of Materials	NTS
47. Compression Response of Thick-Section Composite Materials	Navy	E.T. Camponeschi, Jr. David Taylor Research Center	10/01/86-09/30/91 In-House	To develop an understanding of compression failure for thick-section composites.	Structural Mechanics	MCR

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
48. Computational Mechanics of Thick Composites	Army	A. Tesler U.S. Army Laboratory Command	In-House	To develop analytic methods for predicting mechanical response and failure of advance thick composite structures which may involve stress concentrators such as cutouts, fasteners, delaminations, and defects.	Structural Concepts- Verification	MCR
49. Continuous Low Cost Processing Techniques For Manufacturing of Large Rocket Motors	Air Force	Albert F. Hademann General Technology Application	\$269,090.00	To use composites in large solid rocket motors.	Structural Concepts- Verification	FRUP
50. Control Augmented Structural Optimization of Aeroelastically Tailored Fiber Composite Wings	Air Force F49620-87-K-00-3	Lucien A. Schmitt; Peretz Friedmann University of California at Los Angeles	11/01/86-10/31/89	To develop a control-augmented optimization capability for the efficient aerodynamic tailoring of composite wings and lifting surfaces. The analytical methods should permit extension of formal optimization procedures in design applications beyond current capabilities.	Structural Concepts- Verification	MCR
51. Copper/Graphite Composite at High Heat Flux Boiling Surface	NSF 8811065	W. Yang University of Michigan	09/15/89-02/28/91 \$70,325.00	To investigate experimentally and semi-theoretically nucleate boiling from a copper-graphite composite surface.	Structural Concepts- Verification	FRUP
52. Crack Problems in Orthotropic Plates and Nonhomogeneous Materials	NASA - Langley NAC-1-713	Fazil Erdogan Lehigh University	11/01/86-10/31/90	To evaluate plate and shell structure containing surface cracks under mixed-mode loading conditions.	Mechanics of Materials	MCR
53. Crash Characteristics of Composite Fuselage Structures	NASA - Langley	Huey D. Carden NASA Langley	07/01/82-09/30/89 In-House	To study the crash characteristics of composite transport fuselage structural components.	Mechanics of Materials	MCR
54. Cracking in Polymeric and Composite Systems	Air Force AFOSR-87-0143	C.C. Hsiao University of Minnesota	04/01/87-03/31/90	To develop time-dependent theories for the crazing behavior of polymeric and structural composite systems by understanding the microstructural behavior of the materials during crazing.	Structural Mechanics	MCR
55. Damage Resistance in Rotorcraft Structures	Army	E.A. Armandos Georgia Institute of Technology	-	To explore the benefits of tailoring microstructure, i.e., ply stacking sequence, fiber orientation, and a blend of material plies, to contain and resist damage in rotor systems and airframe structural components.	Mechanics of Materials	MCR

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
56. Damage Tolerance Sensitivity / Durability (See also Table 1, Materials, #80.)	NASA - Langley NAS1-18778	Poe Stanford University	12/16/88 \$450,000.00	To model impact damage and develop damage tolerance sensitivity criteria.	Mechanics of Materials	ACT
57. Damage Tolerance Testing of the ACAP Roof	Army - Army Aviations Systems Command	B. Spiegel U.S. Army ARTA (AVSCOM)	In-House	To verify the damage tolerance design criteria developed under contract by Bell Helicopter Textron, Inc.	Structural Mechanics	MCR
58. Damage Tolerance of Composite Plates	NASA - Langley NAS1-18778	G.S. Springer Stanford University	04/01/89-05/31/95	To develop an analysis to predict the complete damage state during and after low-velocity impact and to predict the residual properties.	Mechanics of Materials	MCR
59. Deformation and Damage Mechanisms in High-Temperature Composites with Ductile Matrices	Air Force AFOSR-88-0150	George J. Dvorak Rensselaer Polytechnic Institute	03/01/88-02/28/91	To develop a basis of understanding of the thermo-mechanical behavior of fibrous composites with ductile matrices and ductile or elasto-brittle fibers, and of the damage mechanisms activated by combined mechanical and thermal loading, both cyclic and monotonic.	Structural Mechanics	MCR
60. Delamination Growth in Tapered Composite Laminates with Internal Ply Drops	NASA - Langley	T. Kevin O'Brien NASA Langley	09/30/89-09/30/92 In-House	To develop analyses which accurately model this delamination failure mode.	Structural Concepts- Verification	MCR
61. Delamination Micromechanics Analysis	NASA - Langley	John H. Crews, Jr. NASA Langley	10/01/85-09/30/90 In-House	To develop 2-D, a fiber-resin stress analysis, for a region near delamination front containing microcracks.	Structural Mechanics	MCR
62. Delaminations in Tapered Composite Laminates with Internal Ply Drops	NASA - Langley	Gretchen B. Murrel NASA Langley	10/00/88-9/30/90 In-House	To characterize delamination failures in tapered composites containing internal ply-drops.	Structural Mechanics	MCR
63. Design Analysis of Composite Test Specimens	Army	S. Chatterjee Materials Sciences Corp.	—	To evaluate current specimen designs for mechanical-property test specimens for composites and to develop design improvements.	Mechanics of Materials	MCR
64. Design Technology for Stiffened Curved Composite Panels and Shells	NASA	James H. Starnes NASA	In-House	To develop verified design technology for generic advanced-composite stiffened curved panels.	Structural Concepts- Verification	MCR
65. Determination of Mechanical Material Properties for Filament Wound Structures	Army	Terry L. Vandiver Army Missile Command	In-House	To develop test standards for the determination of mechanical material properties for filament wound composite structures.	Mechanics of Materials	MCR

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
66. Develop Composite Materials with Embedded Fiber-Optic Sensors for In-Situ Monitoring of Material Properties	NASA - Langley	Robert S. Rogowski NASA Langley	In-House	To investigate fiber-optic sensors as potential internal sensors for composite materials.	Structural Mechanics	MCR
67. Development of Advanced Woven Composite Materials and Structural Forms	NASA - Langley NAS1-18358	Janice Maiden Textile Technologies, Inc.	08/79/86-08/79/90	To develop textile technology to produce 2-D and 3-D woven preforms and structural elements with integral stiffening, multilayers, and multidirectional reinforcement.	Mechanics of Materials	MCR
68. Development of Filament Winding Process for Gr/TP Composite Laminates	NASA - Langley NAS1-18624	G.E. Walker, Jr. Hercules Aerospace Company	04/77/89-04/77/90	To develop and evaluate processes for Gr/TP filament-wound / fiberplacement laminates.	Mechanics of Materials	MCR
69. Development of Ultra-Lightweight Materials-M	Air Force F3615-88-C-5452	Gail L. Dolan McDonnell Douglas Corp.	05/13/88-07/15/91	To demonstrate the potential for advanced ultra-lightweight materials and associated processes that will permit a 50% reduction in the structural weight of state-of-the-art high-performance aircraft that currently utilize up to 10% of advanced composite materials in their structures.	Structural Concepts- Verification	MCR
70. Development of Ultra-Lightweight Materials-N	Air Force F3615-88-C-5447	Anne R. Beck Northrop Corporation, Aircraft Div.	04/79/88-07/01/91	To demonstrate the potential for advanced ultra-lightweight materials and associated processes that will permit a 50% reduction in the structural weight of state-of-the-art high-performance aircraft that currently utilize up to 10% of advanced composite materials in their structures.	Structural Concepts- Verification	MCR
71. Development of an Advanced Fan Blade Containment System	DOT	Alan D. Lane Advanced Structures Tech, Inc.	\$50,000.00	To build an advanced turbine engine for a blade containment system from ceramic tiles and polymer fibers.	Structural Concepts- Verification	FRIP
72. Diffraction Efficiency of Photothermoplastic Layers for the recording of Discrete Holograms	NASA - DC	S.N. Koreshev; Y.A. Cherkasov; T.L. Kislovskiy NASA	In-House	To determine the dependence of eta of a digital phase Fourier hologram of a point object on the amount of deformation delta and to detail the discrete-structure parameters that represent the hologram.	Structural Concepts- Verification	NTS

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
73. Dynamic Behavior of Composites	Navy - Naval Research Laboratory N00014-86-C-2580	Longin B. Greszduk McDonnell Douglas Astronautics Co.	10/01/86-03/31/90	To establish the response of composite materials subjected to large-area dynamic loading from underwater.	Mechanics of Materials	MCR
74. Dynamic Characterization of Advanced Materials	Army	W. Greshaw U.S. Army Materials Technology Lab	In-House	To design and evaluate instrumentation systems and experimental designs to measure load response of advanced composites and homogeneous materials to low speed impact loading.	Mechanics of Materials/ Structural Concepts- Verification	MCR
75. Dynamics and Aeroelasticity of Composite Structures	Air Force F496200-86-C-0066	John Dugundji Massachusetts Institute of Technology	07/01/86-06/30/90	To pursue combined experimental and theoretical investigations of aeroelastic tailoring effects on flutter and divergence of aircraft wings.	Structural Mechanics	MCR
76. Dynamics of Structures	Army	G.E. Foley; J. McMorrow; M.E. Roylance U.S. Army Materials Technology Lab	In-House	To develop modal analysis as a predictive technique for detection of damage in composite structures, such as foam core sandwich panels.	Mechanics of Materials	MCR
77. An Eddy-Current Model and Inversion Algorithm for Nondestructive Evaluation of Materials and Structures	Navy	Harold A. Sabbagh Sabbagh Associates, Inc.	\$549,097.00	To develop a sensor, together with a mathematical algorithm that will allow the three-dimensional quantitative eddy-current non-destructive evaluation of materials and structures.	Mechanics of Materials	FRIP
78. Effects of Surface Cuts on Motor Case Strength - Analytical Model	Air Force	Sailendra N. Chatterjee Materials Sciences Corp.	\$49,810.00	To determine the effect of surface cuts on motor case strength analytical model.	Structural Concepts- Verification	FRIP
79. Effects of Matrix and Interphase on Carbon Fiber Composite Compression Strength	NASA - Langley NAS1-18883	Willard D. Bascom University of Utah	04/01/89-05/31/95	To determine the material parameters that control composite compression strength, so that the fiber/matrix/interphase combination can be optimized.	Structural Mechanics	MCR
80. Eigensensitivity Analysis of Composite Laminates: Effect of Microstructure	Air Force F49620-89-C-0003	Robert Reiss Howard University	11/01/88-10/31/90	To assess the sensitivity of composite laminates' natural (for elastic models) and complex (for viscoelastic models) frequencies to small changes in the properties of their constituents.	Structural Concepts- Verification	MCR

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
81. Electromagnetic Cage Techniques For Dynamic Tensile Fracture	NSF	Chapman Young Santura Recovery, Inc.	\$40,000.00	To use electromagnetics in studying mechanical properties.	Mechanics of Materials	FRIP
82. Environmental Exposure Effect on Composite Materials for Commercial Aircraft	NASA - Langley NASI-15148	Randy Coggeshall Boeing Commercial Airplane Company	11/01/77-12/31/90	To provide a long-term environmental analysis of graphite/ epoxy composite materials.	Structural Mechanics	MCR
83. Epoxy Coated Bars	DOT	R. Turgeon Pennsylvania Dept. of Transportation	-	To evaluate construction and corrosion resistance performance of bridges with epoxy coated reinforcing bars.	Structural Mechanics	FRIP
84. Experimental Displacement Contouring of Pin-Loaded Plates	Army	S. Serbian U.S. Army Laboratory Command	In-House	To apply conventional finite methodologies to pinloaded laminates to obtain both inplane and out of plane displacement components.	Structural Concepts- Verification	MCR
85. Experimental Evaluation of Advanced Composite Material Forms	NASA - Langley	H. Benson Dexter NASA Langley	06/01/84-06/01/90 In-House	To determine the mechanical properties and establish damage tolerance of 2-D and 3-D woven, stitched, and braided composite materials.	Mechanics of Materials	MCR
86. Failure Analysis and Damage Tolerance of Composite Aircraft Structures	NASA - Langley NASI-17925	R.K. Kuntz Lockheed Aeronautical Systems Co.	02/23/85-09/30/90	To develop advanced structural concepts and to advance the analytical capability to predict composite structural failure.	Structural Concepts- Verification	MCR
87. Failure Mechanisms for Composite Laminates with Damage and Local Discontinuities	NASA - Langley	Mark J. Stuart NASA Langley	10/01/76-09/30/90 In-House	To study effects of impact damage and local discontinuities on strength of composite structural components, to identify the failure modes that govern behavior of components subjected to low-velocity impact damage, and to analytically predict failure and structural response.	Mechanics of Materials	MCR
88. Failure Mechanisms in Composite Turbine Blades	Air Force	Som R. Soni Adtech Systems Research, Inc.	\$249,981.00	To develop a technique to predict the different failure modes in the composite turbine blade.	Mechanics of Materials	FRIP

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
89. Failure and Degradation of Adhesive Joints	Army	D. Opliger U.S. Army Laboratory Command	In-House	To provide the Army with improved design, life prediction, and reliability methodology for adhesive joints.	Mechanics of Materials	MCR
90. Failure of Laminated Plates Containing Holes	Air Force AFOSR-87-0204	E.S. Follas University of Utah	04/01/87-03/31/89	To analytically determine the three-dimensional stress field in a laminated plate containing a cylindrical hole through its entire thickness and loaded uniformly in the in-plane direction and to establish failure criteria.	Structural Mechanics	MCR
91. Fatigue Crack Propagation in Polycarbonate Foam	Army - Army Research Office	S.S. Yau; C. Mayer North Carolina State University	-	To determine the resistance to fatigue crack propagation of a glass-reinforced rigid polycarbonate foam in both ambient air and aqueous environments.	Mechanics of Materials/ Structural Mechanics	NTS
92. Fiber Buckling in Laminated Plates	NASA - Langley NAG-1-1040	A. Waas University of Michigan	10/01/89-09/30/90	To conduct experimental and analytical studies to isolate and observe in-situ failure mechanisms for composite structures.	Structural Mechanics	MCR
93. Fiber Composite Structural Durability and Damage Tolerance: Simplified Predictive Methods	NASA - Lewis	C.C. Chamis, C.A. Ginty NASA Lewis	In-House	To present predictive models to evaluate composites for structural durability.	Mechanics of Materials	NTS
94. Fiber Waveguide Sensors for Intelligent Materials	NASA - Langley NAG-1-895	Richard O. Claus Virginia Tech	09/01/88-10/31/90	To develop fiber-optic-based opto-electronic sensing instrumentation for the characterization of materials and structures.	Structural Mechanics	MCR
95. Field and Laboratory Evaluation of Stainless Steel Clad Reinforcing Bars for Bridge Decks	DOT	R.L. McCrum Michigan Dept. of Transportation	-	To evaluate the feasibility of using stainless steel clad and epoxy coated rebars in bridge decks.	Structural Mechanics	FRFP
96. Film-Based Composite Structures for Ultralightweight Space-Based Structures	SDIO	Richard W. Lusignea Foster-Miller, Inc.	\$72,123 G.	To evaluate the usefulness of PBT film-based composite structures for thin-walled space structures.	Mechanics of Materials	FRFP
97. Finite Element Analyses of Shear Localization in Rate and Temperature Dependent Solids	Army - Army Research Office DAA C29-85-0003	J. Le Monds; A. Needleman Brown University	-	To examine the effects of strain hardening, strain rate sensitivity, thermal softening, heat conduction, and the imposed strain rate on the shear localization process in plane strain compression.	Structural Concept- Verification	NTS

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
98. Finite Element Analysis of Composite Shells	Air Force AFOSR-FD-88-0010	Anthony Palazotto Air Force Institute of Technology	04/01/89-09/30/90 In-House	To analyze the static and dynamic characteristics of composite shells. A finite element program has been developed. Perturbation and boundary integral techniques are also being used for baseline and comparison purposes.	Structural Concepts- Verification	MCR
99. Finite Element Correlation of the Advanced Composite Air-Frame Program (ACAP) Dynamic Models	Army - Army Aviations Systems Command	N. Calapodas; D. Kinney U.S. Army ARTA (AVSCOM)	In-House	To conduct detail correlation of the Finite Element (FE) dynamic models of both ACAP airframes.	Structural Concepts- Verification	MCR
100. Finite Element Modeling of Composite Rotor Blades	Army - Army Research Office	S. Lee, A. Vizzini University of Maryland	-	To develop a beam finite element formulation of the combined dynamic bending, torsional, and extensional behavior of composite rotor blades.	Structural Mechanics	MCR
101. Flammability Smoke Toxicity and Mechanical Property Characterization of Novel Thermoplastic-Composite Materials	Navy	David Maass Advanced Composite Products, Inc.	\$85,425.00	To study flammability smoke toxicity and mechanical property characterization of novel thermoplastic composite materials	Structural Concepts- Verification	FRIP
102. Flight Service Evaluation of Composite Components on Commercial and Military Aircraft	NASA - Langley	H. Benson Dexter NASA Langley	03/01/72-12/31/90 In-House	To evaluate the long-term durability of composite components installed on commercial and military transport and helicopter aircraft.	Structural Mechanics	MCR
103. Formal Optimization Procedures for Composite Blades	Army	O.A. Bauchau Rensselaer Polytechnic Institute	-	To develop design and optimization tools that allow for the imposition of multiple constraints for the full application of composite materials to rotor blades.	Structural Concepts- Verification	MCR
104. Fractographic Analysis of Interlaminar Fracture	NASA - Langley	W.D. Bascom; D.J. Bolt; D.L. Hunston; B. Fuller; P.J. Phillips NIST	-	To study the fractographic analysis of interlaminar fracture Mode I.	Mechanics of Materials	NTIS
105. Fractology of Mixed Mode I-II Failure in Graphite/Epoxy and Graphite/Thermoplastic Unidirectional Composites	Air Force - Wright-Patterson 2307/32	S.L. Donaldson Wright Aeronautical Labs	In-House	To study fractures surfaces of fiberite and PEEK composites after both Mode I and Mode II fracture testing to investigate toughness.	Mechanics of Materials	NTIS

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
106. Fracture Mechanics, Laminate Failure Mechanics (See also Table 1, Materials, #160.)	NASA - Langley NAS1-18833	Crews University of Utah	12/08/88 \$179,000.00	To develop laminate failure mechanisms using fracture mechanics.	Mechanics of Materials	ACT
107. Fracture Problems in Pressure Vessels and Reinforced Pipes	NSF	F. Erdogan Lehigh University	11/01/86-04/30/90 \$298,947.00	The effect of material discontinuity which occurs with cracks in clad piping and pressure vessels; modeling of small surface flaws in thin-walled components under general loading conditions; and basic micro-mechanics aspects of fractures produced by flaws at the interface regions in composites.	Mechanics of Materials	FRIP
108. Fracture/Fatigue, Textiles Failure Response (See also Table 1, Materials, #162.)	NASA - Langley NAS1-18840	Whitcomb Rockwell	03/31/89 \$433,000.00	To develop the micromechanics of fatigue failure in composite made from textile preforms.	Mechanics of Materials	ACT
109. Fundamental Mechanisms of Adhesion At The Fiber-Matrix Interface	NSF 8821031	L.S. Penn Brooklyn Polytechnic University	03/01/89-08/31/92 \$185,343.00	To establish a relationship between the modification of the interface in fiber-reinforced polymers, and the performance of the composite material.	Mechanics of Materials	FRIP
110. Hardened Lightweight Aft Cover Design (See also Table 1, Materials, #165.)	Air Force	P.S. Spangler Sunol Sciences Corp.	\$53,187.00	To define crucial aft cover design parameters for meeting the higher nuclear hardness and survivability requirements of advanced re-entry vehicles.	Structural Concepts- Verification	FRIP
111. High Temperature Ceramic Composite	Air Force	Curtis V. Burkland Aerocom Inc.	\$370,850.00	To obtain a new family of ceramic composite materials that can be used at high temperatures, oxidizing, and corrosive atmospheres.	Mechanics of Materials	FRIP
112. High-Performance Flight Research	NASA - Langley	R.V. Harris NASA Langley	In-House	To develop design methods for aircraft to evaluate aerodynamic performance, stability and control.	Structural Mechanics	FRIP
113. High-Resolution Digital Radiographic NDE of Laminar Bonds in Composite Samples	Army	R.T. Bernardi Bio-Imaging Research, Inc.	\$48,537.00	To determine the feasibility of using high-resolution digital radiography, laminography, and computed tomography to examine laminar bonds in composite samples supplied by the Army.	Mechanics of Materials	FRIP
114. High-Resolution Spectral Analysis NDE Techniques for Flaw Characterization Prediction and Discrimination	Army	C.H. Chen Information Research Lab, Inc.	\$418,000.00	To develop high-resolution spectral analysis NDE techniques for flaw characterization prediction and discrimination.	Structural Mechanics	FRIP

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
115. Highly Machinable Fiber For High Performance PWB Reinforcement	Navy	Joseph A. Moore Material Concepts Inc.	\$50,000.00	To study polyimide reinforced quartz composite variations.	Structural Mechanics	FRIP
116. Hybrid Composite Fracture Characterization	Navy - Naval Air Development Center	Lee W. Gause Naval Air Development Center	09/01/85-10/31/89 In-House	To characterize the strength, mechanical properties, and damage tolerance of woven and hybrid composite structures.	Mechanics of Materials	MCR
117. Hybrid Fiber Carbon-Carbon Composite For Improved Compatibility With Oxidation-Resistant Coatings	Air Force	Lawrence E. McAllister Fiber Materials Inc.	\$447,777.00	To determine the feasibility of using hybrid fiber C-C composite to reduce the CTE mismatch between the substrate surface and oxidation-resistant coating.	Structural Mechanics/ Structural Concepts- Verification	FRIP
118. Hygrothermal Effects on the Elastic Properties of Tailored Composite Blades	Army	S.J. Winckler Rensselaer Polytechnic Institute	-	To develop analytical models for predicting changes in stiffness and coupling during hygrothermal conditioning.	Mechanics of Materials	MCR
119. Image Enhancement Techniques for Quantitative Evaluation Studies of Composite Materials	NASA - Langley	Patrick H. Johnston NASA Langley	In-House	To combine quantitative techniques of measurement science with methods of image production, enhancement, and display to aid in the nondestructive characterization and evaluation of composite structures.	Structural Concepts- Verification	MCR
120. Impact Characterization of New Composite Materials	Navy	Lee W. Gause; Leonard J. Buckley Naval Air Development Center	In-House	To study the impact characterization of new composite materials.	Mechanics of Materials	NTIS
121. Impact Damage in Curved Laminated Composites	NSF 8702892	F. Chang Stanford University	07/01/87-12/31/90 \$225,000.00	To study mechanical properties of fibrous reinforced composite materials.	Mechanics of Materials	FRIP
122. Impact Response and Damage in Three-Dimensional Braided Graphite Fiber Composites (See also Table 1, Materials, #191.)	NASA	Bhavani V. Sankar University of Florida	-	To evaluate the impact damage resistance of graphite fiber braided composites, and to compare their performance with that of laminated composites.	Mechanics of Materials/ Structural Mechanics	NASA

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
123. Impact Response and QNDE of Layered Composites	Navy - Office of Naval Research N00014-87-K-0351	A.K. Mal UCLA	04/01/87-12/31/91	To research wave propagation in composite laminates, with the focus on dynamic loading conditions and theoretical aspects of quantitative acoustic microscopy.	Structural Mechanics	MCR
124. Improved Military Mountaineering Ski Development	Navy	Warren W. Houghton Advanced Composites Labs	\$48,810.00	To develop composite military aids.	Structural Concepts- Verification	FRIP
125. Improved Missile Structures Through The Use of Graphite Fiber	Navy	William C. Riley Research Opportunities Inc.	\$48,900.00	To develop composite for missile systems.	Mechanics of Materials	FRIP
126. Improved Technology for Advanced Composite Materials	Air Force F33615-87-C-5239	Rebecca C. Schiavone University of Dayton Research Institute	09/15/87-02/01/92	To evaluate existing matrix materials for use in advanced composite materials.	Structural Mechanics	MCR
127. In Vitro Wear Rates of Three Types of Commercial Denture Tooth Materials	NIST	D.J. Whitman, J.E. McKinney, R.W. Hinman, R.A. Hesby, G.B. Pelle NIST	In-House	To discuss two new denture tooth materials which are more resistant to wear and chemical degradation than conventional materials.	Mechanics of Materials	NTIS
128. Inelastic Mixed-Mode Debonding at Bimaterial Interfaces	NSF 881-3822	K.M. Liechti University of Texas at Austin	09/15/88-02/28/91 \$143,656.00	To examine experimentally and numerically the inelastic effect in mixed-mode crack growths along bimaterial interfaces.	Mechanics of Materials	FRIP
129. Innovative Composite Fuselage Structures	NASA - Langley NAS1-18842	R.B. Deo MS-3853/82 NASA Langley	04/01/89-05/31/95 In-House	To develop innovative concepts for fighter aircraft fuselage structures that will improve structural efficiency while reducing manufacturing costs.	Structural Mechanics	MCR
130. Innovative Concepts, Structural Mechanics Verification (See also Table 1, Materials, #702 and Table 3, Manufacturing, #64.)	NASA - Langley NAS1-18888	Shuarted Lockheed	04/28/89 \$22,526,000.00	To develop composite technology for wing structure and pressurized fuselage structure including innovative structural concepts, structural mechanics, manufacturing technology and verification.	Mechanics of Materials/ Structural Mechanics/ Structural Concepts- Verification	ACT

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
131. Innovative Fuselage Concepts, Scaling, Verification (See also Table 3, Manufacturing, #66.)	NASA - Langley NAS1-18842	Rouse Northrop	05/02/89 \$5,160,000.00	To develop innovative fuselage concepts for high-speed aircraft including scaling laws, structural stability studies, and verification.	Mechanics of Materials/ Structural Mechanics/ Verification	ACT
132. Innovative Wing Concepts, Comingled, RTM, Verification (See also Table 3, Manufacturing, #68.)	NASA - Langley NAS1-18784	Dexter Grumman	04/28/89 \$2,709,000.00	To develop innovative wing concepts for high-speed aircraft, develop manufacturing technology using comingled tow and RTM techniques, and verify with fabrication and test of a wing box structure.	Mechanics of Materials/ Structural Mechanics/ Verification	ACT
133. Interfacial Adhesion and Viscoelastic Response in Chemically Modified Fiber Reinforced Thermoplastic Composites	NSF	L.A. Belfiore Colorado State University	7/01/88-12/31/90 \$59,999.00	To study interfacial adhesion and viscoelastic response in chemically modified fiber reinforced thermoplastic composites.	Mechanics of Materials	FRIP
134. Interlaminar Shear Fracture Toughness (See also Table 1, Materials, #211.)	NASA - Langley	Gretchen B. Murri NASA Langley	05/01/89-09/30/90 In-House	To measure the mode II strain energy release rate of two materials in fatigue using cyclic end-notched flexure tests.	Mechanics of Materials	MCR
135. Internal Damping of Short-Fiber Reinforced Polymer Matrix Composites	Air Force - Bolling AFOSR-83-0154; 2303/A3	C.T. Sun; S.K. Chaturvedi; R.F. Gibson University of Florida	-	To study the internal damping of short-fiber reinforced polymer matrix composites.	Mechanics of Materials	NTIS
136. Internal Material Damping of Polymer Matrix Composites Under Off-Axis Loading	Air Force - Bolling AFOSR-83-0154; 2303/A3	C.T. Sun; R.F. Gibson; S.K. Chaturvedi University of Florida	-	To determine theoretically the material damping of short fiber-reinforced polymer matrix composites.	Mechanics of Materials/ Structural Mechanics	NTIS
137. Investigation of Acoustic Properties of Composite Materials	NASA - Langley NAG-1431	Barry T. Smith Christopher Newport College	09/01/83-09/30/90	To investigate the ultrasonic acoustic properties of composite materials.	Structural Mechanics	MCR

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
138. Investigation of the Mechanical Properties of Improved Carbon Fiber Composite Materials	NASA - DC	Royal Aircraft Establishment (England)	-	To test 12 carbon fiber composite materials for the effects of tension, compression, shear, notch, impact, and fatigue. Materials tested ranged from standard carbon fiber reinforced epoxy systems to high strain and intermediate modulus carbon fibers with toughened epoxy, bismaleimide, and thermoplastic matrices.	Mechanics of Materials	NTIS
139. A Large Area X-Ray Sensitive Video Tube for Nondestructive Testing	Navy	Milton Stoller Spectrascan Inc.	\$49,187.00	To develop a large-area, x-ray sensitive video tube to meet various Navy requirements based on using the display electron-optics with its very high-velocity electron beam.	Structural Concepts-Verification	FRIP
140. Lightweight Aerostructural Composites for 1800 Degrees Fahrenheit to 4000 Degrees Fahrenheit Fastener Applications	Air Force	Brennan A. Forcht Prestigious Technology Service	\$38,959.00	To produce a lightweight, very high Tg material to be used as a fastener in transatmospheric vehicles.	Mechanics of Materials	FRIP
141. Lightweight Cryogenic Fluid Tanks for Space-Based Systems	SDIO	Richard W. Lusignea Foster-Miller, Inc.	\$71,555.00	To evaluate the usefulness of PBT films as a material for making lightweight cryogenic fluid tanks.	Mechanics of Materials	FRIP
142. Lightweight Durable Thermoplastic Sandwich Panel Roadway Surface	Army	David Maass Advanced Composite Products	\$91,999.00	To design, build, and test thermoplastic sandwich panels.	Structural Mechanics	FRIP
143. Lightweight Howitzer Project	Army	D.W. Oplinger U.S. Army Laboratory Command	In-House	To demonstrate the application of composite materials to towed artillery, for the purpose of weight reduction.	Structural Concepts-Verification	MCR
144. Lightweight Towbar for Battlefield Recovery	Army	G. Samavedam Foster-Miller, Inc.	-	To demonstrate the ability of composites to replace steel for weight reduction in towbars used for battlefield recovery of the M1 tank and similar heavy vehicles.	Structural Concepts-Verification	MCR
145. Loading Rate Sensitivity of Open Hole Composites In Compression	NASA - Langley	S.J. Lubowinski; E.G. Guynn; W. Elber; J.D. Whitcomb NASA Langley	In-House	To present results of a study evaluating compressive time dependent behavior of graphite fiber composites.	Mechanics of Materials	NTIS

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
146. Materials and Structures Research and Technology (See also Table 1, Materials, #236.)	NASA 506-43-00	Jovan M. Moacanin California Institute of Technology	-	To investigate new methods for predicting structure-property relations in spacecraft materials.	Structural Concepts- Verification	FRIP
147. Materials and Structures Research and Technology	NASA 506-43-00	C.P. Blankenship NASA Langley	In-House	To develop structures and materials technologies to enhance performance, efficiencies, and reliability of spacecraft.	Mechanics of Materials/ Structural Mechanics	FRIP
148. Materials and Structures Research and Technology	NASA 506-63-00	C.P. Blankenship NASA Langley	In-House	To develop materials technology for use in spacecraft.	Mechanics of Materials/ Structural Mechanics	FRIP
149. Materials and Structures Research and Technology	NASA 506-63-00	S.J. Grissaff NASA Lewis	In-House	To study the behavior of materials and composites for future turbine engines.	Mechanics of Materials/ Structural Mechanics	FRIP
150. McDonnell Aircraft Resin Matrix Composites Development	Air Force	J. Dorr; B. Moenster McDonnell Douglas Aircraft Company	-	To develop an aircraft resin matrix and applications at McDonnell Aircraft Company.	Mechanics of Materials/ Structural Mechanics/ Structural Concepts- Verification	ASC
151. Mechanical Properties of 3-D Woven Fabric	NASA - Langley NCC-1-130	John M. Kennedy Clemson University	08/01/88-08/01/90	To establish the mechanical response and damage tolerance characteristics of 3-D woven fabrics.	Mechanics of Materials	MCR
152. Mechanics Models of 3-D Advanced Composite Forms	NASA - Langley	Charles E. Harris NASA Langley	06/01/88-09/30/89 In-House	To conduct experiments to support the model developments and to verify predictions.	Structural Concepts- Verification	MCR
153. Mechanics of Anisotropic Composite Structures	NASA - Langley	Michael P. Nemeth NASA Langley	10/01/86-09/30/90 In-House	To develop analytical procedures for anisotropic structural components that accurately predict the response for tailored structures.	Structural Concepts- Verification	MCR
154. Mechanics of Anisotropic Structures with Cutouts	NASA - Langley NAG-1-917	E.C. Kiang North Carolina State University	12/01/88-12/01/89	To develop efficient analytical procedures that accurately predict the response of anisotropic structural components with cutouts.	Structural Mechanics	MCR
155. Metallized Kevlar Space Tether System (See also Table 3, Manufacturing, #86.)	NASA	Ralph R. Orban Material Concepts Inc.	\$516,643.00	To study a metallized kevlar for use as tether material in space applications.	Structural Mechanics	FRIP

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PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
156. Micro/Macro Mechanics for Composite Fracture Criteria	Navy	Alan Mueller Flow Research Co.	\$546,975.00	To analyze and compare fractures in microscopic and macroscopic geometries using a singular finite element method.	Mechanics of Materials	FRIP
157. Microlayer Polymeric Composite	NSF 8713041	E. Baer Case Western Reserve University	05/01/88-10/31/90 \$322,000.00	To study solid state structure property relationships in microlayers polymer composites.	Structural Mechanics	FRIP
158. Micromechanics	NASA-DC NAG1-659	E.G. Guyan; W.L. Bradley Texas A&M University	-	To summarize the micromechanics of composite laminates.	Mechanics of Materials	NTIS
159. Micromechanics Modeling of Composite Thermoelastic Behavior	NASA - Langley	David E. Bowles NASA Langley	10/01/86-06/30/90 In-House	To develop analytical methods to investigate thermally induced deformations and stresses in continuous fiber-reinforced composites at the micromechanics level, and predict how these deformations and stresses affect the dimensional stability of the composite.	Structural Mechanics	MCR
160. Micromechanics of Composite Failure	Air Force F33615-88-C-5420	Som R. Somi, AdTech Systems Research, Inc.	10/01/88-09/30/92	To provide exploratory development in thermomechanical response, model material system development composite processing, and failure mechanisms investigations of composite and related constituent materials.	Mechanics of Materials	MCR
161. Micromechanics of Composite Fracture	NASA - DC	P.W.R. Beaumont Cambridge University (England)	-	To examine how the microstructure and properties of the matrix, inclusion, and interface are correlated to fracture.	Mechanics of Materials	NTIS
162. Micromechanics of Composite Laminate Compressive Failure	NASA - Langley NAG-1-659	Walter Bradley Texas A&M University	02/01/86-06/30/90	To characterize the compressive failure behavior of notched laminates under static and sustained loads.	Mechanics of Materials	MCR
163. Micromechanics of Composites	Navy - Office of Naval Research N00014-94-K-0510	B. Budiansky Harvard University	06/01/84-09/30/91	To research the micromechanical enhancement of the fracture toughness of ceramics and intermetallics by the incorporation of toughening agents such as fibers, whiskers, ductile particles, and phase-transforming particles.	Mechanics of Materials	MCR

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
164. The Micromechanics of Fatigue Failure in Woven and Stitched Composites	NASA - Langley NAS1-18940	Brian Cox Rockwell International	04/01/89-05/31/95	To develop experimental techniques to characterize the initiation and growth of fatigue damage.	Mechanics of Materials	MCR
165. Micromechanics of Interfaces in High-Temperature Composites	Air Force AFOSR-89-0629	Toshio Mura Northwestern University	02/01/89-01/31/92	To establish the microstructural variables which promote toughness in brittle matrix composites by means of analytical and experimental perspectives, and to construct the mechanics/material sciences-based model for predicting the behavior of such materials.	Mechanics of Materials	MCR
166. Microscopic Aspect of Fiber & Fracture in Cross-Ply Fiber-Reinforced Composite Laminates See also Table 1, Materials, #252).	Army	S. Bandyopadhyay; E.P. Gellert, V.M. Silva; J.H. Underwood; Army Armament Research	In-House	To study the micromechanisms of tensile fracture and interlaminar mode I delamination failure.	Mechanics of Materials	NTIS
167. Mixed-Mode Delamination Testing	NASA - Langley	James P. Reeder NASA Langley	09/01/87-09/30/90 In-House	To measure delamination fracture toughness of laminated composites material subjected to combined mode I & mode II loadings and, thereby develop a mixed-mode delamination failure criterion.	Mechanics of Materials/ Structural Concepts Verification	MCR
168. Modeling Techniques for Composites Subjected to Rapid Thermal Loading on Laminated Composites	Air Force	Steven F. Stone Mission Research Corp.	\$224,970.00	To determine the effect of rapid thermal loading on laminated composites in the presence of debonding or delaminations.	Structural Mechanics	FRIP
169. Modeling and Design Analysis Methodology for Composite Primary Structure	NASA - Langley NAS1-18754	L.W. Reihfield University of California at Davis	04/01/89-05/31/95	To develop and validate new structural models for aerodynamically tailored wings.	Mechanics of Materials	MCR
170. Multi-Hollow Composite Shell Bridge Deck (See also Table 3, Manufacturing, #90.)	Army	August H. Kruesel Elfin Corp d/b/a U.S. Composites	\$316,640.00	To design a multi-hollow bridge deck based on new manufacturing techniques including braiding and wet lamination to achieve the necessary performance at an acceptable cost.	Structural Concepts- Verification	FRIP
171. NASA/Aircraft Industry Standard Specification for Graphite Fiber Toughened Thermoset Resin Composite Material	NASA - Langley	NASA Langley	In-House	To develop standard specifications on graphite fiber reinforced thermosets to provide uniform requirements and tests for acceptance of prepreg system.	Structural Concepts- Verification	NTIS

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
172. NDE for Composite Structures	Air Force	R.A. Armitstead Advanced Research & Applications	\$649,758.00	To computationally and experimentally assess and derive a laminographic NDE system design which facilitates the carbon-carbon and filament wound composite structure application.	Structural Concepts/ Verification	FRIP
173. NDI of Composite Structural Materials by Gamma Scatter	DOT	Charles C. Blatchley Spire Corp.	\$50,000.00	To improve nondestructive testing with gamma ray scattering counting, a form of radiometry widely used to measure thickness and composition with emphasis on developing a portable system capable of characterizing defects in laminates of varying thickness.	Structural mechanics	FRIP
174. National Center for Composite Materials Research	Navy - Office of Naval Research N00013F101	S.S. Wang University of Illinois	09/01/86-09/30/91	To conduct a well-structured, multidisciplinary research program in composites spanning the disciplines of solid mechanics, materials science, chemistry, and surface physics.	Structural Mechanics	MCR
175. New Acoustic-Ultrasonic Techniques Applied to Aerospace Materials	NASA - Lewis	H.E. Kautz NASA Lewis	In-House	To investigate the use of an NDYAG pulsed laser for generating ultrasonic waves for NDE in resin matrix composites.	Structural Concepts/ Verification	NTIS
176. New Composite Material Structures for the Speed/Power Enhancement of Nonlinear Optical Devices	NSF 8815141	M.H. Bimboldt Rensselaer Polytechnic Institute	03/15/89-08/31/90 \$125,064.00	To study composites of coated metallic nanospheres suspended in a non-linear optical polymer matrix.	Mechanics of Materials	FRIP
177. New NDE Capability for Thin-Shelled Structures	Air Force	James H. Stanley Advanced Research & Applications Corp.	\$544,842.00	To develop a powerful, new imaging modality ideally suited for thin-shelled structures but considerably more general in nature.	Structural Mechanics/ Structural Concepts/ Verification	FRIP
178. Nondestructive Evaluation of Carbon-Carbon Composites	NASA - Langley	Ron Kline University of Oklahoma	09/01/89-09/30/95	To measure the elastic moduli of carbon-carbon material and integrate the results with FEM codes to predict the behavior of components.	Mechanics of Materials	MCR
179. Nonlinear Optical Properties of S. all Grain Composites (Joint Research Effort)	NSF 8813028	J.W. Hays Rensselaer Polytechnic Institute	05/01/89-10/31/90 \$85,525.00	To study non-linear properties of noble metal grains and semi-conductor grains embedded in glasses or suspended in colloidal solutions.	Structural Concepts/ Verification	FRIP

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
180. Novel Composites for Wing and Fuselage Applications	NASA - Langley NAS1-18784	James Suarez Grunman Aerospace Corp.	04/28/89-07/31/93	To integrate innovative design concepts with cost-effective fabrication processes to achieve damage-tolerant structures that can perform at a design ultimate strain level of at least 6000 micro in./in.	Structural Mechanics	MCR
181. Optimization of Composite Drive Shafts	Army	M. Darlow; O.A. Bachau Kensel Polytechnic Institute	-	To develop a computerized process for designing composite drive shafts for rotorcraft that can operate at supercritical rotational speeds.	Structural Concepts- Verification	MCR
182. Optimum Aeroelastic Characteristics for Composite Super-Maneuverable Aircraft	Air Force AFOSR-89-0055	Dr. Gabriel Oyibo Polytechnic University, Farmingdale, NY	10/01/88-09/30/91	To identify, characterize, and model the effects of constrained warping on the dynamics and aeroelastic stability of aircraft composite wings.	Structural Mechanics	MCR
183. Out-of-Plane Analysis for Composite Structures	Navy - Naval Air Development Center N62269-87-C-0226	C.R. Saff McDonnell Aircraft Company	09/01/87-09/30/89	To develop and verify an analysis methodology that provides an up-front capability to identify potential out-of-plane loading situations in composite structures and determine strength and failure mode without resorting to expensive three-dimensional finite element analysis.	Mechanics of Materials	MCR
184. Polymer Concrete for Bridge Deck Overlay	DOT	R. Turgeon Pennsylvania Dept. of Transportation	-	To evaluate the effectiveness of polymer concrete deck overlays.	Structural Mechanics	FRUP
185. Polymer Film and Conducting Salt Electrodes	NSF 8718057	J.Q. Chambers University of Tennessee at Knoxville	02/01/88-07/31/90 \$122,231.00	To understand the charge transport process through polymer blend on composite films.	Structural Concepts- Verification	FRUP
186. Polymer, Metal, and Ceramic Matrix Composites for Advanced Aircraft Engine Applications	NASA - Lewis	D.L. McDaniel; T.T. Serafini, J.A. Dicardo NASA Lewis	in-House	To study the materials used in aircraft engine (Polymers).	Mechanics of Materials	NTIS
187. Portable Lightweight Field Dental Chair Utilizing Composite	Army	Douglas E. Bahniuk Adelsys Inc.	\$49,967.00	To invent a new dental chair formed from composite.	Structural Concepts- Verification	FRUP

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PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
188. Postbuckling and Crippling of Compression-Loaded Composite Structural Components	NASA - Langley	James H. Starnes, Jr. NASA Langley	03/01/79-09/30/90 In-House	To study the postbuckling and crippling of compression-loaded composite components and to determine the limitations of postbuckling design concepts in structural applications.	Structural Concepts/ Verification	MCR
189. Postbuckling of Flat Stiffened Graphite/Epoxy Shear Webs	NASA - Langley	Marshall Rouse NASA Langley	07/01/81-09/30/90 In-House	To study the postbuckling response and failure characteristics of flat stiffened graphite/epoxy shear webs.	Mechanics of Materials/ Structural Mechanics	MCR
190. Presidential Young Investigator Award: Micro-Mechanics of Fiber Reinforced Composites	NSF 8451080	P.S. Self Carnegie-Mellon University	\$250,000.00	To study the mechanical properties of fiber-reinforced composite materials.	Structural Mechanics	FRIP
191. Presidential Young Investigator Award: Studies in Structural Mechanics	NSF 8657628	G.R. Miller University of Washington	07/15/87-12/31/90 \$160,005.00	To study structural mechanics of composite materials including wood composites.	Mechanics of Materials/ Structural Mechanics	FRIP
192. Presidential Young Investigator Award: Environment Effects on Mechanical Properties of Composites	NSF	S.V. Nair University of Massachusetts	05/30/86-11/30/90 \$257,936.00	To apply fracture mechanics developed for conventional strength materials to novel, raw materials.	Mechanics of Materials	FRIP
193. Pressurized Structures, Structural Mechanics, Verification (See also Table 1, Materials, #327 and Table 3, Manufacturing, #103.)	NASA - Langley NAS-18889	Freeman Bodding	05/12/89 \$22,647,000.00	To develop composite technology for pressurized fuselage structures including innovative structural concepts, structural mechanics, manufacturing technology and verification.	Mechanics of Materials/ Structural Mechanics/ Verification	ACT
194. Probability of Structural Analysis to Evaluate the Structural Durability of SSME (Space Shuttle Main Engine) Critical Components	NASA - Lewis	C.C. Chamis NASA Lewis	In-House	To discuss the structural mechanics of the space shuttle main engine parts.	Mechanics of Materials	NTIS
195. Quantitative Acoustic Emission Analysis of Adhesive Bond Failure	NASA - Langley	William H. Prosser NASA Langley	In-House	To study the influence of fracture toughness of the adhesive, mode of fracture, and crack velocity on the acoustic emission released during adhesive bond failure.	Structural Mechanics	MCR
196. Quantitative Nondestructive Evaluation of Composite Materials Based on Ultrasonic Wave Propagation	NASA - Langley NSG-1-601	James C. Miller Washington University	09/01/81-09/30/90	To develop and apply quantitative ultrasonic techniques to problems of nondestructive evaluation of composites materials.	Structural Mechanics	MCR

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PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
197. Quantitative Ultrasonics Measurements in Composites	Navy - Office of Naval Research N00014-85-K-0460	W. Sachse Cornell University	07/01/85-09/30/92	To establish quantitative active and passive ultrasonic measurement techniques for characterizing the microstructure and mechanical properties as well as the dynamics of delamination processes in a variety of composite materials.	Mechanics of Materials	MCR
198. Quantitative Measurements of Materials Properties	NASA - Langley	Eric Madaras NASA Langley	In-House	To develop advanced measurement systems for improved non-destructive characteristics of composite materials.	Structural Mechanics	MCR
199. Rapid Thermal Loading of Delaminated Composite Structures	Air Force	Rocky Richard Arnold Aramet Labs Inc.	\$49,950.00	To develop a theoretical approach to the problem of rapid thermal loading of delaminated composite structures.	Structural Concepts- Verification	FRIP
200. Reaction Engineering Aspects of Manufacturing of Finite Inorganic Fibers	NSF 8813918	V. Hlavacek SUNY Buffalo	12/01/88-05/31/91 \$186,531.00	To study the effect of different chemical and heat treatments on various inorganic fibers.	Mechanics of Materials	FRIP
201. Repair of Thick Fiberglass Reinforced Plastic Structures	Army	W. Novis Smith Sunrez Corporation	\$50,000.00	To study the armor field repair system based on a new ultraviolet curable thermoset.	Mechanics of Materials	FRIP
202. Research Initiation: A Three-Dimensional Mixed Finite Element Method to Integrate the Dynamic Crack Growth and Failure Mechanisms in a Composite Laminate	NSF	W. Bachrach Columbia Univ.	09/01/88-02/28/91 \$59,990.00	To model the three-dimensional dynamic crack growth and failure mechanism in a composite laminate subjected to low velocity impact.	Structural Concepts- Verification	FRIP
203. Research Initiation: Influence of Carbon Fibers Surface Modifications on Mechanical Properties of C-C Composites	NSF 8808853	W. Kowbel Auburn University	10/01/88-03/31/91 \$64,049.00	To find effective surface treatments and detreatments which would lower chemical bondings and internal coefficient of frictions.	Mechanics of Materials/ Structural Concepts- Verification	FRIP
204. Research Initiation: Modeling and Characterization of Ceramic Matrix Composites with 2-D and 3-D Reinforcements	NSF 8809790	J. Yang University of California at Los Angeles	08/01/88-01/31/91 \$70,000.00	To assess the potential of developing ceramic matrix composites with various 2-D and 3-D reinforcements for high temperature structural applications.	Structural Concepts- Verification	FRIP

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PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
205. Research Initiation: Superconductive Composite Wire (SCOW)	NSF 8809813	A.A. Ogle Clemson University	06/15/88-11/30/90 \$59,843.00	To incorporate superconductive particles into a tough polymeric matrix to produce composite wire.	Structural Concepts- Verification	FRIP
206. Research Initiation: The Effect of Interface on the Thermo- Mechanical Properties of Composite Materials. A Micromechanics Inclusion Approach	NSF 8810920	Y.M. Jastak Michigan State University	06/15/88-11/30/90 \$51,779.00	To understand the fiber-matrix load transfer mechanism.	Structural Mechanics	FRIP
207. Research Initiation: Volume Holographic Optical Interconnection	NSF 8810288	H. Lee Polytechnic University, Brooklyn, NY	06/15/88-11/30/90 \$63,000.00	Theoretical and experimental investigation of a three-dimensional class of photonic interactions utilizing photorefractive crystals.	Mechanics of Materials	FRIP
208. Research on Processing of Metal Matrix and Ceramic Matrix Composites	NSF 8805427	H. Dharan University of California at Berkeley	11/01/88-10/31/89 \$70,000.00	To develop basic understanding of metal matrix composites.	Mechanics of Materials	FRIP
209. Signal Processing for Acoustic Emission and Ultrasonic Testing	NSF	B. Lieu Princeton University	08/01/87-01/31/91 \$285,572.00	To apply recent advances in the development of processing algorithms and programmable integrated circuits to nondestructive evaluation (NDE).	Mechanics of Materials	FRIP
210. Single-Sided NMR for Moisture-Content Evaluation of Composites	Navy	Ronald E. Sager Quantum Design, Inc.	\$49,596.00	To measure the difference in model relaxation rates to detect and measure the amount of water which has been absorbed into composite materials.	Structural Concepts- Verification	FRIP
211. Stability of Elastically Tailored Rotor Systems	Army	D. Hodges, L. Rehfield School of Aerospace Engineering	-	To develop mathematical modeling and analysis procedures to determine the aeroelastic stability characteristics of bearingless helicopter rotors on elastic supports in axial flow and tilt rotor aircraft with elastic wings in axial flight in the helicopter mode and in the airplane mode.	Structural Concepts- Verification	MCR
212. Strengthening of Flexural Members Through the Use of Epoxy Bonded Overlays Under Static and Repeated Loads	DOT	B.M. Douglas University of Nevada, Reno	-	To develop dynamic testing on highway bridge structures using epoxy-bonded overlays.	Structural Mechanics	FRIP

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PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
213. Structural Behavior of Prestressed Concrete Beam with Epoxy-Coated Strand	DOT-FHWA	M. Gajanan Sabnis (Consultant)	—	To determine structural behavior of prestressed concrete beam with epoxy coated strand.	Structural Mechanics	FRUP
214. Structural Damping	Navy	D.J. Barrett Naval Air Development Center	10/01/87-09/30/90 In-House	To improve the damping properties of structures through the redesign of basic structural components as composites of stiffness and damping materials.	Mechanics of Materials	MCR
215. Structural Design Criteria for Filament-Wound Composite Shells	NASA - Langley NAG-1-982	H.T. Hahn Pennsylvania State University	05/15/89-05/15/90	To develop structural design criteria that can be used to scale up filament wound-composite shells.	Structural Concepts- Verification	MCR
216. Structural Optimization for Improved Damage Tolerance	NASA - Langley NAG-1-166	Raphael T. Haftka Virginia Tech	09/01/81-10/15/90	To develop a structural optimization procedure for composite wing boxes that includes the influence of damage-tolerance considerations in the design process.	Structural Concepts- Verification	MCR
217. Structure and Formation of Lipid Tubules	NSF 8815027; 8815027	P. Yeager University of Washington	01/01/89-06/30/90 \$126,541.00	To research and test a theory of tubule formation with respect to the crystallinity of the tubules.	Structural Concepts- Verification	FRUP
218. Structures Technology Applications	Army - Army Aviations Systems Command	R.L. Bolinott; M.W. Dixon; G.L. Farley; D.J. Baker U.S. Army ARTA	In-House	To explore and demonstrate innovative structural concepts and design methodologies that will provide lighter, safer, and more survivable structures for aircraft.	Structural Concepts- Verification	MCR
219. Structural Panels	NASA - Ames	J.A. Parker; A.H. Helmreich; M.S. Hew; T.S. Chen NASA Ames	In-House	To patent copolymers of vinyl pyridines and bismaleimides to make fire retardant structure.	Mechanics of Materials	NTIS
220. Studies in Fracture and Materials Mechanics	NSF 8812779	J.W. Hutchinson Harvard University	07/01/88-12/31/90 \$156,033.00	To study the relationship of micromechanics and the toughening mechanism of ceramics.	Mechanics of Materials	FRUP
221. Studies in the Delamination Fracture Behavior of Composite Materials	Air Force AFOSR-84-0064	Walter L. Bradley Texas A&M University	08/01/87-07/31/89	To elucidate the micromechanisms underlying delamination failures in polymer composites which are subjected to mixed-mode loading.	Structural Mechanics	MCR

TABLE 2
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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
222. Study of Tailored Composite Structures of Ordered Staple Thermoplastic Materials	NASA - Langley NAS1-18758	M.H. Santare University of Delaware	04/01/89-05/31/95	To conduct model studies of thermoplastic composites curved-beam structures.	Mechanics of Materials	MCR
223. Supervoltage NDE Techniques for Large Aerospace Structures	Air Force	James H. Stanley Advanced Research & Applications	\$73,932.00	To develop various technical approaches for detecting and characterizing bulk defects in large aerospace structures.	Mechanics of Materials	FRIP
224. Tailoring of Composite Links for Optimal Damped Elasto Dynamic Performance	NASA - Lewis	D. A. Saravanan; C. C. Chamis NASA Lewis	In-House	To develop an optimal design of composite links based on dynamic performance criteria directly related to structural modal damping and dynamic stiffness.	Mechanics of Materials	NTIS
225. Test of a Moisture Conditioning Procedure Using 70 Degrees Celsius, 95% Relative Humidity	NASA - DC	Centre d'Essais Aeronautique de Toulouse (France)	-	To test a moisture conditioning procedure using 70 degrees Celsius distilled water instead of a gas atmosphere at 70 degrees Celsius, 95% relative humidity.	Mechanics of Materials/ Structural Concepts- Verification	NTIS
226. Textiles, RTM, VIM, Stitching, Verification (See also Table 1, Materials, #389 and Table 3, Manufacturing, #117.)	NASA - Langley NAS1-18862	McDonnell Douglas	03/31/89 \$23,750,000.00	To develop manufacturing technology for primary aircraft structure with emphasis on textiles, RTM, stitching, thermoplastic forming, and verification.	Mechanics of Materials/ Structural Mechanics/ Structural Concepts- Verification	ACT
227. A Theoretical and Experimental Investigation of the Hygrothermal Response of Flexible Linkages Fabricated with Fibrous Polymeric Composite Materials	NSF 8514087	B.S. Thompson Industrial Technology Institute	01/01/86-12/31/89 \$190,524.00	To study ambient hygrothermal environment on polymeric composites.	Structural Mechanics	FRIP
228. Therm-X Tooling Methods (See also Table 1, Materials, #392 and Table 3, Manufacturing, #119.)	NASA - Langley NAS1-18799	Deaton Skoraky	05/09/89 \$1,059,000.00	To develop Therm-X processing for advanced composite fuselage structures.	Structural Concepts- Verification ¹	ACT
229. Thermal Viscoplasticity in Metal Matrix Composites	NASA - Langley L-24457C	Yehia A. Bahad-Ei-Din Kensselaar Polytechnic Institute	07/01/87-01/31/90	To develop an analytical method for estimating thermal viscoplasticity stresses and strains in continuous fiber-reinforced metal matrix composites due to fabrication and/or subsequent thermal cycling and mechanical loadings.	Structural Mechanics	MCR

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Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
230. Thermal and Mechanical Stability of Composite Materials	NASA - Langley	Stephen S. Tompkins NASA Langley	10/01/83-09/30/93 In-House	To develop and evaluate structural composite materials that are dimensionally stable and/or have stable thermal and mechanical properties when subjected to simulated long-term LEO and GEO space service environments.	Structural Mechanics	MCR
231. Thermally Induced Interfacial Stress-Strain Behavior in Resin Matrix Composites	NASA - Langley NAS1-18231	B.N. Cox Rockwell Science Center	08/01/87-07/31/88	To investigate the thermally induced interfacial stress-strain behavior in aerospace resin matrix composites.	Structural Mechanics	MCR
232. Thickness Discontinuity Effects	NASA - Langley NAG-1-537	Eric R. Johnson Virginia Tech	10/01/85-09/30/90	To develop verified analytical models of compression-loaded laminates with thickness discontinuities and dropped plies.	Structural Concepts- Verification	MCR
233. Three-Dimensional Finite Element Modeling of Pin-Loaded Laminates	Army	S. Serabian U.S. Army Laboratory Command	In-House	To model 0/90, +45/-45, and 0/90/+45/-45 pinloaded laminates and obtain 3D finite element approximations to their mechanical response.	Mechanics of Materials	MCR
234. Time-Temperature-Stress Capabilities of Composite Materials for Advanced Supersonic Technology Application	NASA - DC NAS1-12308	J.R. Kerr; J.F. Haskins General Dynamics/ Astronautics	—	To evaluate the time-temperature-stress capabilities of polymer composites.	Mechanics of Materials	NTIS
235. Toughening of Structural Polymers by Rigid Polymer Particles	NSF 8708405	A.F. Yee University of Michigan	09/01/87-11/30/90 \$1,522,000.00	To study toughening of glassy polymers by second phase rigid polymer particles.	Mechanics of Materials/ Structural Mechanics	FRIP
236. Tracking Progressive Fracture Toward Retirement for Cause	Air Force	Jigjen Chen Advanced Technology & Research Inc.	\$402,459.00	To develop new and more accurate dynamic system identification techniques for systems with high modal density.	Structural Mechanics/ Structural Concepts- Verification	FRIP
237. U.S. - Brazil Cooperative Research on Interpenetrating Polymer Network Formation	NSF 8901872	H.L. Frisch SUNY Albany	\$9,310.00	To modify polymers by the formation of interpenetrating polymer networks.	Mechanics of Materials/ Structural Mechanics	FRIP

TABLE 2
PMC RESEARCH: STRUCTURES

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
238. US-France Cooperative Research: Structure and Properties of Crystalline-Amorphous Composite Coatings on Stainless Steel	NSF 8815495	R. Sinclair Stanford University	04/01/89-09/30/91 \$10240.00	Study of the formation and properties of coatings on stainless steel through ion-assisted coating technology.	Structural Concepts- Verification	FRIP
239. Ultrasonic Correlator for Nondestructive Characterization of Materials	NASA	Harold Berger Industrial Quality Inc.	\$547,537.00	To develop an ultrasonic method to characterize materials.	Mechanics of Materials	FRIP
240. Ultrasonic Digital Signal Processing (DSP)	Army	B. Taber U.S. Army Materials Technology Lab	In-House	To develop DSP techniques that enhance ultrasonic inspection capabilities in conjunction with NDE of composites and other applications.	Structural Concepts- Verification	MCR
241. Ultrasonic Examination of High Performance Polymer Composites	NASA - DC	F. Guitierrez; R. Limpert; U. Steinhof Defense Research Information Center	-	To develop a fully automated ultrasonic examination of high performance polymer composites.	Mechanics of Materials	NTS
242. Unit Cell Geometry of Complex Preforms for Structural Composites	NASA - Langley NCC-1.136	Christopher M. Pastore; Frank K. Ko Drexel University	05/01/89-05/01/92	To develop computerized graphics models for a variety of 2-D and 3-D textile fiber architectures for use in micromechanics analysis.	Mechanics of Materials	MCR
243. Use of Ultrasonic Techniques for Composite Cure Monitoring and Characterization of Resin System During Processing	NASA - Langley	William P. Winfree NASA Langley	In-House	To develop techniques for determining the material properties of composites during their cure.	Structural Mechanics	MCR
244. Vibration Control and Optimization in Composite Structural Elements by Use of Add-on Damping Materials	Army	C.T. Sun; P. Hajela University of Florida	-	To develop techniques of vibration control through add-on damping for structures fabricated from composite materials.	Structural Mechanics	MCR
245. Viscoelastic Response of Composite/Honeycomb Panels for Precision Reflectors	NASA - Langley NAG-1.343	M.W. Hyer Virginia Tech	08/16/88-07/31/90	To investigate the viscoelastic response of sandwich panels fabricated from composite facesheets and honeycomb cores.	Mechanics of Materials	MCR
246. Z-Direction Tape Reinforcement For Composite Laminates	Navy	Joseph S. Boyce Foster-Miller, Inc.	\$307,516.00	To improve compression strength of composites by use of boron fibers.	Mechanics of Materials	FRIP

MANUFACTURING TECHNIQUES

Despite indications from OTA and other sources that finding efficient, economical methods for manufacturing, repairing, and recycling products constructed from PMC materials is essential to gaining wide-ranging industry acceptance in constructing automobiles and other products, research focusing on the development of improved PMC manufacturing techniques accounted for only 133 projects (119 dedicated to manufacturing techniques exclusively and 14 dedicated to 2 or more research areas). Of the four leading agencies—DoD, NASA, NSF, and DOT—only NSF, at 20 percent, devotes even one-fifth of the projects included in the survey to manufacturing techniques.

Subcategorization by the survey team of 127 manufacturing projects for which sufficient data existed in three areas—processing, repair/in-service maintenance, and joining—revealed that the vast majority of projects (94) concentrate on processing techniques. One example of processing work is a project titled "Air-Free Kevlar/Urethane Composites." The Navy awarded this \$500,000 contract to Texas Research Institute Inc., with the charge to develop methods that allow the complete saturation of a large Kevlar cord with a polyurethane resin. Under "Thermoplastic Matrix Fiber Composite Materials," a three-year NSF contract that ends in 1990, Stanford University received slightly more than \$400,000 to develop a new approach manufacturing thermoplastic matrix continuous-fiber composite materials by using computer-controlled rollers that form an initially flat composite laminate into a complex-shaped component.

More than half of the 14 projects subcategorized as repair/in-service maintenance were DOT contracts awarded by the Federal Highway Administration to state highway administrations. The objectives of many of these contracts were to test the effectiveness or durability of PMC materials, such as thermoplastic road markings, used in highway or bridge construction. Interestingly, all DOT projects identified for inclusion in this survey concentrated on some aspect of highway or bridge construction; no research related to auto frames or other transportation-related issues was identified.

DoD sponsored most of the remaining repair projects. One contract, "Ultrasonically Enhanced Paint Removal," is a \$50,000 award to S.R. Taylor & Associates. The project goal is to invent an ultrasonic device for removing paint from composites. Another is a \$550,000 contract awarded to Technology for Energy Corp. The corporation's objective is to develop a program in which an existing portable x-ray residual stress analysis system can be modified and adapted for field use in a naval aircraft maintenance environment.

Among the eight projects categorized as "joining" is a \$50,000 award to Aero-Vironment, Inc., under which Aero-Vironment is developing a simple joining technique for use in space for the Army. Under a larger contract (\$250,000) awarded by NASA, Memory Metals, Inc., is exploring the feasibility of using shape memory effect materials for joints and couplings.

Project Data

Described in table 3, which appears on pages 105-120 of this report, are each of the 133 projects categorized as research of manufacturing techniques. The projects are listed in alphabetical order by study title, and each project is numbered. As indicated above, 14 projects classified as manufacturing research also relate to at least one other area of research. A notation follows the title of each of those projects referencing the other table(s) in which it appears.

Tabular information for every project includes the project sponsor and the performing organization (where applicable). To the extent data is available, the table also provides contract numbers, principal investigators' names, contract duration periods, and funding amounts (or notations of in-house work).

Also included in table 3 are briefly stated project objectives. Following the objective statements is a column that shows the subcategory(ies) assigned to each project (processing, repair/in-service maintenance, or joining).

In the final column, the table indicates primary data source for each project identified.

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
1. 700 Degrees Fahrenheit Properties of Autoclave Cured PMR-2 Composites (See also Table 1, Materials, #3.)	NASA - Lewis	R.D. Vannucci, D. Ciani NASA Lewis	In-House	To investigate the processing parameters for autoclaving polyimide composites.	Processes	NTIS
2. Advanced Fiber Placement Fuselage Technology Program	NASA - Langley NAS1-18887	R.L. Anderson M.S. X11K4, Hercules, Inc.	04/01/89-05/31/95	To develop breakthrough technology for cost-effective fabrication of damage-tolerant composite fuselage structures.	No subcategory established	MCR
3. Advanced Fiber Placement Studies (See also Table 1, Materials, #13.)	NASA - Langley NAS1-18887	Freeman Hercules	04/06/89- \$1,134,000.00	To study an advanced automated fiber placement process for fabricating in grid and curved panels.	Processes	ACT
4. Advanced Polymer Matrix Resins and Constituents: An Overview of Manufacturing, Composition, and Handling	Air Force AAMRL-TR-89-008	M.R. Kantz Harry G. Armstrong Aerospace Medical Research Lab	--	To review the manufacturers of a available prepregs and polymer matrix resins.	No subcategory established	CA
5. Advanced Technology Composite Aircraft Structures	NASA - Langley NAS1-18889	P.J. Smith Boeing Commercial Aircraft	04/01/89-05/31/95	To evaluate composite material for aerospace application.	Processes	MCR
6. Air-Free Kevlar/Urethane Composites	Navy	Patrick E. Cassidy Texas Research Institute Inc.	\$529,167.00	To develop methods which allow the complete saturation of large kevlar cord with a polyurethane resin.	Processes	FRIP
7. Assessment of Fiber Weaving Processes for Production of Turbine	Air Force	Leon Bryn Textile Technologies, Inc.	\$33,392.00	To assess fiber weaving processes for production of turbine. To review assessment.	Processes	FRIP

Note The data sources have been abbreviated according to the following key: ACT = Advanced Composites Technology; ASC = Proceedings of the American Society for Composites; CA = Chem Abstracts; FRIP = Federal Research in Progress; MCR = Mechanics of Composites Review; NTIS = National Technical Information Service; and US/J = U.S./Japan Composites Workshop.

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
8. Automated Evaluation of Composite Materials (See also Table 1, Materials, #24.)	Army	G.L. Hagauer; S.G.W. Dunn U.S. Army Material Technology Lab	In-House	To increase laboratory productivity and improve the quality of test information needed to evaluate fiber-reinforced polymeric matrix composite materials and guide their specification, design, and manufacture.	Processes	MCR
9. Biodegradation of Polyurethane Paint	Air Force	Gail Bowers-Irons Technical Research Association	\$55,000.00	To study biodegradation of polyurethane paint by bacteria.	Processes	FRIP
10. Business Assessments of the Advanced Engineering Composites Industry	Economic Development Administration EDA-RED-803-G-83- 5, EDA-99-7-13611; SRI/76	N. Fishman; R.H. Trampanou Industrial Research Institute, Inc.	-	To perform a business assessment of composites.	No subcategory established	NTIS
11. Ceramic Fiber/Ceramic Matrix Composites	NASA	M.K. Cox Fiber Materials, Inc.	\$520,990.00	To construct a durable, lightweight material for thermal and oxidation protection of EXO and atmospheric vehicles.	Processes	FRIP
12. Characterization of the Relationship of the Cure Cycle Chemistry to Cure Cycle Processing Properties (See also Table 1, Materials, #39.)	NASA - DC NAG1-237	D.E. Krahnuehl College of William and Mary	-	To study the use of dielectric analysis used to examine the curing of polymer systems and thermoplastics.	Processes	NTIS
13. Coated-Fiber Reinforced Ceramics	SDIO	Dave Richardson Sullivan Mining Corp.	\$49,806.00	To examine coated-fiber reinforced ceramics.	Processes	FRIP
14. Comparison Among Process Monitoring Techniques	NIST	B.M. Fancott; D.W. Wang; D.L. Hunston NIST	In-House	To compare six different techniques used to monitor processing of polymer matrix composites.	Processes	NTIS
15. Composite Material Designs For ASROC Launcher MK112	Navy	W.L. Murphy Abatis	\$549,055.00	To determine the appropriate composite materials and manufacturing methods for substitution of the ASROC launcher's components.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
16. Composite Material Tester	Air Force	Karsten Majdzadeh Resource International Inc.	\$49,146.00	To develop a dynamic testing device capable of achieving strain rates in the range of 104/min. for testing graphite composite material.	Repair	FRIP
17. Composite Materials Evaluation for Filament Winding	Army	Terry L. Vandiver Army Missile Command	In-House	To evaluate new fibers for filament winding.	Processes	MCR
18. Composite Piping Systems	Navy	Richard H. Lee Specialty Plastics, Inc.	\$533,876.00	To develop advanced composite piping systems.	Processes	FRIP
19. Composite Repair Prepreg Using Microencapsulated Catalysts With	Air Force	Norman S. Strand Quantum Composites Inc.	\$49,928.00	To repair composite using microencapsulated catalysts.	Repair	FRIP
20. Composite Wing Design and Fabrication	Army	J. Frank Woodarski, Terry L. Vandiver Army Missile Command	In-House	To design and fabricate an all composite wing with an elliptical platform.	Processes	MCR
21. Confined Plasma Armature Design for Improved Railgun Performance	SDIO	S.N. Rosenwasser Sparta, Inc.	\$94,057.00	To develop the design for confined plasma armature for improved railgun performance.	Processes	FRIP
22. Conformal Thermoplastic Composite Materials for Compound Curvature	Army	David Mass Advanced Composite Products, Inc.	\$88,954.00	To make helicopter parts from a graphite/PEEK thermoplastic composite.	Processes	FRIP
23. Continuous Heated Roll-Forming of Thermoplastic Composite Materials	Air Force	David Mass Advanced Composite Products, Inc.	\$388,906.00	To develop a prototype stapling device to improve delamination resistance and reduce damage to in-plane fibers.	Processes	FRIP
24. Controllable Reactivity Epoxy Resins for Composites Repairs	Air Force	Mark Markowitz Insulating Materials, Inc.	\$69,091.00	To develop Novolac and cycloaliphatic epoxides as heat resistant curing agents for thermosetting composites.	Repair	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
25. Controlled CTE High Performance Films for Space Structures	NASA	Richard W. Lusigna Foster-Miller, Inc.	\$50,000.00	To develop a film processing method to orient the semicrystalline thermoplastic BTBA film to improve and control different properties.	Processes	FRIP
26. Cost and Service Life of Pavement Markings	DOT	J.J. Henry Pennsylvania Transportation Institute	-	To determine "on-road" service life and cost of various types of pavement-marking materials.	Repair	FRIP
27. Develop and Demonstrate Manufacturing Processes for Fabricating Graphite Filament Reinforced Polyimide (GR/PI) Composite Structural Elements	NASA - DC NAS1-14784	V.A. Chase, E.S. Harrison General Dynamics/Convair	-	To assess the merits of using graphite/polyimides NR-150B2 resin for structural applications on advanced space launch vehicles.	Processes	NTIS
28. Development of Electromagnetic Induction Heating for Fusion of Thermoplastic Composites	Air Force	W.H. Pfeifer PDA Engineering	\$49,980.00	To assess the feasibility of using electromagnetic induction heating techniques to fuse thermoplastic composites.	Joining	FRIP
29. Development of Optimum Electromechanical Marine Kevlar Cables	Navy	Philip T. Gibson Tension Member Technology	\$542,742.00	To identify improved cable configurations and manufacturing techniques which will provide reliable sonobuoy cables.	Processes	FRIP
30. Development of Planar Isotropic Near Zero CTE GR/AL Spherical Reflectors	Navy	Olin Hudson DWA Composite Specialties, Inc.	\$49,974.00	To fabricate and evaluate high-angle cross-ply graphite-aluminum spherical reflectors.	Processes	FRIP
31. Development of Tied Joints for Concrete Pavement Repair	DOT-FHWA	J.E. Simonsen Michigan Department of Transportation	-	To use several types of rebar or dowel systems as tied joints for concrete pavement repair.	Repair	FRIP
32. Development of a Continuous Manufacturing Method for a CFRP (Carbon Fiber Reinforced Plastic) Collapsible Tube Mast	NASA - DC ESTEC-6106/84/NL /AN (SC)	D.H. Bowen; R. Davidson; R.J. Lee, Jr.; T. Thorpe UKAEA Atomic Energy Research	-	To develop a continuous manufacture method for a CFRP.	Processes	NTIS
33. Development of a New Beryllium/Graphite-Epoxy Sandwich Composite	Navy-DARPA	C.T. Sun Advanced Composite Engineering	\$49,280.00	To construct a sandwich composite consisting of distinct alternating layers of beryllium and graphite epoxy.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
34. Development of a Rapid-Curing Resin Glass Composite Wrap for Field Cable Sheath Repair and Armor Protection	Army	R.H. Keth; C.W. Frost Minnesota Mining and Manufacturing Co.	-	To develop a rapid-curing resin glass composite wrap for field cable sheath repair and armor protection.	Repair	NTIS
35. Effect of Fabrication Variables on Composite Structures	Army	C.E. Foley; S. Ghiorse; M.E. Roylance U.S. Army Materials Technology Lab	In-House	To determine the advantages and/or disadvantages of different manufacturing techniques, such as braiding, filament winding, and lay-up on the mechanical properties, as well as the environmental durability of these composites.	Processes	MCR
36. Electric Resistance Heating and Consolidation of Thermoplastic	Air Force	John B. Bertolet PMI - Phoenix	\$67,537.00	To evaluate the feasibility of using electric resistance heating in the manufacture of thermoplastic matrix composite parts.	Processes	FRIP
37. Electroceramic Composites	NSF 8707686	A. Safari Rutgers University at New Brunswick	06/01/87-11/30/89 \$70,000.00	To prepare composites with high volume of piezoelectric ceramics	Processes	FRIP
38. Electromagnetic Detection of Stress and Crack Propagation in critical Aircraft Components	Navy	R.J. Churchill American Research Corp.	\$548,548.00	To correlate probe impedance changes with both stress level and crack growth and to investigate several less conventional electromagnetic measuring techniques.	Repair	FRIP
39. Electronic Equipment Shelters	Air Force	Bradford L. Whitley Advanced Composite Technology	\$550,000.00	To make electrical equipment shelters with a polyethylene outer shell.	Processes	FRIP
40. Embedded Fiber Optic Sensors for Polymer Matrix Composite Process Monitoring	NASA	Ian Aeby Geo-Centers Inc.	\$49,866.00	To develop embedded fiber optic sensors and to use them to monitor polymer matrix composite process.	Processes	FRIP
41. Emulsion Pathways To Composite Polymeric Membranes For Separation Processes	NSF 8909948	E. Ruckenstein SUNY Buffalo Chemical Engineering	\$120,984.00	To develop a membrane for the separation of one solvent from its solution in another solvent.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
42. Engineering Research Equipment: Dynamic Mechanical Equipment for On-Line Real-Time Monitoring and Control of Composite Curing	NSF 8604641	B.Z. Jang Auburn University	06/01/86-11/30/89 \$33,000.00	To study polymer processing research.	Processes	FRIP
43. Epoxy Thermoplastic (ETP) Pavement Marking Material	DOT-FHWA	J. Dorla-Medina District of Columbia Dept. of Public Works	-	To use and evaluate the effectiveness of epoxy thermoplastic (ETP) pavement marking material	Processes	FRIP
44. Evaluation and Application of Roadway Marking Materials	DOT-FHWA KY-HPR-84-93	K.R. Agent J.G. Pigman Kentucky Transportation Research Program	-	To evaluate the durability and reflectivity of various roadway marking materials	Repair	NTS
45. Evaluation of Finite Element Codes	Army	David McNelli, J. Frank Wlodarski Army Missile Command	In-House	To find a commercially available PC-based finite element code that can be utilized with little training.	Processes	MCR
46. Evaluation of High Temperature Adhesive For Reentry Vehicles	Air Force	Richard Kent Spears Pern Research Co	\$230,000.00	To evaluate the available adhesives for bonding to aluminum, composites and silver.	Joining	FRIP
47. Evaluation of the "Balvac" Vacuum Sealing Systems Applied to a Bridge Deck	DOT-FHWA	P. Jurach California Department of Transportation	-	To investigate the "Balvac" system to seal deck cracks and voids with vacuum impregnation of epoxy.	Repair	FRIP
48. Evaluation of the Adequacy of a Concrete Bridge Girder Repair Procedure and the Durability of Epoxy/Concrete Repair	DOT-FHWA	Ramey Auburn University	-	To evaluate the durability of epoxy/concrete repair procedure for ruptured concrete bridge girders.	Processes/Repair	FRIP
49. Expert System for Job Aiding in Composite Aircraft	Air Force	William L. Murphy Abaris	\$49,860.00	To develop a portable expert system that will aid the field or organizational technician in the interpretation of ultrasonic non-destructive inspection for the determination of the scope, magnitude, and impact of internal damage to composite laminate structure.	Repair	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
50. Eye Protection Research	Army	J.J. Walls, Jr. Evaporated Coatings, Inc.	\$23,930.00	To conduct eye-protection research.	Processes	FRIP
51. Feasibility of the Use of Fiber-Reinforced Sheetmolded Thermoplastics in Wheelchair Components	Economic Development Administration	Scott F. Raney Fiberlite Composites	\$30,000.00	To manufacture the major components of a 17-pound general-purpose wheel-chair.	Processes	FRIP
52. Fiber Reinforced Thermoplastic Bridge Deck	Army	Joseph S. Boyce Foster-Miller, Inc.	\$72,763.00	To apply roll-forming and welding technique to produce fiber reinforced PEEK deck.	Processes	FRIP
53. Fiber Reinforced Thermoplastic Orthotics	NSF	Nancy J. Potish Quality Composites, Inc.	\$40,000.00	To develop a lightweight thermoplastic brace.	Processes	FRIP
54. Filament Winding Process for Thermoplastic Matrix Composites	NASA	Ronald E. Allred PDA Engineering	\$49,997.00	To develop a method for fusion and compaction using in situ filament winding of thermoplastic/graphite fiber coextruded strands.	Processes	FRIP
55. Filament Winding Thermoplastic Composites	NSF	G. Springer Stanford University	12/01/88-05/31/90 \$107,309.00	To review filament winding thermoplastic composites.	Processes	FRIP
56. Fractionation of Sturries by Periodic Sedimentation and Flow	NSF 8814686	R.J. Adler Case Western Reserve University	04/15/89-03/31/90 \$78,000.00	To study technique used for size-fractionation of small particles.	Processes	FRIP
57. High Performance Polyimide Film Using LARC-TP1	NASA	Richard W. Lusignea Foster-Miller, Inc.	\$249,941.00	To further develop film processing methods to orient polyimide film using LARC-TP1.	Processes	FRIP
58. High Strength Electrical Insulation Composites	SDIO	Richard Weisman Foster-Miller, Inc.	\$416,983.00	To study fabrication methods and mechanical and electrical properties of four types of insulating composites.	Joining	FRIP
59. Hot-Drawn Fiber-Reinforced Thermoplastic Wire	NSF	R.J. Seymour University of California	\$29,959.00	To examine hot-drawn fiber-reinforced thermoplastic wire.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
60. Implementation Verification of Concrete Bridge Deck Hollow Plane Repair: Using Injected Epoxy	DOT-FHWA	F.W. Stratton Kansas Department of Transportation	—	To document the durability and comparative cost of epoxy injection.	Repair	FRIP
61. Improved Composite Flywheel Storage Devices for Electromagnetic Radiation	Army	Ronald E. Allred PDA Engineering	\$49,998.00	To apply a previously developed surface chemical modification process to polyethylene fibers to produce unidirectional epoxy composites.	Processes	FRIP
62. Industrial Process Profiles for Environmental Use: Chapter 10A. The Plastics and Resins Processing Industry	EPA EPA-68-02-3994	Radian Corporation	—	To process raw materials into consumer goods.	Processes	NTS
63. Innovative Composite Aircraft Primary Structures (ICAPS)	NASA - Langley NAS1-18862	Raymond J. Palmer McDonnell Douglas Corp.	03/31/89-09/30/94	To develop fiber perform for transport wing and fuselage structures.	Processes	MCR
64. Innovative Concepts, Structural Mechanics, Verification (See also Table 1, Materials, #202 and Table 2, Structures, #130.)	NASA - Langley NAS1-18888	Stuart Lockheed	04/28/89- \$22,526,000.00	To develop composite technology for wing structure and pressurized fuselage structure including innovative structural concepts, structural mechanics, manufacturing technology and verification.	Processes/Joining	ACT
65. Innovative Fabrication Processing of Advanced Composite Materials Concepts for Primary Aircraft Structure	NASA - Langley NAS1-18799	S.P. Carbo United Technologies	05/09/89-08/09/92	To develop fuselage structures amenable to the Therm-X pressure molding process.	Processes	MCR
66. Innovative Fuselage Concepts, Scaling Verification (See also Table 2, Structures, #131.)	NASA - Langley NAS1-18842	Rouse Northrop	05/02/89- \$5,160,000.00	To develop innovative fuselage concepts for high speed aircraft including scaling laws, structured stability studies, and verification.	Processes/Joining	ACT
67. Innovative Methods for Processing of Thermoplastic Matrix Fiber Composite Materials to Final Net Shapes	NSF 8713319	A.K. Miller Stanford University	12/15/87-05/31/90 \$310,937.00	To study methods of processing to final complex shapes of composite structural materials with high-temperature thermoplastic polymer matrices.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
68. Innovative Wing Concepts, Comingled, RTM, Verification (See also Table 2, Structures, #132.)	NASA - Langley NAS1-18784	Dexter Grumman	04/28/89 \$2,706,000.00	To develop innovative wing concepts for high speed aircraft, develop manufacturing technology using comingled tow and RTM techniques, and verify with fabrication and test of a wing box structure.	Processes/Joining	ACT
69. Integration of CAD/CAM for Injected-Molded Plastic Parts. Progress No. 12 (Revised)	NSF NSF-DMC05-07371	K.K. Wang, S.F. Shen; C. Cohen; C.A. Hieber; R.C. Ricketson Cornell University	\$977,232.00	To develop further the injection of polymeric materials aimed at an integrated computer program for mold design and manufacture as well as for simulation and prediction of optimum process control.	Repair	NTIS
70. Interface-Modified Glass Fiber/Thermoplastic Matrix Composite	Navy	Richard W. Lusignea Foster-Miller, Inc.	\$49,941.00	To improve glass fiber/thermoplastic resin interaction by applying high-temperature polyimide resin coatings to glass fibers.	Joining	FRIP
71. Ion-Milled Gratings	NSF	Bernhard W. Bach Hyperline, Inc.	\$37,006.00	To transfer the groove profile of a blazed original grating into the glass substrate via ion milling.	Processes	FRIP
72. Joints Design and Scaling for Large Space-Based Structures	SDIO	David Maass Advanced Composite Products, Inc.	\$75,952.00	To conduct empirical study of lightweight tubular square truss with thermoplastic composites.	Joining	FRIP
73. Laser Paint Removal System	Air Force	J. Peter Niedzielski Laser Technologies Inc.	\$124,969.00	To study the various effects of the laser paint removal system.	Processes	FRIP
74. Laser-Generated Surface Acoustic Waves for Flaw Detection in Transportation Systems	DOT	Russell J. Churchill American Research Corp.	\$348,742.00	To develop a laser generation and a laser detection system with the establishment of the relationship between laser properties and material properties in relation to launching of acoustic waves for use in flaw detection.	Repair	FRIP
75. Lightweight Advanced Composite Gondola for Stratospheric Balloons	NASA	Donald C. Guichard PDA Engineering	\$49,994.00	To develop a lightweight gondola for stratospheric balloons.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
76. Lightweight Composite Roadway Surfacing System - Preliminary Design	Army	Frank J. Schwan Materials Sciences Corp.	\$50,000.00	To establish the feasibility of designing and fabricating a roadway surfacing system of composite materials.	Processes	FRIP
77. Low-Cost Preforms	Army	David A. Evans Foster-Miller, Inc.	\$67,808.00	To propose a process for producing an oriented fiber felt.	Processes	FRIP
78. Low-Cost Resin Transfer Molding of High Performance Composite	Air Force	Dimitrije Milovich Radius Engineering & Tooling	\$49,825.00	To develop innovative tooling and processing technology for high performance composite aircraft components.	Processes	FRIP
79. Low-Cost Tooling Material & Process For Graphite & Kevlar	NASA	Norman S. Strand Quantum Composites, Inc.	\$520,000.00	To substitute the tooling technology, suited to manufacture of components fabricated from modern polymers and composites, for laminated fiberglass/tooling.	Processes	FRIP
80. Low Density-Activated Fibrous Carbon-Carbon Composite Cryogen Containment System	NASA	Gilbert W. Brassell Nuclear Filter Technology, Inc.	\$41,957.00	To fabricate carbon composites for use in Cryogen Containment Systems.	Processes	FRIP
81. Machining of Lightweight Composite Materials with Abrasive Waterjets	Army	Mahamed Hashish Flow Industries Inc.	\$515,287.00	To integrate the micromachining capabilities of abrasive waterjets with a lathe to produce a new tool for turning composites.	Processes	FRIP
82. Machining with Abrasive Waterjets	NSF	M. Hashish Flow Research, Inc.	12/01/87-05/31/90 \$245,678.00	To conduct Phase II research on machining with abrasive-waterjets under the SBIR Program.	Processes	FRIP
83. Manufacturing Science, Reliability and Maintainability Technology	Army	T.W. Chou; R.L. McCullough University of Delaware	-	To conduct on-line evaluation of composite manufacturing.	Processes	MCR
84. Manufacturing Thermoplastic Matrix Composite	Air Force - Wright-Patterson F33615-84-C-5049; 2419, 01	G.S. Springer Stanford University	-	To develop and test a model of the steps involved in the manufacturing process of semicrystalline thermoplastic matrix composites.	No subcategories established	NTIS
85. Material and Process Development of Novel Graphite/ Thermoplastic	Air Force	David Maass Advanced Composite Products, Inc.	\$219,637.00	To develop textile form and associated processing methods for "hybrid yarn" thermoplastic composites.	Processes	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
86. Metallized Kevlar Space Tether System (See also Table 2, Structures, #155.)	NASA	Ralph R. Orban Material Concepts, Inc.	\$516,643.00	To study a metallized kevlar for use as tether material in space applications.	Processes	FRIP
87. Microwave Dielectric Analysis of Curing Resin Systems	DOC	Bruce W. Maxfield KDC/ISI Joint Ventures	\$230,000.00	To demonstrate the feasibility of using microwave devices to evaluate the in situ dielectric properties of epoxy matrices during fabrication.	Processes	FRIP
88. Microwave Polymerization of Composite Structures	NASA - DC	J.L. Milane; B. Pracher; D. Beziers Societe Nationale Industrielle	-	To study microwave curing of epoxy resins and field distribution of the microwave.	Processes	NTIS
89. Monitoring and Control of Composite Cure Processes Using Mechanical Impedance Analysis (MIA)	NSF 8601416	B.Z. Jang Auburn University	06/15/86-05/31/90 \$170,913.00	To study nondestructive method for use in controlling curing in polymer composite structures.	Processes	FRIP
90. Multi-Hollow Composite Shell Bridge Deck (See also Table 2, Structures, #170.)	Army	August H. Kruel Eljin Corp d/b/a US Composites	\$316,640.00	To design a multi-hollow bridge deck based on new manufacturing techniques including braiding and wet lamination to achieve the necessary performance at an acceptable cost.	Processes	FRIP
91. A New Method for the Ultrasonic Repair of Composites	Air Force	David A. Evans Foster-Miller, Inc.	\$68,824.00	To propose a new method for the ultrasonic repair of thermoplastic composites by focusing the energy at the surfaces to be joined.	Repair	FRIP
92. Novel Epoxy Resins and Process for Polymer Impregnated Timber	Navy	Mark Markovitz Insulating Materials, Inc.	\$60,897.00	To examine novel epoxy resins and process for polymer impregnated timber.	Processes	FRIP
93. Novel High Surface Area Interlocking Composite Films	HHS	Victor R. Koch Covellant Associates Inc.	\$50,000.00	To use composite films as insulators on metal substances in vitro.	Joining	FRIP
94. Optimal Cure Cycle Design of a Resin-Fiber Composite Laminate. Final Report. Period Ending January 15, 1987	NASA - DC NAG1-561	J.W. Hore; J. Sheen Old Dominion University	-	To study the design of cure cycles for composites aided by computer.	Processes	NTIS

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
95. Optimization of Aircraft Interior Panels	NASA - Ames	D.A. Kourtidis; W.D. Roper NASA Ames	In-House	To fabricate eight different graphite composite panels using four different resin materials.	Processes	NTIS
96. Ordered Polymers for High-Performance Composite Structures	Army	Richard W. Lusignea Foster-Miller, Inc.	\$68,960.00	To use PBT film laminates on large scale.	Processes	FRIP
97. Ordered Staple Manufacturing Technology (See also Table 1, Materials, #293.)	NASA - Langley NAS1-18738	Jegley University of Delaware	09/30/88 \$251,000.00	To develop manufacturing technology utilizing ordered staple goods such as long discontinuous fiber (LDE) mats.	Processes	ACT
98. Pavement Marking Materials for Maintenance Restriping	DOT	Bryden NY State Dept. of Motor Vehicles	-	To evaluate chlorinated rubber and two component epoxy system-based pavement marking materials for maintenance restriping.	Repair	FRIP
99. Performance of Thermoplastic Pavement Markings	DOT-FHWA	J.E. Bryden; G.F. Gurney New York State Dept. of Transportation	-	To document the performance of thermoplastic markings installed 434 railroad crossing sites in 1976; and on 173 resurfacing projects between 1979 and 1981.	Repair	NTIS
100. Polyphosphoric Acid Solvated Blends and Molecular Composites	Air Force	James Radich Foster-Miller, Inc.	\$61,021.00	To process molecular composites and two polymer blends using polyphosphoric acid as a solvent.	Processes	FRIP
101. Powdered Tow, Commingled, Thermoplastics (See also Table 1, Materials, #316.)	NASA - Langley NAS1-18834	Johnston BASF	04/13/89 \$1,771,000.00	To develop powdered and commingled tow from thermoplastics and thermosets.	Processes	ACT
102. Preparing Heterostructure Epitaxies for TEM/HREM High Resolution	Air Force	David C. Ryding II-VI, Inc.	\$80,000.00	To investigate new methods of preparing electron transparent cross-sections in epitaxially layered structures.	Processes	FRIP
103. Pressurized Structures, Structural Mechanics, Verification (See also Table 1, Materials, #327 and Table 2, Structures, #193.)	NASA - Langley NAS1-18889	Freeman Boeing	05/12/89 \$22,647,000.00	To develop composite technology for pressurized fuselage structures including innovative structural concepts, structural mechanics, manufacturing technology and verification.	Processes/Joining	ACT
104. Process Monitoring of Polymer Matrix Composites Using Fluorescence Probes	NIST	B. Fanconi; F. Wang; R. Lowry NIST	In-House	To study the use of fluorescence probes used to measure viscosity of the polymer resin.	Processes	NTIS

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
105. Processing Graphite with PEEK Using A Thermoplastic Welding Head	Army	Kenneth B. Bubeck Automated Dynamics Corp.	\$50,000.00	To develop a thermoplastic welding head.	Processes	FRIP
106. Protected Graphite Materials for High-Temperature Industrial Applications	NSF	Oliver J. Murphy Lynntech Inc	\$50,000.00	To modify the chemistry surface of graphite by anodic oxidation and electrochemical induced impregnation.	Processes	FRIP
107. Pulse Energy Fabrication of Surface Composites	NSF	Rong Wang Flow Research Company	\$40,000.00	To process a number of materials with electromagnetic pulses.	Processes	FRIP
108. Reinforced Fluoropolymers for Torpedo Windows	Navy	Robert Kovar Foster-Miller, Inc.	\$50,445.00	To formulate mixtures of commercially available fluoropolymer aqueous dispersions and then coat reinforcement fabrics via multiple coating and fusion steps.	Processes	FRIP
109. Resin Applicator Ring For Manufacture of Lightweight High Performance Braided Composite	Army	August Hugo Kruesi U.S. Composites Science Park	\$350,550.00	To develop a resin applicator ring for manufacture of high performance braided composites.	Processes	FRIP
110. Resin Transfer Molding/Resin Injection Molding (RTM/RIM) Processing	Army	Audie Price Vantage Assocs, Inc.	\$58,346.00	To utilize resin transfer molding vs. resin injection molding composites as processing choice.	Processes	FRIP
111. SME Joints and Coupling for Advanced Composite Materials	NASA	Stephen M. Fisher Memory Metals, Inc.	\$246,775.00	To explore the feasibility of using shape memory effect materials for joints and couplings.	Joining	FRIP
112. Simplified Composite Structure Joining Techniques for Space Applications	Army	W. Ray Morgan Aero-Vironment, Inc.	\$49,498.00	To develop a simple joining technique for use in space.	Joining	FRIP
113. Study of X-Ray Residual Stress Measurements in Naval Aviation Maintenance Environments	Navy	Robert W. Hendricks Technology for Energy Corp.	\$549,285.00	To develop a program in which an existing portable x-ray residual stress analysis system is modified and adapted for field use in a naval aircraft maintenance environment.	Repair	FRIP

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
114. Study of the Application of Automation to Composites Manufacture	Army - Army Materials Technology Lab DAAAG46-85-K-0001	S.M. Krolewski Massachusetts Institute of Technology	-	To evaluate effect of direct labor savings, quality improvements and process flexibility on manufacturing cost to identify desirable characteristics for new equipment.	No subcategory established	NTIS
115. Study on Partially Polymer Impregnated Concrete for Field Work	DOT	M. Kawakami Akita University (Japan)	-	To study partially polymer impregnated concrete for field work.	Processes/Repair	FRIP
116. Surface Roughness of Structural Thermoplastic Mouldings	NASA - DC	J. Koszka Defence Research Information Centre	-	To study surface roughness of structural thermoplastic mouldings.	Processes	NTIS
117. Textiles, RTM, VIM, Stitching, Verification (See also Table 1, Materials, #389 and Table 2, Structures, #226.)	NASA - Langley NAS1-18862	McDonnell Douglas	03/31/89 \$23,750,000.00	To develop manufacturing technology for primary aircraft structure with emphasis on textiles, RTM, stitching, thermoplastic forming, and verification.	Processes/Joining	ACT
118. The Use of Polymer Grids as Reinforcement in Cement-Based Composites	DOT (with Science and Engineering Research Council)	A.J. Watson Sheffield Univ. (England)	-	To study properties of polymer grid reinforced cement.	Processes	FRIP
119. Thermo-X Tooling Methods (See also Table 1, Materials, #392 and Table 2, Structures, #228.)	NASA - Langley NAS1-18799	Deaton Sikorsky Helicopter	05/09/89 \$1,069,000.00	To develop Thermo-X processing for advanced composite fuselage structures.	Processes	ACT
120. Thermoplastic Composite Processing Via Ultrasonics	Air Force	Scott R. Taylor Taylor S.R. & Assoc	\$51,740.00	To use ultrasonic activation for improved processing of resin composites.	Processes	FRIP
121. Thermoplastic Matrix Fiber Composite Materials: A Small Machine for Die-Less Forming of Large Components	NSF	A.K. Miller Stanford University	05/15/87-10/31/90 \$403,731.00	To develop a new approach to the manufacture of thermoplastic matrix continuous-fiber composite materials by means of computer-controlled rollers which form an initially flat composite laminate into a complex shaped component.	Processes	FRIP
122. Thermoplastic Prepreg Manufacturing	NSF	K.E. Goodman and A.C. Loos Virginia Tech	-	To manufacture thermoplastic resin-impregnated with continuous graphite fiber.	Processes	ASC

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
123. Tough Thermoplastic Composite Bridge Deck Development	Army	David Maass Advanced Composite Products, Inc.	\$33,424.00	To develop a manufacturing process and sample hardware for a lightweight tough composite bridge deck.	Processes	FRIP
124. Toughened Thermosets, RTM Systems	NASA - Langley NAS1-18841	Hergenrother Dow	04/11/89. \$5,293,000.00	To develop toughened thermosets and resin transfer molding (RTM) systems.	Processes	ACT
125. Trans-Laminar Reinforcement of Organic Matrix Composite	Air Force	Charles R. Harrison CTL-Aerospace, Inc.	\$46,376.00	To develop a method to implant high modeling fibers or strand between plies to increase translaminar strength.	Processes	FRIP
126. U.S.-Austria Cooperative Research: Synthesis of High-Performance Ceramic Fibers by Chemical Vapor Deposition for Advanced Metallics Reinforcing	NSF 8813593	V. Hlavacek SUNY Buffalo	12/15/88-11/30/90 \$8,991.00	To manufacture ceramic materials via chemical vapor deposition process.	Processes	FRIP
127. Ultrasonically Enhanced Paint Removal	Air Force	Scott R. Taylor Taylor S.R. & Assoc	\$50,082.00	To invent ultrasonic device for removing paint from composites.	Repair	FRIP
128. Ultrasonically Improved Resin Matrix Composites	Army	George R. Moulder Energy & Minerals Research Co.	\$49,950.00	To apply ultrasonics to reduce voids in epoxy composites.	Processes	FRIP
129. Using Electric Fields to Control Fiber Orientation During The Manufacturing of Composite Materials	Navy	G.M. Knobloch FMC Corporation	-	To demonstrate the ability to control the orientation of fibers using electric fields.	Processes	ASC
130. Void Formation Study In Filament Wound Structures	Army	Steven F. Stone Mission Research Corp.	\$49,979.00	To study different winding processes in order to decrease void formation.	Processes	FRIP
131. Winding With Thermoplastic Polymers	NASA - DC	J.L. Tsane, J. Bouvard Societe Nationale Indust. Aerospatiale	-	To study the filament winding of continuous fibers impregnated with thermoplastic resins.	Processes	NTIS

TABLE 3
PMC RESEARCH: MANUFACTURING

Project Number/Title	Sponsor/ Contract #	Principal Investigator/ Performing Organization	Duration/ Funding	Objective	Subcategory	Source
132. Woven Fabric Reinforcements for Composites	Army	Norris F. Dow Materials Sciences Corp.	\$427,000.00	To develop guidelines for the extension of the technology of weaving triaxial fabrics to provide woven structures having through-the-thickness running yarns in addition to in-plane triaxial constructions.	Processes	FRIP
133. X-Ray Computerized Tomography Applications To Ceramics And Composites	NSF 8960677	J.C. Sharer National Science Foundation	\$50,000.00	To use computerized tomography to quantitatively measure fiber concentration.	Processes	FRIP

4. SUMMARY OF FINDINGS

Although advanced PMCs are still in their infancy, the results of this survey clearly show that Federal agencies recognize their potential power. Even their limited use to date in constructing such products as aircraft, automobiles, and industrial equipment demonstrates that the use of PMC materials can increase product life and save energy.

Despite the magnitude of the Federal research effort, and the efforts of governments and industry worldwide, a number of issues wait to be addressed. Following a brief summary of current trends in Federally sponsored research revealed by the survey, this section outlines some of those issues. Addressed first are several broad challenges, including economy of use, fundamental understanding of the issues, and the need for education and training in the field. Next is an examination of research needs pertaining to five specific applications, or "target technologies": aircraft fuselage, automobile frames, high-speed machinery, electronic packaging, and construction. Because of the superior strength and stiffness of PMCs, and their light weight, the application of advanced composites offers these technologies the potential for improved product performance, longer life, and energy savings.

The section concludes with a brief examination of the state of international PMC research.

TRENDS IN FEDERAL RESEARCH

Key Contributors

As the survey results in tables 1-3 of this report indicate, several agencies of the Federal government—most notably DoD, NASA, NSF, and DOT—sponsor PMC research. DoD, which forecasts spending more than \$60 million a year for the years 1989-1991, continues as the leader of Federally sponsored PMC research. However, through the ACT program, NASA plays a more predominant role now than it has in the past. After spending \$23 million on PMC research in FY85, NASA budgeted only \$8.7 million in FY86 and \$5 million in FY87. In those same years, DoD budgeted \$29.2 million and \$33.8 million. With the ACT program, which began in FY89, NASA has significantly increasing funding, allocating \$140 million to ACT, to be expended over six years (FY89-FY94). It must be noted, though, that ACT does not concentrate solely on PMCs. Other advanced composites are also the subject of ACT research.

Areas of Research

The survey results indicate that, although the goals of some Federal studies include improvement of PMC structures or the development of new manufacturing techniques, the Federal government currently places greatest emphasis on PMC materials research.

The trend in materials research appears to be toward developing materials with improved performance. Researchers are making attempts to improve performance by increasing material

strength and stiffness or by improving fracture toughness and compression after impact. Other projects focus on improving thermo-oxidation stability or increasing environmental resistance.

Although thermosets and thermoplastics currently receive almost equal attention from Federal researchers, thermoplastics have become a major thrust in the arena of composite technology not only because they are more impact resistant than some of the older materials, but also because they hold the potential for easy formability, or even re-formability. Current thermoplastic programs include extensive research regarding the possibility of placing a variety of well-bonded polymeric materials (resins) onto fiber or fabric to create a "prepreg." A prepreg typically consists of a single layer of 35-40 weight resin applied to a 60-65 percent fabric (glass, aramid, or graphite). The resulting polymer-fabric prepreg is then laminated to other prepregs to generate a multi-layer fiber.

In the area of thermosets, some researchers are investigating ways to improve the "shelf life" of epoxy-toughened resins. In addition, efforts to make thermosets tougher by combining them with thermoplastics to create "interpenetrating polymer networks" are taking place. This concept of supportive hybrid structures is a relatively new approach to forming composites and appears to be replacing earlier approaches using rubber-toughened composites. The advantage that thermosets currently hold over thermoplastic materials lies in their ability to withstand extremely high temperatures, even up to 600 or 700 degrees Fahrenheit. The development of PMCs that can withstand high temperatures like thermosets and still maintain the lightweight strength of thermoplastics could be a key to the acceptance of PMCs by auto makers and the commercial aircraft industry. Recognizing this need, some federal researchers are studying ways to improve the temperature resistance of thermoplastics.

Trends in structures and manufacturing research include the development of improved adhesive bonding or joining technology, which includes both improved fasteners for mechanical joints and new adhesives for bonded joints. In addition, a number of matrix resins are being researched to find ways to improve PMC processibility and overall quality.

Structures and manufacturing research lag behind materials research both in dollars allocated and in sheer number of projects. NASA's ACT program, however, has a structures orientation and may be responsible for the initiation of more work in the area of structures.

Despite indications from OTA and other sources that finding efficient, economical methods for manufacturing, repairing, and recycling products constructed from PMC materials is essential to gaining wide-ranging industry acceptance in constructing automobiles and other products, only 15 percent of all projects identified in the PMC survey concentrate on manufacturing techniques. Some of the projects that have been undertaken concentrate on the use of artificial intelligence, or "smart" systems. The goal of smart systems is twofold: to increase the effectiveness of the curing process and to reduce manufacturing costs.

Applications

PMCs show promise in a variety of applications. Both the survey results and information obtained during interviews reveal that Federal researchers are seeking ways to use PMCs to build

products ranging from artificial limbs to protective clothing to artillery. Research related to the use of components made of PMCs in constructing conventional aircraft may be of particular interest to DOE, not only because it is the subject of a significant number of projects, but also because the energy savings associated with aircraft constructed in part—or even wholly—from advanced composites.

NASA devotes considerable effort to studies of the role of PMCs in aircraft fuselages and wings, as well to their use in constructing space vehicles. DoD also has an interest in this area. Existing military aircraft currently hold a larger proportion of composite materials than commercial aircraft (about 10 percent of the components of the FA-18A are composites), although two commercial aircraft builders—Beech Aircraft and Avtek—have constructed all-composite prototype airplanes and have applied for FAA certification. DoD is seeking ways to improve composites and, ultimately, to increase their use in military aircraft. Among the organizations within DoD participating in this effort are Wright Aeronautical Laboratories, the Naval Air Development Center, and the Aviation Applied Technology Directorate of U.S. Army ARTA.

Although the incorporation of PMC components into auto frames could significantly reduce the amount of energy required for operation, little, if any, Federally sponsored research directly associated with auto-frame construction is taking place. Although DOT's planned budgets for PMC research for the next ten years indicate a renewed interest in PMCs, that interest lies within FHWA, whose primary concern is the construction of highways and bridges. Interviewees at DOT and the Transportation Research Board personnel had no knowledge of ongoing or proposed auto-frame research.

RESEARCH CHALLENGES

Despite the magnitude of PMC research in the U.S. and other nations, a number of issues wait to be addressed. Three such issues are economy of use, processing, and education and training. Each of these issues can have an important impact on reducing manufacturing costs associated with PMCs and therefore can play an important role in the eventual acceptance of PMCs by auto makers and other commercial users. Acceptance in turn will lead to the incorporation of PMCs into the construction of auto frames, which ultimately will result in enhanced performance and reduced energy needs.

Economy of Use

Perhaps no issue presents a greater challenge to the continued development and use of composite materials in engineering structures than economy of use. In addition to the cost of materials and manufacturing, a number of other factors play a role in the economy of use, including multifunctionality of design, standardization, maintainability, durability, and lifetime cost. To meet this challenge, the U.S. scientific community must develop new matrix and fiber materials. It must also establish new design philosophies and new standards for the application of materials to structures.

Processing

Closely related to economy of use is the need to improve processing or fabrication methods. Fabrication methods for high-strength, fiber-reinforced composites frequently are slow and costly, and some of them produce significant variations in product quality. Research is needed to deal with the science of fabrication as well as the technology of the subject, including the development of automated devices (including robotics, computer control, and intelligent systems), filament winding, and pultrusion techniques. Important to this effort is the development of materials, especially matrix materials, that can be fabricated efficiently.

Education and Training

The field of composite materials is highly technical and highly disciplinary. The creation of successful composite systems, components, and structures requires the full integration of disciplinary perspectives as broad as mathematics and physics and requires the promulgation of a creative flow of ideas in all technical directions. Measures that may help create this environment include establishing more university programs of education in composite materials; selecting and implementing continuing education strategies; the forming substantial relationships between universities and government and industry laboratories; and creating laboratories and technical centers dedicated to composite materials science.

Fundamental Understanding

Continued development of a fundamental understanding of the behavior and properties of composite materials is important. Technological advances in the last two decades have greatly outdistanced development of the underlying basic science associated with properties, mechanical response, processing, joining, and material synthesis. Understanding can provide the basis for optimization, exploitation, engineering development, and economic success.

TARGET TECHNOLOGIES

PMCs and other advanced composites can improve the strength, performance, and durability of myriad products. Described below are five "target technologies," each representing an applicant areas in which PMCs hold great promise. The technologies are:

1. Aircraft fuselage.
2. Automobile frames.
3. High-speed machinery.
4. Electronic packaging.
5. Construction.

Aircraft fuselage and auto frames may be of special interest to DOE because of their energy-saving potential. The use of PMCs in building high-speed machinery may also result in some energy savings.

Target Technology: Aircraft Fuselage

Although the use of PMCs in aircraft fuselages is an area of research receiving significant attention at NASA and DoD, its transfer from government to commercial aircraft has been limited. In the technology of aircraft fuselage, life prediction is a major issue. Also important is material development. In the past, most research focused on thermosets such as epoxy. Today, a growing number of projects concentrate on more flexible, adaptable thermoplastics. Finally, economy is an important factor. The basic costs, such as manufacturing, maintenance, and design, as well as lack of experience in the use of these materials, all limit the use of composites.

Target Technology: Automobile Frames

The auto industry is the largest single user of custom-designed integrated circuits (used for controlling engine functions). It also relies heavily on reinforced plastics. Yet, interest in advanced composites appears to be waning in the U.S. auto industry.

A prominent issue is manufacturing technology. The ability to produce high-quality parts from high-volume production is currently stymied by the slow development of material systems and fabrication techniques. New design approaches could change the pace. Developments in multifunctional design are needed to reduce the number of parts in an automobile (about 1,500 in today's cars). Another area for enhancement lies in understanding the impact resistance of composite structures. Although composite materials have the potential to absorb more energy per unit weight than steel, researchers have yet to determine how to incorporate this capability into an automobile's structure. Considerations include durability and maintainability of advanced-composite components, as well as standardization of manufacturing aspects.

Target Technology: High-Speed Machinery

Composite materials are ideal for many applications involving industrial machinery; machine parts made of composites generate less friction, which in turn can reduce energy consumption. Widespread awareness of this application, however, is lacking. Therefore, dissemination of information to industrial audiences on the general capabilities of composite materials and the techniques required to manufacture components from these materials may be beneficial. Understanding of the behavior and durability of PMCs is also important to their acceptance by makers and users of high-speed machinery.

Target Technology: Electronic Packaging

Composite materials play a major role in the electronics industry, one application being electronic packaging/interconnecting structures. These structures, also known as P/I boards, support and connect the analog and digital devices that make up electronic equipment. This field

could benefit from the development of additive processing techniques for the manufacture of circuit boards, as well as from research in thermomechanical engineering for such purposes as finding ways to prevent warping of circuit boards.

Also important to the successful use of composite materials in electronic packaging is the adoption of a systems approach to engineering design issues. More university research programs on the fundamentals of packaging and interconnecting structures may help achieve this aim.

Target Technology: Construction

The survey results indicate that FHWA is working with state highway administrations to study the use of composite materials in bridge construction. Two additional major avenues for potential large-scale application of composite materials to construction are (1) complex assemblies such as window frames and (2) load-bearing members of buildings where the strength-to-weight ratio, self-damping characteristics, and corrosion resistance of composites offer substantial benefits.

Joining of composites materials to other materials to make construction components requires understanding and technology that may exceed present levels. In addition, a need may exist to be able to specify standard materials and standard components such as sheets, beams, etc., that have known properties and performance, not only to serve the needs of industry, but also to allow building codes and other regulations to be developed for these materials.

Finally, like other industries, the construction industries may require low-cost material development techniques if PMCs are to find significant building applications. In addition, the technological support for "unsophisticated" industries may be necessary.

GLOBAL PERSPECTIVE

Today, the United States possesses an extensive data base in polymer-based composites as well as a strong position in composite manufacturing and processing technology. The major emphasis, however, is on aerospace materials. Waning interest in Detroit has combined with stringent export controls to dampen the enthusiasm of auto makers and other potential users of this energy-saving technology¹. Limitations to DoD's future research budget may also have a negative impact on non-aerospace PMC research, although it is possible that DOE could fill the gap that DoD may create.

Overseas activity, on the other hand, is increasing, and the composite technologies of other nations are beginning to rival those of the U.S. In fact, in some instances, the U.S. government has sponsored PMC research abroad. The PMC survey identified more than 20 contracts awarded by Federal sponsors to private companies, universities, and other research organizations outside the U.S. NASA funds most of the contracts; other sponsors include DOT and the Air

1 "U.S. Loses Edge in Composite Materials," *Wall Street Journal*, December 29, 1989.

Force. Topics of research include: evaluation of the corrosion resistance of bridge slabs with epoxy-coated reinforcing bars due to deicing chemicals (Japan); the study of transversal cracks in composite materials (France); the study of thermoplastic additives in glass fiber-reinforced polyesters (Spain); and testing of carbon fiber composite materials for the effects of tension, compression, shear, notch, impact, and fatigue (United Kingdom).

Outside the U.S., most PMC and other advanced-composite research and production is concentrated in Japan, France, West Germany, the United Kingdom, and Italy. Among Japan's research efforts is the 10-year Research & Development Project on Basic Technology for Future Industries, funded at \$32 million and initiated in 1981. Research topics of this project, which is sponsored by the Agency of Industrial Science and Technology Council (MITI), include both composites and ceramics. The project emphasizes aerospace and automotive applications.

Western Europe has also shown keen interest in the use of advanced composites in both the aerospace and automotive industries, although, like the U.S., the primary emphasis is on aerospace. In 1985, these nations produced 2,500 tons of advanced composites, worth \$550 million².

Commercial Acceptance in Other Nations

Although many U.S. commercial end users are reluctant to make the investment in advanced composite materials prior to resolution of processing issues and the development of economical manufacturing methods, other nations have had more success in commercializing their materials technology. This success may be due, at least in part, to government-industry cooperative efforts. Japan promotes the use of advanced composites through a joint government-industry program. France, another leader in advanced-composite research, also has government-industry cooperative efforts, as do the United Kingdom and West Germany. In addition, at least two European Community programs sponsor research on advanced materials and their production technology.

2 OTA, 227-230.

APPENDIX A. RESEARCH METHODOLOGY

Appendix A provides a detailed description of the methodology used to identify ongoing and recently completed research in the field of polymer matrix composites (PMC), categorize this research, and determine trends in the research.

DATA COLLECTION

As a first step, Walcoff defined the research parameters. Based on contractual requirements and discussions with Department of Energy (DOE) personnel, Walcoff determined that the focus of the search would be on research projects that met all of the following criteria:

- ❑ Federally funded.
- ❑ Sponsored by any agency except DOE.
- ❑ Ongoing or completed since 1985.

Data Sources

With the parameters established, Walcoff selected three methods of data collection. As its primary source of data, Walcoff selected computerized, online literature searches. Walcoff supplemented the primary source with data obtained from print publications and during interviews with recognized leaders in the field. In designing the methodology, Walcoff acknowledged the following limitations of the survey:

- ❑ Only unclassified projects were likely to be identified.
- ❑ Projects not reported by Federal sponsors to the online literature sources might not be detected.
- ❑ Projects initiated during the survey time frame might not be detected.

Each of the survey methods is described below.

Online Research

Using DIALOG, a library of computerized, online literature resources operated by Dialog Information Services, Inc., Walcoff conducted exhaustive searches of two data bases: Federal Research in Progress (FEDRIP) and National Technical Information Service (NTIS). Walcoff selected these two data bases from among several possibilities within the DIALOG library (e.g., Aerospace, Engineered Materials, DOE Energy, DMS Contractors, Materials Business File, CA Search, and Polymer Online). The project team, which included specialists in the fields of conventional and computerized library research as well as experts in composites research,

selected FEDRIP as the most viable source of ongoing research pertinent to the contract. As described by the *DIALOG Database Catalog, 1989*, the FEDRIP data base "provides access to information about ongoing federally funded research projects in the fields of physical sciences, engineering, and life sciences."

Recognizing that completed projects, in many instances, still reflect the state of the art, Walcoff expanded the survey to include projects completed since 1985. To identify these projects, Walcoff searched NTIS. According to the DIALOG catalog, this multidisciplinary data base "consists of [unclassified] government-sponsored research, development, and engineering plus analyses prepared by federal agencies, their contractors, or grantees." NTIS houses data on research projects dating back to 1964.

To ensure that the literature search yielded the full range of projects that should be considered for inclusion in the survey, the project team devised a list of "key terms" designed to incorporate pertinent projects and exclude others. The team carefully avoided selecting terms that would define the scope of the search too narrowly, to prevent inadvertent exclusion of PMC projects. In all, three separate literature searches, employing more than 60 key terms, were conducted.

A complete list of the key terms used is contained in appendix B.

Publications

Print publications were an additional resource for identifying new projects and for obtaining supplemental data for projects identified by other means. To identify projects initiated after July 1989 (not yet available in FEDRIP) the project team consulted *Chemical Abstracts*. Other project sources included 1) *Mechanics of Composites Review*; 2) *1989 Materials Laboratory and Manufacturing Technology Directorate Combined Roadmap Review*; 3) *A Detailed Technology Roadmap for: COMPOSITE MATERIALS*; 4) *FY90 Materials Technology Area Plan*; 5) *Advanced Organic Composite Materials for Aircraft Structures - Future Program*; 6) *Enclosure Program Plan For Advanced Composites Technology*; 7) *U.S.-Japan Composites Workshop*; 8) *American Society of Composites Proceedings*; 9) *Proceeding Notes: Workshop on Polyimides*; and 10) *Polyimides: Chemistry Materials, Characterizations*. These publications describe programs being conducted within Federal agencies, trends and parameters for composites, applications and benefits, technical areas with little research support, advancement inhibitors, and recommended actions.

Interviews

A Walcoff Technical Specialist conducted telephone and personal interviews with a diverse group representing both government and private industry, all leaders in the field of composites research. Personal interviews were conducted at the National Aeronautics and Space Administration's (NASA) Langley Research Center and at Wright-Patterson Air Force Base. Telephone interviewees included other NASA and Department of Defense personnel, as well as officials of DOE and the Defense Advanced Research Projects Agency (DARPA). Representatives of private industry came from Boeing and Lockheed, among others. A complete

list of interviewees is included in appendix B. The major focus of the interviews was the scope of work, the areas being researched, and the "state of the art" in PMCs.

Although an important objective of the interviews was to obtain input on the most effective approach to categorizing and analyzing data collected, the Walcoff interviewer also gathered information concerning the scope of work within each interviewee's facility and concerning contracted work with universities and private industry at each of the agencies. Almost without exception, the interviewees described their composites programs in detail, providing data on current projects, including funding amounts if available.

The interviews focused on gathering the following information:

- ❑ The major thrust of ongoing work in relation to types of materials, e.g., thermoplastics, thermosets, and molecular composites.
- ❑ Identification of the Federal agencies most active in PMC research and development.
- ❑ Funding set aside for PMC research.
- ❑ Identification of contractors, and the nature of specific projects.
- ❑ Assessment of the importance of cost factors in establishing research programs.
- ❑ Comparison of research in private industry with that sponsored by the Federal government.
- ❑ Comparison of research in the United States with research in other countries.
- ❑ The future for composites in five years. In ten years.

Initial Data Entry

The project team entered the data gathered into a data base. The data base contained fields established for recording the following:

- ❑ Project title.
- ❑ Project sponsor.
- ❑ Principal investigator.
- ❑ Name and address of performing organization.
- ❑ Contract number.
- ❑ Funding.

- Duration (time frame) of contract.

Project data varied somewhat depending on the source utilized. NTIS, for instance, included no funding data, and contract numbers and duration data were available sporadically. In all instances, the project title was available, and data to fill the fields established for sponsor, investigator, and performing organization were available in most cases. Additional fields were established for the purpose of holding project objective statements and data related to the broad nature of the research being conducted. These fields were completed during the early stages of analysis.

ANALYSIS

Project-By-Project Analysis

Following project identification and initial data entry, Walcoff reviewed each project individually. Based on abstracts provided by the data sources, subject experts wrote an objective(s) statement for each project and defined the nature of the research according to three broad categories—materials, structures, and manufacturing techniques. Further, Walcoff subcategorized each project, and, in the case of materials research projects, further defined them by subsets. The subcategories established for each area of research are set out in figure A-1.

Figure A-1

As the project team categorized the projects and completed objective statements, the data was entered into the data base.

Analysis of Data Base

After completion of the data base, the project team analyzed the data gathered to identify trends in research. Four major areas were addressed: (1) areas of research—primary areas, subcategories, and subsets; (2) sponsors of research; (3) target areas of research for the leading agencies; and (4) funding levels (how much is being expended and which areas of research receive the highest-dollar funding).

APPENDIX B. BIBLIOGRAPHY OF SOURCES

COMPUTERIZED ONLINE LITERATURE SEARCHES

Online Research Sources

1. National Technical Information Service (NTIS)
2. Federal Research in Progress (FEDRIP)

Key Terms Used During Online Research

Polymer Matrix Composite?	Avimid
Organic Matrix Composite?	Polybenzimidazole?
PMC	PBI?
Thermoset?	Benzimidazole?
PMR	Benzthiazole?
PMR 15	Polybenzthiazole?
BMI	Polybenzoxazole?
Bismaleimid?	Benzoxazole?
Thermoplastic?	Polyphenylquinoxaline?
Molecular Composite?	Polyquinoxaline?
Graphite	Quinoxaline?
PEEK	NDE
Kevlar	Non Destructive Test
Fiberglass?	Wear?
Polyimide Composite	Tribolog?
PEEK Composite	Fatigu?
Epoxy Composite	Fractur?
BMI Composite	Crack?
Prepreg?	Craz?
Epoxy	Polyimide
LARC	Polymer?
Polyimide	Organic
Polyether Ether Ketone	Matrix
Polyarylene Ether Ketone	Composite?
Liquid Crystal	Polymer Composite Material
Polyester	Bismaleimides Composites
Polysulfone?	Plastic?
UDEL	Resin?
Polyarylene Ether Sulfone	Polyimide Composite?
Vitrex	BMI Composite?
Polyamide Imide	Fiber?
Torlon	Polymeric Composite Material?
Aramid?	

Note: A question mark (?) is used at the end of a word stem to retrieve variations in word endings (i.e., composite? searches both composite and composites).

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Santa Ana, CA 92705

PDA Engineering
2975 Red Hill Avenue
Costa Mesa, CA 92626

PMI - Phoenix Metallurgical Inc.
Box 12 - 7 Airport Drive
Hopedale, MA 01747

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Promatec, Inc.
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Pultrusion Technologies, Inc.
Twinsburg, OH 44087

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3275 W 12600 South
Riverton, UT 84065

Quantum Composites Inc.
4702 James Savage Rd.
Midland, MI 48640

Quantum Design Inc.
11568 Sorrento Valley Rd.
San Diego, CA 92121

Radian Corp.
7655 Old Springhouse Road
McLean, VA 22101
(703) 734-2600

Radiation Monitoring Devices
144 Hunt St.
Watertown, MA 02172

Radiation Science, Inc.
P.O. Box 293
Belmont, MA 02173
(617) 494-0335

Radius Engineering & Tooling
13474-S 2300RD E
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Refractory Composites Inc.
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Laguna Hills, CA 92653

Specialty Plastics Inc.
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Spectrascan Inc.
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South Windsor, CT 06074

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Patriots Park
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Springborn Materials Science
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South Nyack, NY 10960

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Melbourne, FL 32902

Sullivan Mining Corp.
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San Diego, CA 92104

Sunburst Recovery Inc.
P.O. Box 1173
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APPENDIX D. PRESENT AND FUTURE MARKETS FOR HIGH PERFORMANCE COMPOSITES

In an address to the Interdisciplinary Symposium on Recent Advances in Polyimides and Other High Performance Polymers, Peter W. Kopf of Arthur D. Little, Inc., assessed the present and future markets for high-performance composites. Mr. Kopf examined market trends, with a view especially toward aerospace, automotive, industrial, and military applications of advanced composites. Mr. Kopf also described growth trends in global use of thermoplastic resins and polyimides, and offered a glimpse at future opportunities for the use of advanced composites.

On the following pages are graphics excerpted from Mr. Kopf's presentation.¹

GLOBAL MARKET: PRESENT AND FUTURE

Advanced Composites: A High-Value, Low-Volume Portion of the Reinforced Plastics Business

- ❑ In the United States, advanced composites account for less than 1% by weight (nearly 15 million lb.), but approximately 1% by value (about \$900 million for fabricated parts) of the 2.3 billion-lb., \$2.5 billion reinforced plastics market.
- ❑ Advanced composites also have a much higher growth rate than reinforced plastics as a group: 16-17%/year versus less than 3%/year.

1 Kopf, Peter W., "Present and Future Markets for High Performance Composites," Proceedings of The Interdisciplinary Symposium on Recent Advances in Polyimides and Other High Performance Polymers (San Diego, January 22-25, 1990). Reprinted with permission of the American Chemical Society, Washington, D.C.

Past and Anticipated Future Use of Advanced Composites

	1987		1988		1993	
	MM#*	\$MM**	MM#	\$MM	MM#	\$MM
US	15.0	900	17.4	1,030	36.5	1980
(AGR)	(16)	(14)				
Western Europe	3.8	235	4.5	270	9.9	540
(AGR)	(17)	(15)				
Asia Pacific	6.1	245	7.2	280	16.5	570
(AGR)	(18)	(15)				
World	24.9	1,380	29.1	1,580	62.9	3,090

*Pounds **Dollars

Distribution Among Markets: U.S. and Worldwide

Market	Distribution (1988)	
	US	Worldwide
Aerospace	79%	55%
Recreation	4	25
Industrial	10	17
Automotive	1	--
Military	2	--
Other	4	3
	100%	100%

Key Growth Segments for the U.S.

Market	Market Value		Annual Growth Rate
	1988	1993	1988-1993
Aerospace	\$810,000,000	\$1,560,000,000	14%
Recreation	40,000,000	50,000,000	5
Industrial	100,000,000	180,000,000	12
Automotive	10,000,000	15,000,000	8
Military	20,000,000	110,000,000	30
Other	40,000,000	55,000,000	5
Average	\$1,020,000,000	\$1,970,000,000	14

AEROSPACE APPLICATIONS

Aerospace Market: Large Growth Potential for Advanced Composites

- Current penetration is low. It will increase because of:
 - Increasing high-performance materials needs of the aerospace industry.
 - Diminishing factors that constrain uses of advanced composites.
- The late 1980s and early 1990s will be a boom period for aircraft sales.

The Driving Forces for Aerospace Applications

- Weight reduction needs:
 - In military aircraft, weight reduction is worth \$500-\$1,000/lb. saved.
 - In commercial aircraft, it is worth \$200-\$500/lb. saved.
- For military aircraft: Increasingly higher performance requirements.
- For commercial aircraft: Cost reduction needs.

Some Reasons for Advanced Composites' Slow Penetration of the Overall Aerospace Market

- The extreme consequences of failure and the resulting conservativeness with respect to introducing new materials and technology.
- The need to develop new design technology specifically for composites.
- Labor-intensive and expensive methods of fabrication.

Penetration of Commercial Airline Sector: Still Slow

Growth Prospects For Advanced Composites in the Long Term

Advanced Composites' Penetration (percent of structural weight)

Aerospace Sector	Current	Potential	Timeframe
Military	15-50	50-80	10 years
Commercial	3-7	30-60	25-30 years
Civillan	<10	60-80	10-15 years

Growth Rates Within the Aerospace Industry

<u>Segment</u>	<u>1988 Value</u> (Millions of \$)	<u>Growth Rate</u>
Military	178	10-12%
Commercial	259	12-16
Business	24	20-25
Helicopters	138	10-12
Space, Missiles	211	25-30
Total	810	14%

AUTOMOTIVE APPLICATIONS

Product Maturity/Life Cycle of Automotive Applications of Advanced and Engineered Composites

ORDNANCE (MILITARY) APPLICATIONS

Ordnance Market: Still Embryonic But Expected To Grow In the Next 10-15 Years

- ❑ Army, Navy, and Marines have significant programs.
- ❑ Applications are highly specialized.
- ❑ Some can reach fairly high volumes.

Selected Ordnance Applications of Advanced and Engineered Composites

- ❑ Personnel armor.
- ❑ Mobile bridging.
- ❑ Hardened shelters.
- ❑ Vehicle armor.
- ❑ Weapons.
- ❑ Ship structures.
- ❑ Submarine structures.

POLYIMIDE AND THERMOPLASTIC RESINS

Worldwide Polyimide and Thermoplastic Resins: The Fastest-Growing Raw Materials

		1987	1988	1993	AGR
<i>Resins</i>	Epoxy	7.6	8.8	17.4	14%
	Polyimide	1.0	1.2	2.7	18%
	Thermoplastic	1.0	1.2	3.3	22%
	Other	1.6	1.9	3.9	16%
	<i>Resins Total</i>	11.2	13.1	27.3	16%
<i>Fibers</i>	Carbon	5.5	6.4	14.3	16%
	Aramid	3.5	4.2	9.3	16%
	Glass & Other	4.7	5.4	12.0	16%
	<i>Fibers Total</i>	<u>13.7</u>	<u>16.0</u>	<u>35.6</u>	16%
Total (millions of lbs.)		<u>24.9</u>	<u>29.1</u>	<u>62.9</u>	16%

Leading Materials Producers for U.S. Advanced Thermoplastic Composites Business

Amoco Chemical	Polysulfones
	Polyamide-imides
	Polyetheretherketone
BASF	Polyether sulfone
	Polyetherketone
	Liquid crystal polymers
DuPont	Polyimides
	Polyamides
General Electric	Polyetherimide
	Polyimide
Hoechst Celanese	Polyamide
	Liquid crystal polymers
ICI	Polyether sulfone
	Polyetheretherketone
Phillips Petroleum	Polyphenylene sulfide

POTENTIAL APPLICATION OPPORTUNITIES

Potential Applications of Advanced Thermoplastic Composites

Aircraft	Automotive	Military
Access panel	Structural components	Ballistic armor
Radomes		Portable structures
Tail surfaces	Electronics	
Wing skins	EMI, RFI shielding	Recreation
Spars	Printed circuit boards	Fishing rods and reels
Ribs	Industrial	Tennis rackets
Nacelles	Gears, impellers	Boat parts
	Oilfield equipment	

Compression and Automated Layup: Fastest-Growing Production Processes

<u>Process</u>	<u>1989 Volume (million lbs)</u>	<u>Share</u>	<u>Annual Growth Trend</u>
Autoclave	5.0	25%	16%
Compression	1.2	6	25
Filament Winding	6.0	30	16
Manual Layup	3.0	15	8
Automated Layup	1.0	5	25
Pultrusion	0.4	2	18
Vacuum bag	2.2	11	8
Other	<u>1.4</u>	<u>6</u>	<u>16</u>
Total	20.2	100%	16%

Key Future Opportunities For Advanced Composites

- ❑ Specialty ordnance materials such as bridging, shelters, and armor.
- ❑ Structural automotive parts.
- ❑ Commercial aircraft primary structures.
- ❑ Industrial equipment such as agitators, robot arms, vessels.
- ❑ Spacecraft, space station components.

APPENDIX E. ACRONYMS

ACT	Advanced Composites Technology
CMC	Ceramic Matrix Composite
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
ERC	Engineering Research Center
FAA	Federal Aviation Administration
FEDRIP	Federal Research in Progress
MITI	Agency of Industrial Science and Technology Council
MMC	Metal Matrix Composite
MTAP	Materials Technology Area Plan
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
NTIS	National Technical Information Service
OIP	Office of Industrial Programs
ONR	Office of Naval Research
OTA	Office of Technology Assessment
PEEK	Polyether-etherketone
PMC	Polymer Matrix Composite
R&T	Research and Technology
RAM	Radar-Absorbing Materials
SDIO	Strategic Defense Initiative Office
STC	Science and Technology Research Centers
VPI&SU	Virginia Polytechnic Institute & State University

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