Metal Matrix Composites (MMC)

Sector Study

An Assessment of the MMC Technology Base, Applications, and Marketplace

August 1993

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NORTH AMERICAN TECHNOLOGY AND INDUSTRIAL BASE ORGANIZATION

Technology Base Enhancement Program

Metal Matrix Composites

Prepared by:
BDM Federal, Inc.

Prepared for:
The North American Defense Industrial Base Organization (NADIBO)

August 30, 1993

Foreword

This report addresses the collection and analysis of technical, market, and policy information related to the world-wide Metal Matrix Composite (MMC) industry sector. The report includes information gathered from a wide variety of sources. Where appropriate, references are cited in the text in superscript format referring to the numerical listing of references presented in Appendix D.

The report was prepared by BDM Federal, Inc. (BDM), 1501 BDM Way, McLean, Virginia 22102 for the U.S. Army Industrial Engineering Activity (IEA); the Productivity Branch, Industrial Base Division, Manufacturing Directorate, Wright Laboratory, Wright Patterson Air Force Base, U.S. Air Force; and the Directorate of Defence Industrial Resources of the Canadian Department of National Defence on behalf of the North American Defense Industrial Base Organization (NADIBO) under contract number DAAA08-91-D-0008. Ed Dorchak managed the MMC sector study. Principal authors were Michael Brown, David Fox, Mel Hafer, Donald Higgins, and Ellen Solos.

The authors would like to express their appreciation to the many individuals throughout the U.S. and Canadian MMC community, from industry and within the U.S. and Canadian governments (see Appendix C) for their cooperation in providing essential information, thus making this effort possible.

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Executive Summary

Introduction

In an era of declining defense budgets, the North American defense industrial base faces the challenges of advancing and maintaining technological superiority with reduced government research and development funding. In response to this challenge, the North American Defense Industrial Base Organization (NADIBO) sponsored the Metal Matrix Composites (MMCs) assessment as a case study to assess the potential for emerging technologies to continue to advance and to remain viable in the current and projected economic environment. This assessment provides a methodology and framework for conducting similar studies in the future and identifies opportunities to enhance the level of joint effort between the U.S. and Canada in creating and sustaining a viable MMC marketplace.

Scope

This study assesses the MMC technology base, detailing production capabilities, process and product technology developments, the current marketplace, and future potential markets and applications. Facilitators and barriers affecting the MMC sector are outlined, and roadmaps of actions designed to enhance MMC development activities and foster joint U.S./Canada activities in this arena are provided.

In the course of this study, government, industry and academic representatives were interviewed and site visits were conducted. Figure EX-1 identifies the types of information gathered. An extensive database of the MMC and composite information was compiled.

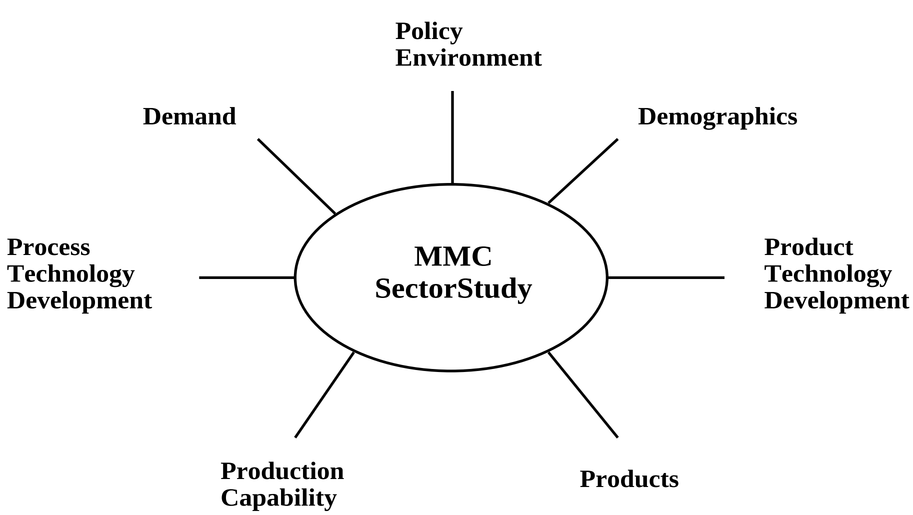

Figure EX-1. MMC Sector Study Scope

The MMC Sector

Currently, there are nine major North American companies supplying MMCs - Duralcan/Alcan, Amercom, DWA, Advanced Composites Materials Corporation (ACMC), Textron, 3M, Alcoa, Lanxide, and Ceramics Kingston Ceramiques (CKC). Table EX-1 presents more detail on the MMC production capability of each company.

Company	Material	Sales Vol/ Year (lbs or units/year)	Production Capability (lbs or units/year)
Duralcan/Alcan	Low Volume Particulate Reinforced Metals	1,000,000 lbs	25,000,000 lbs
Amercom	Boron/Aluminum Graphite Reinforced Metals	400 lbs/Space Shuttle Minimal	3600 sheets (32 in x 122 in) 200,000 units
DWA	Particulate Reinforced Aluminum Graphite Reinforced Metals Monofilament Comps	Proprietary	150,000 lbs 1000 - 5000 lbs 3000 - 5000 lbs
ACMC	Whisker Reinforced Aluminum	Proprietary	150,000 lbs
Textron	Fiber Reinforced Metals	800 lbs 100% T&E	2000 lbs
3M	Fiber Reinforced Metals	Minimal 100% T&E	Minimal
Alcoa	Low Volume Particulate Reinforced Metals High Volume Particulate Reinforced Metals	15,000 lbs 1000 parts	500,000 - 800,000 lbs 10,000 - 30,000 units
Lanxide	Low Volume Particulate Reinforced Metals High Volume Particulate Reinforced Metals Fiber Reinforced Metals		500,000 lbs
CKC	Whisker Reinforced Metals	Minimal 100% T&E	Minimal

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Table EX-1. Domestic MMC Supply Capabilities

The MMC marketplace can be broken down into two distinct areas: continuously reinforced (non-broken filament) and discontinuously reinforced (chopped fibers, particulates or whiskers) MMCs. Continuously reinforced MMCs, which generally have mechanical and physical properties superior to discontinuously reinforced MMCs, have a critical defense demand, but limited commercial demand potential. Discontinuously reinforced MMCs, on the other hand, have both considerable defense and commercial demand potential. Distinctions between continuous and discontinuous MMCs are found in Table EX-2.

Discontinuous	Continuous
■ Property Improvements Over Matrix by <2X	■ Usually Net or Near Net Shape
■ Improved Properties Over Monolithic Alloy (a) good wear resistance (b) high stiffness (c) low toughness (d) low strength	■ Improved Properties Over Monolithic Alloy (a) high toughness (b) high strength (c) high stiffness
■ Tailorable Properties (a) mechanical (b) physical	■ Expensive to Manufacture
■ Lower Cost to Manufacture	■ Tailorable Properties (a) mechanical (b) physical
■ More Reliance on Matrix	■ Requires Accurate Fiber Placement
■ Tailorable CTE	■ Thermal Conductivity/Management Applications
■ Higher Volume % of Reinforcement Utilizes Net Shape Processes	■ Tailorable CTE
■ At Lower Vol % Levels Can Use Conventional Methods to Produce Wrought Products	■ High Temperature Applications
■ Structural Applications Are Generally Reinforced <25% Volume	
■ Maintain Near Design and Fabrication Characteristics of Matrix	

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Table EX-2. Distinctions Between Discontinuous and Continuous MMCs

MMC applications can be broken down into five specific categories: military, aerospace, automotive, commercial, and recreational. The study provides details on the maturity of the applications within these categories - whether it is theoretical, in the prototype phase, or in production. To date, MMC applications are sparse and fragmented. No true high volume applications exist. Table EX-3 lists potential and existing applications of MMCs and the benefits their use provides.

Significant research and development interest worldwide has been generated toward MMCs. Numerous consortia address specific capabilities and potential applications of

MMCs. Both the U.S. and Canada have a complex and interconnected infrastructure to deal with the science and technology base. Numerous government programs are offered by the countries to propel the advanced materials effort forward.

Extensive foreign interest in MMCs, mainly from Europe and Japan, could begin to overtake domestic MMC capabilities. An increasing number of North American producers are being purchased by foreign companies. DWA and ACMC, which both receive Title III funding to develop MMC capabilities, are two examples of former U.S. companies that have been purchased by European and Japanese companies, respectively.

Potential and Existing Applications \ Benefits	Weight Reduction	Wear Resistance	Stiffness	Tailorable Thermal Conductivity	Increased Performance at Elevated Temperatures	Tailorable CTE	Corrosion Resistance	Resistance to Radiation	High Strength
Aircraft Skins	•				•				•
Bearings	•	•					•		•
Bicycle Frames	•		•						•
Boat Masts & Spars	•		•						•
Brake Rotors	•	•							
Electronics Packaging	•			•	•	•		•	
Electronics/Avionics Racks	•			•	•	•			
Engine Cylinder Liners	•	•							
Fastening Equipment in Chemical Environment- Bolts and Screws	•						•		•
Ground Vehicles	•								•
Landing Gear Struts	•		•						•
Medical Implants	•						•		•
Optical/Guidance Systems Structures	•		•	•		•			
Pistons	•	•							
Satellite Antenna Masts	•		•						
Sea Vehicles	•		•				•		
Space Structures	•		•	•				•	
Transmission Components	•	•					•		
Tubing in Nuclear Plants	•						•	•	
Turbine Engine Components	•	•			•				•
Worm Gears	•	•							•

Table EX-3. Applications of MMCs

Significant technology advancement and policy barriers affect the MMC area, as defined in Table EX-4. Technology advancement barriers generally impede the use of MMCs more widely in new applications and in product improvements to existing applications either due to lack of knowledge or confidence in MMCs or due to present limitations of MMCs. Policy barriers generally are economic disincentives which drive corporate decisions to invest either alone or cooperatively with other MMC participants.

Facilitators that could prove of great benefit in advancing the MMC industry include the number of current and proposed U.S. policy initiatives and programs geared towards offering industry many incentives to becoming more involved in R&D activities, with emphasis on stimulating R&D partnerships, promoting technology transfer, and pushing dual use products. In regard to joint U.S./Canada efforts, the two nations have a number (approximately 2500) of agreements and programs in place to foster cooperative arrangements in the science and technology arena.

Technology Advancement Barriers	Policy Barriers
Cost	Large Capital Investment Required; Lack of Investment Incentives
Lack of Commercial Applications	MMC Producers' Profit Margin Considerations
Lack of Standardized Test Procedures	Government's R&D Focus on Technology Path
Lack of Reliable Analytical Modeling Techniques	Long Incubation Time Between Need Identification and Product Commercialization
Lack of Widely Accessed MMC Material Techniques	Government Policies and Regulations
Lack of Federal and Industry Standards	Lack of a Cohesive Planning Process
CTE Mismatch Between Matrix and Reinforcement	Intellectual Property Rights Concerns
Lack of Nondestructive Evaluation Techniques	Protection of Proprietary Information
Lack of Repair Techniques	Import Controls
Lack of Recycling Techniques	Transmission of Classified Data

Table EX-4. MMC Advancement Barriers

Goals

Four goals for advancing MMC technology to support industrial base needs through joint efforts were identified:

1) Lower the cost of producing and using MMCs;
2) Improve communications between government, industry, and academia;
3) Improve the commercial viability and increase the commercial demand for MMCs; and
4) Strive to overcome the technical shortcomings of MMCs.

Recommendations

Recommendations designed to assist in fulfilling these goals are divided into two groups - general advancement recommendations, which are geared towards policy initiatives and apply broadly to all technology base advancement activities, and specific recommendations, which emphasize specific MMC technology plans. Figure EX-2 presents a roadmap with short and long term target recommendations to achieve general advancement strategies. These recommendations are organized under three strategies. Strategy One is to improve the economic viability associated with advancing new technologies. Strategy Two entails improving communications between government, industry, and academia. Strategy Three involves improving MMC awareness and capabilities through improved education.

Figure EX-3 presents a roadmap of specific technology recommendations separated into five discrete strategies. The five strategies are to: 1) create a low cost MMC insertion program for automotive applications, 2) develop a program to create military retrofit applications for MMCs, 3) develop a program to improve secondary processing techniques for MMCs, 4) improve production techniques for continuous MMCs, and 5) broaden the scope and improve the existing MMC design, analysis, and test techniques.

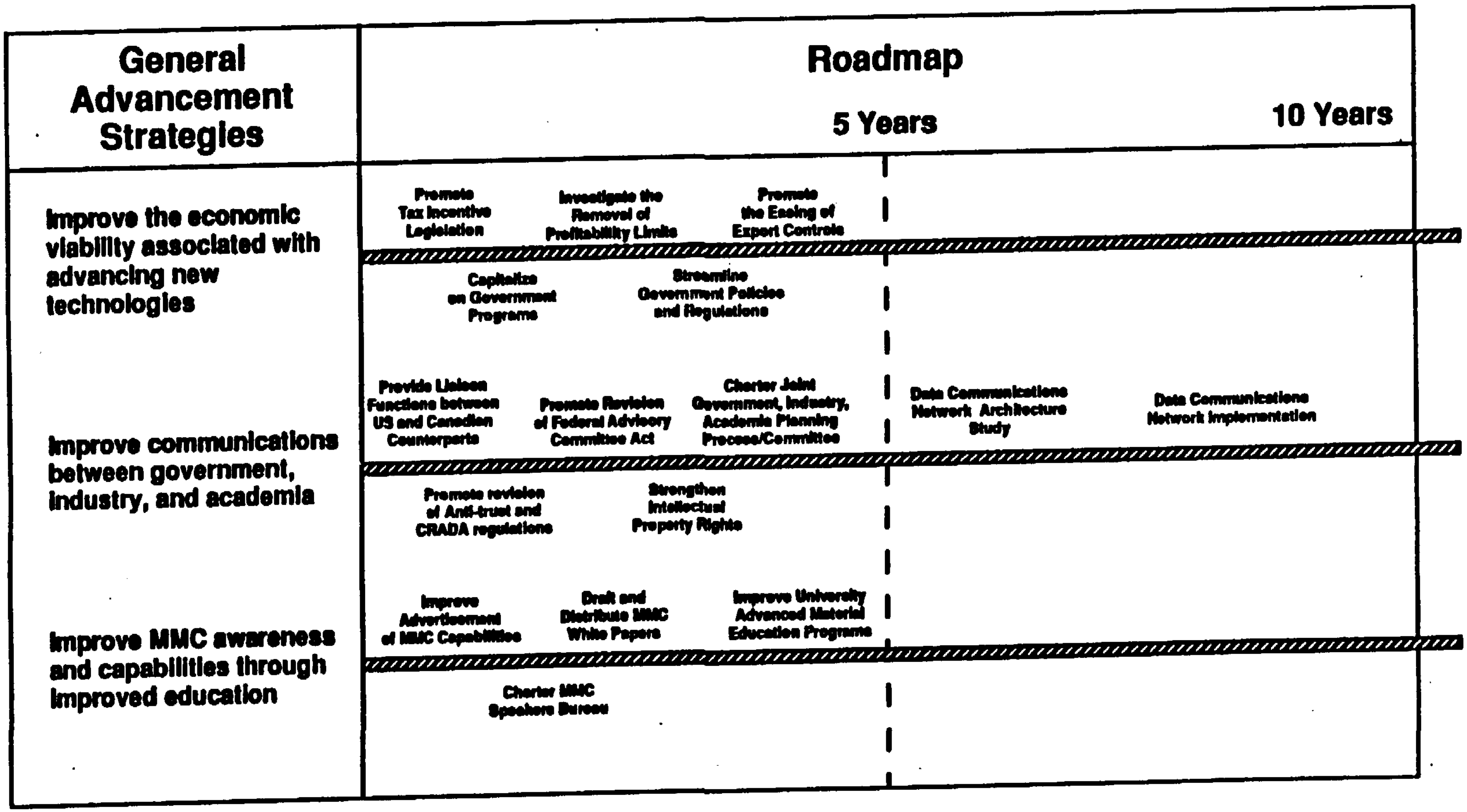

Figure EX-2. Roadmap of General Advancement Strategies for NADIBO Consideration

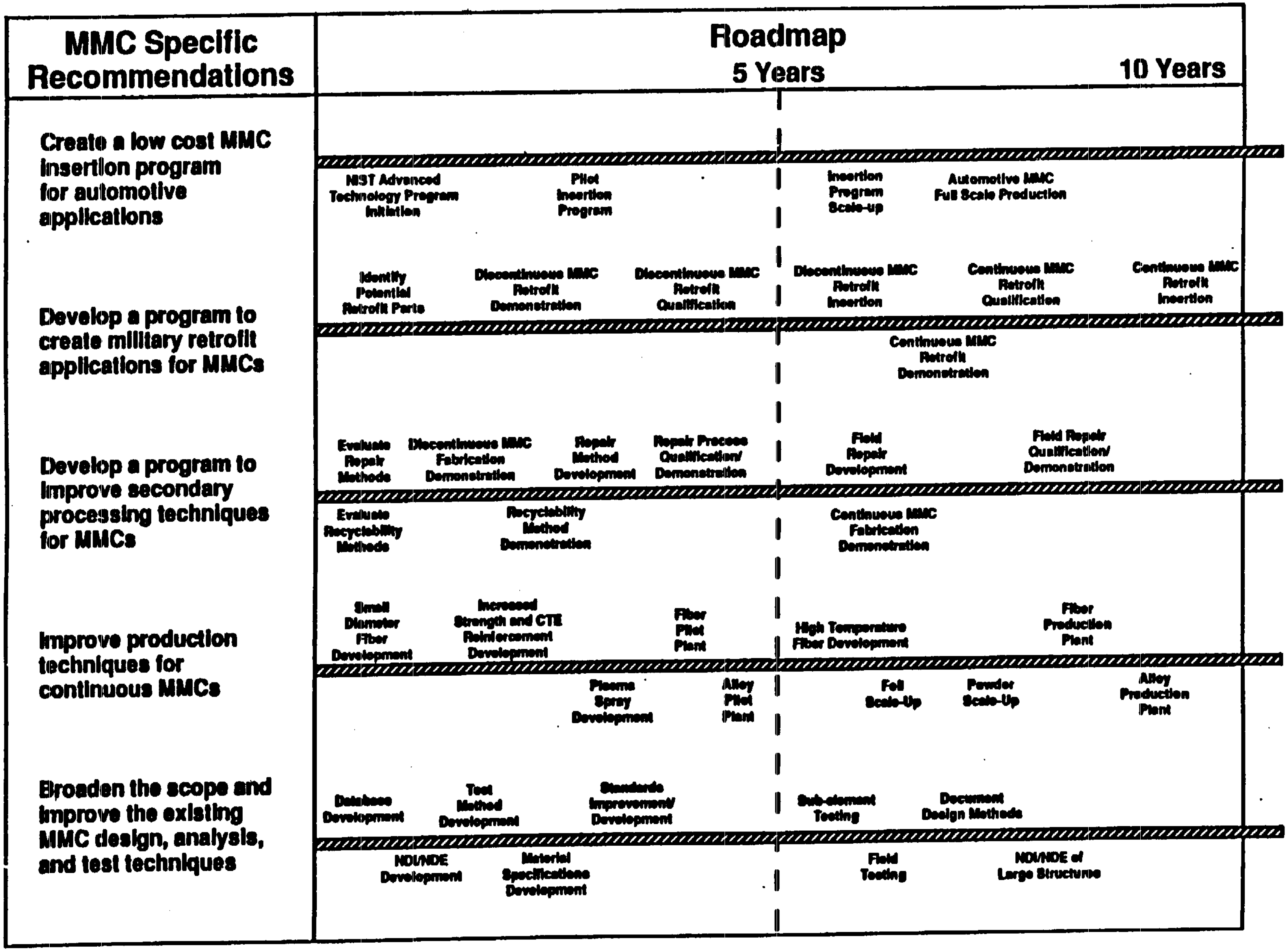

Figure EX-3. Roadmap of Specific Recommendations for NADIBO Consideration

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1.0 Purpose

In an era of declining defense budgets, the North American defense industrial base faces the challenges of advancing and maintaining technological superiority with reduced government research and development funding. Meeting this challenge requires the implementation of three fundamental strategies: leveraging and promoting commercial use and investment in technologies which will have both defense and industrial applications and broadening of the industrial base to include both U.S. and Canadian resources so that investment costs may be shared across a broader base. These challenges apply across all of the technologies cited in the U.S. Department of Defense's (DOD) Critical Technologies List and comparable Canadian documents.

The North American Defense Industrial Base Organization (NADIBO) is chartered to foster cooperative planning and defense industrial base program development between the U.S. and Canada. In order to address the challenges discussed above, the Organization embarked on an effort to exploit a mission driven technology of mutual interest to both countries, where both countries have a joint capability, ideally of a complementary nature. In accomplishing this objective, the study group furthered refined this objective by citing the need to assess the potential for technology sectors to continue to advance and to remain viable in the current and projected economic environment and to enhance the level of joint effort in creating and sustaining this viable marketplace. The purpose of this effort is to identify those actions needed to create a market environment in which technological advances are supported and encouraged by commercial demand and there is significant participation within the marketplace by both U.S. and Canadian organizations. The metal matrix composites (MMC) technology was selected as a case study to determine opportunities for improvement and to develop a methodology and framework for conducting similar studies in the future.

2.0 Objectives and Report Structure

The study assesses the MMC technology base, detailing production capabilities, process and product technology developments, the current marketplace and future potential markets and applications. Facilitators and barriers affecting the MMC sector will be determined, including policy/regulatory implications and industry specific areas. This analysis involves a comprehensive review of civilian and military markets, addressing demographics, products (both military and commercial applications), demand, and potential dual use products/applications. Specific points that will be addressed include:

- Identifying relationships between MMC products and end users (commercial and defense),

- Identifying technological issues inhibiting the development and/or commercialization of MMCs,

- Identifying the infrastructure available to support MMC development and the mechanisms by which the infrastructure will affect MMCs,

- Identifying barriers to MMC development:
  - within the U.S.
  - within Canada
  - jointly between the U.S. and Canada

- Developing a roadmap of actions which will enhance MMC development activities and foster joint U.S./Canada activities in MMC development and commercialization, and

- Distinguishing between MMC-specific and general technology development issues and use as a model for other assessments.

From the analysis, a joint government/industry plan of action will be developed, highlighting specific recommendations aimed at enhancing joint activities and overcoming identified barriers. These recommendations will be forwarded to the NADIBO Steering Group for consideration and action.

3.0 Scope

This study entails the collection and analysis of technical, business and policy information related to MMC research and production capabilities in both the U.S. and Canada. Two distinct MMC materials were addressed: continuously reinforced (non broken filament) and discontinuously reinforced (chopped fibers, particulates or whiskers).

4.0 Background

4.1 Programmatic Background[76, 111, 95]

The NADIBO established the Technology Base Enhancement Working Group (TBEWG), consisting of members from the U.S. Army Industrial Engineering Activity; the Productivity Branch, Industrial Base Division, Manufacturing Directorate, Wright Laboratory, Wright Patterson Air Force Base, U.S. Air Force; and the Directorate of Defence Industrial Resources of the Canadian Department of National Defence, to explore the potential for joint activity in the application of critical technologies to the North American Defense Industrial Base (NADIB). In March 1991, the NADIBO Policy Committee sponsored a Critical Technologies Rationalization Workshop at the Defense

Systems Management College to define whether it was feasible to undertake an integrated critical technology program which exploits a mission driven technology of mutual interest with a joint capability, ideally of a complementary nature.

During this Workshop, participants assessed relevant U.S. and Canadian documents on critical technologies. They began by reviewing the DOD critical technologies list and a similar document from Canada. These areas were explored with technical experts until the areas of concern were narrowed down to a list of four technology areas: Advanced Materials, Flexible Manufacturing, Passive Sensors, and NBC Protection. Further research led to the identification of four or five sub-technologies embedded in each major technology area.

A survey soliciting "expert" opinions from industry, government, and academia was conducted to rank the sub-technologies. Approximately 200 surveys were sent out within the U.S. and Canada. Initial survey selection pointed to two sub-technologies - MMCs and Infrared/Electro Optic sensors.

Subsequent evaluation led to the selection of MMCs as the best candidate for the initial sector study. A detailed briefing describing the evaluation process that was involved in choosing MMCs is included as Appendix G. MMCs were chosen because:

- they could be used in a broad range of military applications,
- they have several potential commercial applications,
- they are being developed in both the U.S. and Canada,
- they constitute a definable and manageable business area, and
- they provide a promising investment window for investing small amounts of industrial base funds to leverage significant changes in the industry.

The NADIBO Steering Group gave approval for conducting the MMC feasibility study at the August 1991 Steering Group meeting. The study was officially kicked off in January 1993.

4.2 MMCs in the Context of North American National Security Objectives

The Department of Defense (DOD) continues to emphasize science and technology development as essential to achieve significant improvements in war fighting capability and to maintain battlefield advantage. At the core of this strategy are seven thrusts that focus the science and technology program to address the users' most pressing military and operational requirements:

- Global Surveillance and Communications,
- Precision Strike,
- Air Superiority and Defense,
- Sea Control and Undersea Superiority,
- Advanced Land Combat,

- Synthetic Environments, and
- Technology for Affordability.

Eleven key technology areas have been determined to be essential to achieving these science and technology objectives. Materials and Processes is one of these 11 technology areas. This area is described as the development of man-made materials (e.g., composites, electronic and photonic materials, smart materials) for improved structures, higher temperature engines, signature reduction, and electronic systems, and the synthesis and processing required for their application. Materials and processes were deemed to be very important to achieving the goals set forth in almost all of the seven thrust areas. Advanced materials have been recognized as being critical to maintaining the international competitiveness of U.S. manufacturing industries by the Office of Science and Technology Policy, the U.S. Departments of Commerce, Defense and Energy, as well as the National Center for Advanced Technology, the Aerospace Industries Association, and the Council on Competitiveness.[38, 47]

Canada has also developed a research and development strategic plan geared towards addressing the priority needs of the Canadian Forces. These defense needs include surveillance, verification, command and control, communications, information gathering and interpretation, versatility/flexibility, mobility, human protection, survivability/vulnerability, minimize O&M costs, training and simulation, and firepower. Materials were deemed a key technology in this plan. The area of materials and design and manufacturing technologies was judged as one of four pervasive technology focuses that will have the greatest impact on Canadian Forces operational capabilities during the next 20 years.[46, 334]

Composite materials are used in defense applications for their high strength, low weight, and, in some instances, the ability to withstand high temperatures. These materials hold significant promise for improving weapon performance, design, and affordability. They are becoming increasingly important to the design and manufacture of present and future military systems. Composite materials are recognized as the enabling technology essential for fulfilling demanding thermal management, structural, and mechanical requirements in advanced gas turbines, deep submergence vehicles, and spacecraft. They will be needed in making future systems more effective in a wide spectrum of vehicle structures, including high-temperature propulsion systems, hypervelocity vehicles, and short vertical take-off and landing vehicles, as well as for spacecraft, protection against directed energy threats, and advanced hull superstructures and forms and submarine structures.[4]

5.0 Methodology

To conduct the Metal Matrix Composite technology study, a clear, concise and well defined methodology was required to effectively survey the industry and develop an objective view of the entire MMC sector, including military, commercial, foreign, political and academic perspectives. At a macro level, the methodology consisted of information source identification, data collection and data analysis. This section discusses each of these areas, the specific objectives and goals of each step of the methodology, and how each step was executed. Figure 5-1 provides a mapping of the inputs and outputs for each step of the methodology as well as the associated information flow.

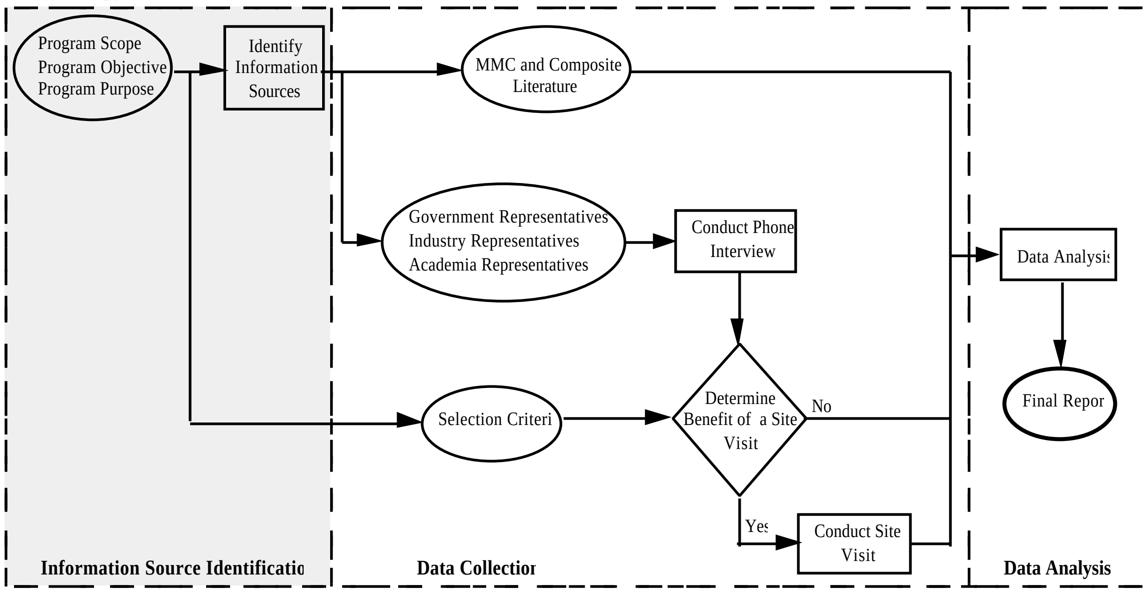

Figure 5-1. Methodology

The methodology developed for this study provides a framework for future technology base enhancement studies, or technology sector studies. Traditional sector studies focus on established industries or technologies where the goal is to conduct a comprehensive assessment of the industrial base supporting a specific industry or technology. For this study there was no established industrial base or industry; the goal was to develop recommendations to help advance the development and establishment of an industrial base.

5.1 Identification of Information Sources

The information sources available for emerging technologies, in particular MMCs, are numerous and varied. Few companies have an established market for MMCs. Many companies and research facilities are active in the technology because of the open marketplace and potential to establish a market niche as the market develops. To identify information sources for this study, the goal was to address all aspects of the market including MMC production, research, use, and regulations. As the technology advances and industry leaders are established, many of the players currently active in MMC technology will vanish. An attempt was made to assess who the key players are today and who will be the key players in the future in order to focus the data collection on those information sources that best reflect where the technology is heading. The identification of key players was based on a company's current and past levels of investment in MMCs, existing MMC markets, funding levels for current government MMC programs, and input from identified industry experts.

The information supporting this study was drawn from past reports on MMCs and general composites, journal articles, and discussions with U.S. and Canadian representatives from industry, academia, and government. Appendix C and D contain a point of contact data base and a material database, respectively, noting the information sources used for this study.

5.2 Data Collection

The data collection process consisted of:

1) review and analysis of documents discussing MMCs;
2) review and analysis of policy and regulatory documents influencing material development, production, and use; and
3) interviews, both in-person and over the phone, of industry, government and academic representatives.

Past documents gave the necessary history and background of the technology to provide an understanding of how the technology has progressed to date as well as some insight into where the technology is heading. In addition, this material served as a source for identifying points of contact within the industry. Numerous policies and regulations were reviewed to understand what role domestic and foreign governments may take in the development of this emerging technology. The focus of the data collection process was extensive interviewing of industry, government and academic personnel directly influencing MMCs. Due to the large number of players active in the MMC arena, selection criteria were required to narrow the number of in-person interviews to be conducted.

5.2.1 Site Visit Selection

The site visit selection process provided a systematic approach for identifying representatives to contact. The first factor for determining MMC representatives to visit was to meet with a broad spectrum of the MMC industry. This required visits to representatives from academia, industry and government. Sites selected included active MMC representatives from each of these areas in the U.S. and in Canada.

Certain key industry representatives were selected to visit because of their extensive knowledge and background of the technology. Referrals were used to identify these companies and individuals. Additional selection criteria used to select other site visits included size of operation, geography (location), specific knowledge (e.g., standards, thermal applications, production capabilities), availability and willingness to talk, U.S./Canadian interaction, military relevance, cooperative activities (e.g., academia, other companies) and diversity of products, production approach, and R&D. A complete listing of the selection criteria considered in selecting sites to visit is included in Appendix E.

5.2.2 Site Visits

Site visits were conducted in four regional trips: Canada, Southwest, Southeast, and the Northeast. Prior to each regional trip phone interviews were conducted with identified representatives from the region. The phone interviews served four functions:

1) Identification of sites not included on the trip itinerary that should be included,
2) Identification of sites included on the trip itinerary that should not be included,
3) Execution of extensive phone interviews with sites not included on the trip, and
4) Collection of background information from sites scheduled to be visited.

The first two functions support the site selection process of the data collection, the third function supports the phone interview process of data collection, and the final function supports the site visit process of data collection.

The phone interviews conducted as part of the site selection process provided background information for each site visit. The background information identified specific MMC-related areas of activity that an organization was involved in, information the organization could provide, and information/knowledge to be obtained during a site visit. A program overview and survey questionnaire were forwarded to each site prior to a visit to provide organizations with an understanding of the MMC sector study and the type of information being sought.

Site visits began by providing site personnel with an overview of the MMC study and information on how and why the NADIBO selected this technology to study; the goals, objectives and scope of the MMC study; the current status of the MMC study; and the basic goal or objective of the site visit. The objective of each visit was to gather specific information related to the organization's activities in the MMC industry and to solicit opinions on what barriers impeded industry advancement and what steps could facilitate industry advancement. Information and opinions were collected either through open conversation, direct presentation by the representative, or direct review of the survey questionnaire.

5.2.3 Phone Interviews

When it was determined that an industry, university or government representative was not to be included on a site visit, a more extensive phone interview was conducted. A detailed questionnaire was developed, based on the selection criteria, to ensure all necessary information was collected from each phone interview. If representatives were unwilling to complete the questionnaire over the phone, the questionnaire was faxed to the representative to allow them to complete it at their convenience. An approximate 50 percent response rate was experienced with phone interviews. Two of the prominent factors contributing to a representative's unwillingness to either participate in the phone interview or to complete the questionnaire were time and unwillingness to release proprietary data.

Appendix C lists the MMC representatives contacted over the course of the study. In addition, the listing notes whether site visits were conducted or if extended phone interviews were employed.

5.3 Data Analysis

As papers, questionnaires, regulations, and journal articles were received, they were reviewed for relevance and referenced in the materials data base. The material data base contains a comprehensive listing of the material used in preparing this report. All relevant material was thoroughly reviewed and analyzed in relation to other collected material and knowledge gained through phone screens and site visits.

Because MMCs are an emerging technology, numerous existing and potential players are looking to advance their standing in the developing marketplace. The perspective and origin of all material gathered from industry and academia was key to maintaining an objective view of the industry and generating unbiased recommendations.

As data were collected from relevant documents, site visits, and phone interviews, the data was analyzed and incorporated into a report. The report functioned as a working document throughout the data collection phase of this study.

6.0 Technical Description of the MMC Sector

The following section presents a technical description of the Metal Matrix Composite (MMC) sector. It includes a MMC definition, MMC components, MMC production methods, areas of application, and MMC research and development. Section 6.1 presents discussions on MMCs in general. Sections 6.2 and 6.3 present detailed discussions on the two types of MMCs that parallel the discussion in Section 6.1.

6.1 MMC Definition

MMCs are a manufactured combination of at least two distinctly different materials. The composite consists of a metal matrix reinforced with particulates, flakes, whiskers, continuous fibers, filaments, wires, or layered or woven continuous fibers (Figure 6-1). It is formed through processes utilizing a variety of matrix and reinforcement combinations (Figure 6-2). Principal composite advantages are tailored physical properties and improved mechanical properties, usually at less weight than conventional metals. Since most reinforcements have a relatively high melting point, these advantages of MMCs over other composites and monolithic metal alloys are quite noticeable at higher temperatures. Additionally, since MMCs are metal based, electrical and thermal conductivity modifications also can be realized.

6.1.1 MMC Components

The metal matrix is a specific metal or metal alloy. The matrix serves as the binder to hold the reinforcement together and to distribute the improved properties, attained via the reinforcement, uniformly or in a specified direction. The total dependency of the composite upon the matrix varies with the combination of matrix and reinforcement type, as well as the combining process used.

The addition of reinforcement to the metal matrix improves the physical and mechanical properties over the monolithic matrix. Reinforcements differ in their chemical composition and structure, with a clear distinction in their properties and fabrication methods (Figure 6-3). Reinforcements used in MMCs range from ceramics to graphite and carbon to metals. They come in three general forms: particulates (or particles) with a length to diameter ratio of about 1; chopped fibers or whiskers, with an L/D of about 50; and continuous fibers, with an L/D of greater than 1000. As stand-alone materials, they exhibit both positive properties (for instance, the high elastic modulus of ceramics and graphite) and negative properties (such as the brittleness of ceramics). In MMCs, the negative properties are counteracted by the matrix material.

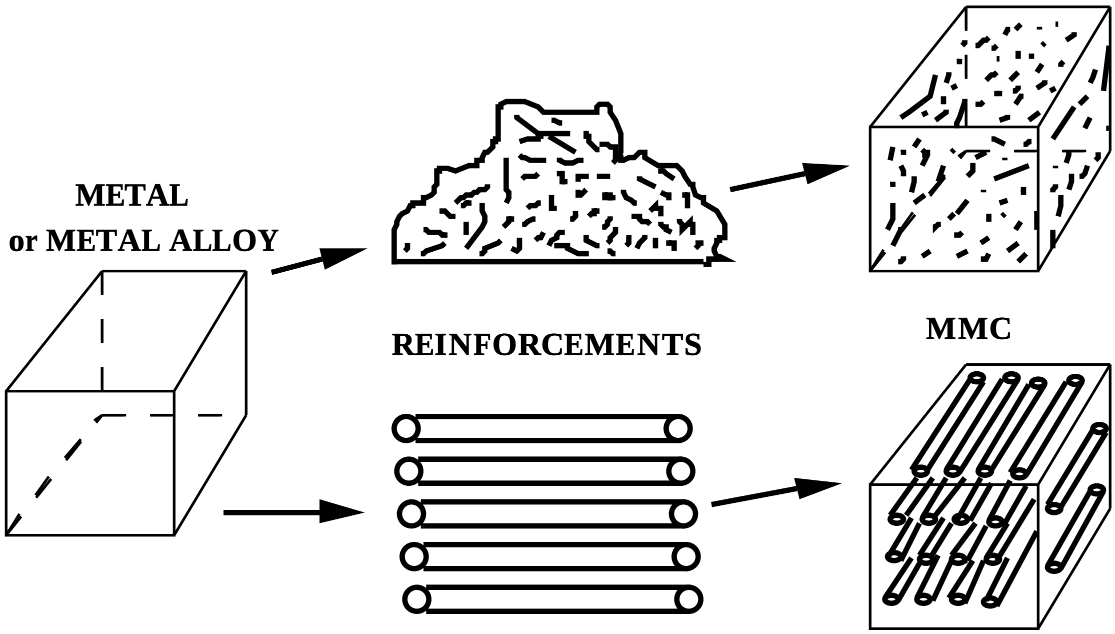

Figure 6-1. MMC Definition

MATRICES \ REINFORCEMENTS	Al2O3	Alumina/Silica	Boron	Graphite	Molybdenum	Niobium	Silicon Carbide	Si3N4	Steel	Titanium	TiB2	TiC	Tungsten	Yttrium	Zr
Aluminum	•	•	•	•			•	•				•		•	•
Berylides		•				•	•	•		•	•	•		•	•
Copper				•			•				•		•		
Iron									•						
Iron Aluminides						•	•			•	•			•	•
Lead	•									•					
Magnesium	•			•				•							
Nickel Aluminides		•				•	•	•		•	•	•		•	•
Superalloys					•	•			•				•		
Titanium				•			•			•	•	•			
Titanium Aluminides		•				•	•	•		•	•	•		•	•

Figure 6-2. Matrix/Reinforcement Combinations

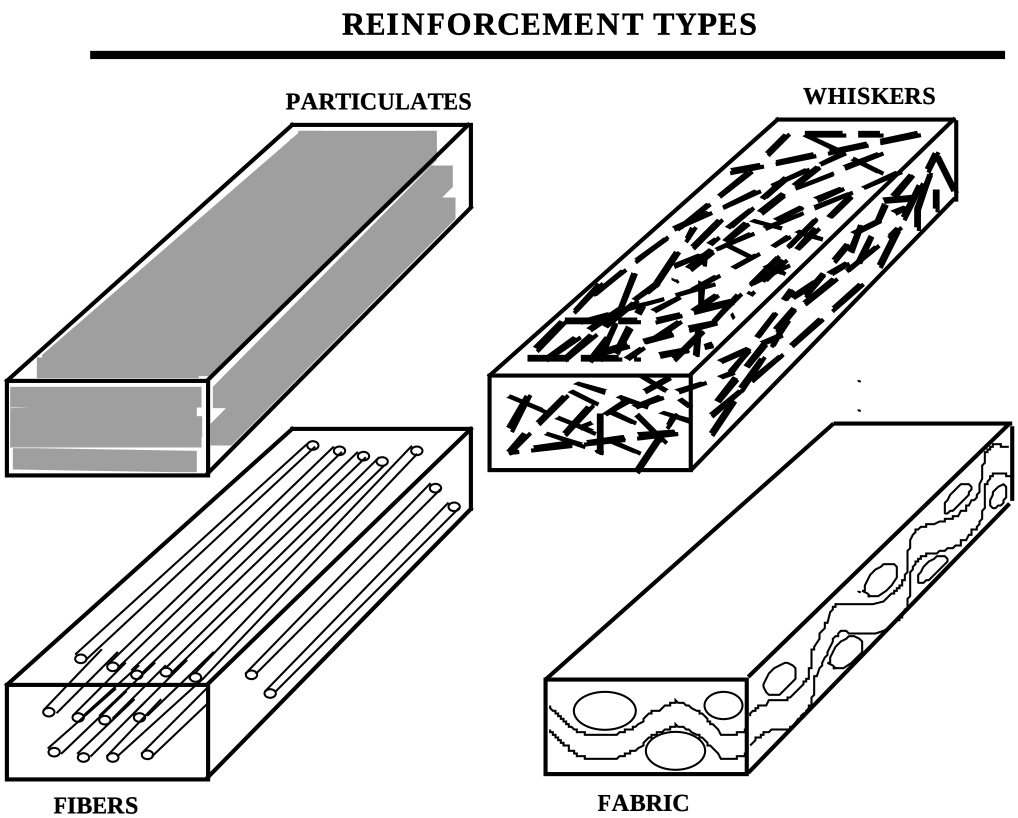

Figure 6-3. Reinforcement Types

The wide selection of matrices and reinforcements permits the development of application tailored MMCs. For example, reinforcing aluminum with a ceramic fiber can increase strength and stiffness 300 percent with essentially no change in weight. Although aluminum loses most of its strength at 600° Fahrenheit, reinforced aluminum can retain 90 percent of its room temperature strength at the elevated temperature.

In another example, aircraft electronic packaging components require a low coefficient of thermal expansion (CTE), high thermal conductivity (TC), and low density; except for beryllium, no metals have all three properties. Since beryllium is very expensive and is toxic, MMCs are a viable alternative. By combining ultra-high modulus graphite fibers with aluminum, a composite can be manufactured to meet these three requirements simultaneously.

DISCONTINUOUS MMCs PHYSICAL and MECHANICAL PROPERTY DATA							
MMC	**Ultimate Strength**	**Yield Strength**	**Density (lb/in.^3)**	**CTE (ppm/°F)**	**Youngs Modulus**	**Elongation Percentage**	**Company**
2124-T6 Al/SiCp 30% Optical Grade			0.105	6.9	17 Msi		ACMC
2124-T6 Al/SiCp 30% Optical Grade			0.107	6	21 Msi		ACMC
2009 AL/SiCw 15% sheet	Length 88 Ksi	Length 64 Ksi	0.102			3.3	ACMC
X2080-T4 Al/SiCp 15%	70 Ksi	53 Ksi	0.102		14.5 Msi	7.5	Alcoa
X2080-T6 Al/SiCp 15%	75 Ksi	62 Ksi	0.102		14.5 Msi	4	Alcoa
X2080-T8 Al/SiCp 15%	79 KSi	75 Ksi	0.102		14.5 Msi	4	Alcoa
X2080-T4 Al/SiCp 20%	75 Ksi	57 Ksi	0.1028		16 Msi	6	Alcoa
X2080-T6 Al/SiCp 20%	78 Ksi	66 Ksi	0.1028		16 Msi	4	Alcoa
X2080-T8 Al/SiCp 20%	81 Ksi	78 Ksi	0.1028		16 Msi	2	Alcoa
Comral-85 (6061 Al/Al2O3 20% p)	47 Ksi	44.2 Ksi			12.3 Msi	3.4	Commonwealth Aluminum Technologies
Al/SiC-T6 10% Permanent Mold	49 Ksi	44 Ksi	0.0979	13.7	12.5 Msi	1.2	Duralcan
Al/SiC-T6 20% Permanent Mold	52 Ksi	49 Ksi	0.0999	11.7	14.3 Msi	0.4	Duralcan
Al/SiC 15% Sand Cast	48 Ksi	46 Ksi	0.0986	9.9	13.4 Msi	0.3	Duralcan
Al/SiC 20% Sand Cast	51 Ksi	49 Ksi	0.0996	9.1	14.0 Msi	0.7	Duralcan
2014 Al/SiCp 50%	83 Ksi	72 Ksi			23 Msi		DWA Composites
6092 Al/SiCp 40%	82 Ksi	75 Ksi		6.7	20 Msi		DWA Composites
7001 Al/SiCp 30%	110 Ksi	98 Ksi		7.8	18 Msi		DWA Composites
6091 Alloy Al/SiCp 15%	62.5 Ksi	57 Ksi			13.5 Msi	5.5	DWA Composites
6091 Alloy Al/SiCp 20%	65 Ksi	57.5 Ksi			15 Msi	4.1	DWA Composites
6091 Alloy Al/SiCp 25%	70 Ksi	58.5 Ksi			16.5 Msi	3.8	DWA Composites
6091 Alloy Al/SiCp 30%	72 Ksi	59 Ksi			17.5 Msi	3	DWA Composites
6091 Alloy Al/SiCp 40%	78 Ksi	62.5 Ksi			20 Msi	1.9	DWA Composites
Al-Si-Mg/SiCp 70%	32 Ksi		0.1084	3.4	38 Ksi		Lanxide
Al/Al2O3 45%	65 Ksi		0.1156	8.3	22.5 Ksi		Lanxide

Figure 6-4. MMC Numerical Properties

6.1.2 Classification of MMCs

There are two distinct classifications for MMCs - discontinuous and continuous. This classification is based on the reinforcement length-to-diameter ratio. Continuously reinforced MMCs have reinforcements with a large length-to-diameter ratio (i.e., a non-broken filament). Discontinuously reinforced MMCs have reinforcements with a small length-to-diameter ratio (i.e., chopped fibers, particulates, or whiskers). Continuously reinforced MMCs generally have mechanical and physical properties superior to discontinuously reinforced MMCs.

The type and percentage of reinforcement determines virtually every aspect of the composite, including the mechanical properties, the composite cost, and the approach and cost of manufacturing. In general, property improvement and cost increase as the length to diameter ratio increases. The ability to process the composite works in the opposite direction. Particulate MMCs are more easily produced than whisker MMCs, which are more easily produced than fibrous MMCs.[397]

6.1.3 MMC Properties

Properties of continuous MMCs are dependent on fiber direction and layup within the matrix. This allows for tailoring of specific properties in specific directions. The highest values for strength and modulus are obtained when the reinforcing fibers are straight and parallel. Properties parallel to the fiber direction reflect fiber characteristics, while those perpendicular to the fiber are dominated by the metal matrix.

The class of discontinuously reinforced MMCs has received considerable attention. This attention results from the availability of reinforcements at competitive costs, the successful development of manufacturing processes to produce the MMCs, and the availability of standard or near standard metal working methods that can be used to form the MMCs. In discontinuous MMCs, the reinforcing materials are usually homogeneously distributed within the metal matrix. In applications not requiring extreme loading or thermal environments, such as in automotive components, discontinuously reinforced MMCs have been demonstrated to offer essentially isotropic (having equal properties in all directions) properties with substantial improvements in strength and stiffness relative to those with unreinforced metals.

Figure 6-4 presents specific properties associated with currently manufactured MMCs and includes the manufacturer, MMC composition, and mechanical and physical properties. The data presented was obtained from individual company literature. Figure 6-5 presents a qualitative comparison of properties between discontinuously and continuously reinforced MMCs.

Discontinuous	Continuous
Property Improvements Over Matrix by <2X	Usually Net or Near Net Shape
Improved Properties Over Monolithic Alloy (a) good wear resistance (b) high stiffness (c) low toughness (d) low strength	Improved Properties Over Monolithic Alloy (a) high toughness (b) high strength (c) high stiffness
Tailorable Properties (a) mechanical (b) physical	Expensive to Manufacture
Lower Cost to Manufacture	Tailorable Properties (a) mechanical (b) physical
More Reliance on Matrix	Requires Accurate Fiber Placement
Tailorable CTE	Thermal Conductivity/Management Applications
Higher Volume % of Reinforcement Utilizes Net Shape Processes	Tailorable CTE
At Lower Vol % Levels Can Use Conventional Methods to Produce Wrought Products	High Temperature Applications
Structural Applications Are Generally Reinforced <25% Volume	
Maintain Near Design and Fabrication Characteristics of Matrix	

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Figure 6-5. Qualitative Comparison of Discontinuous and Continuous MMC Properties

6.1.4 MMC Life Cycle

The MMC life cycle can be broken down into four generic stages (Figure 6-6). Raw materials are developed, then combined to create the MMC. The MMC is then secondarily fabricated (or machined) and implemented into an application. The following paragraphs discuss these four stages. Section 6.1.4.1 discusses stages 1 and 2, which result in an output of MMC material. As discussed below, Figures 6-7 amd 6-8 describe the organization and relationships between raw materials and MMC materials. Section 6.1.4.2 discusses stages 3 and 4, in which MMC materials are fabricated to produce user applications. Figures 6-9 and 6-10 extend the previous taxonomies to trace the relationship to the end user application.

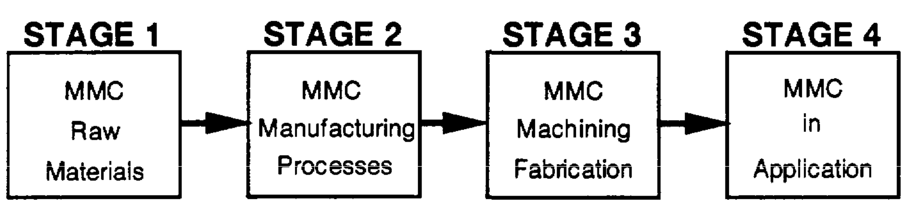

Figure 6-6. The MMC Life Cycle

METAL MATRIX RAW MATERIAL TAXONOMY GROUP A

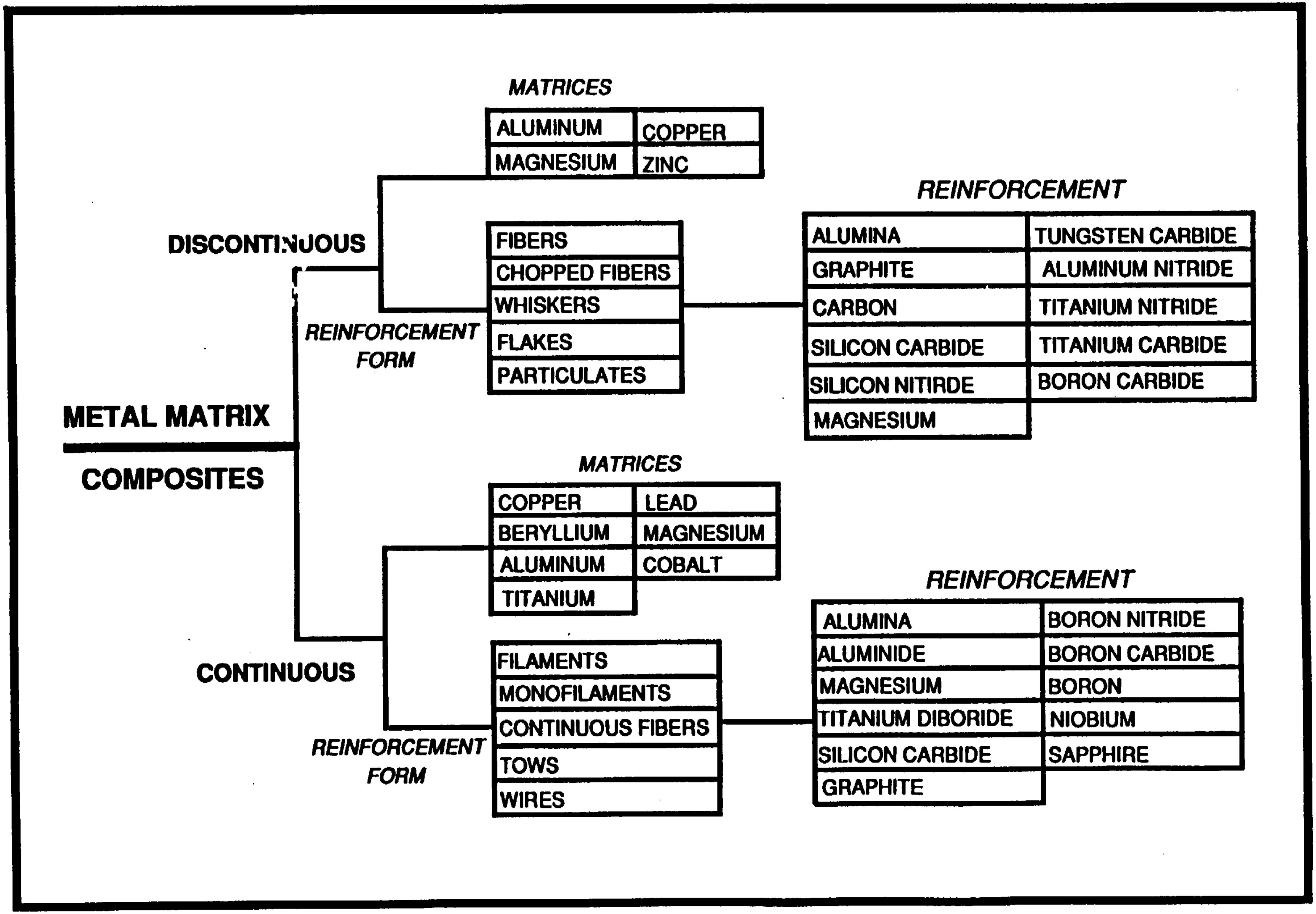

Figure 6-7. Metal Matrix Raw Material Manufacturing Taxonomy Group A

METAL MATRIX RAW MATERIAL MANUFACTURING TAXONOMY GROUP B

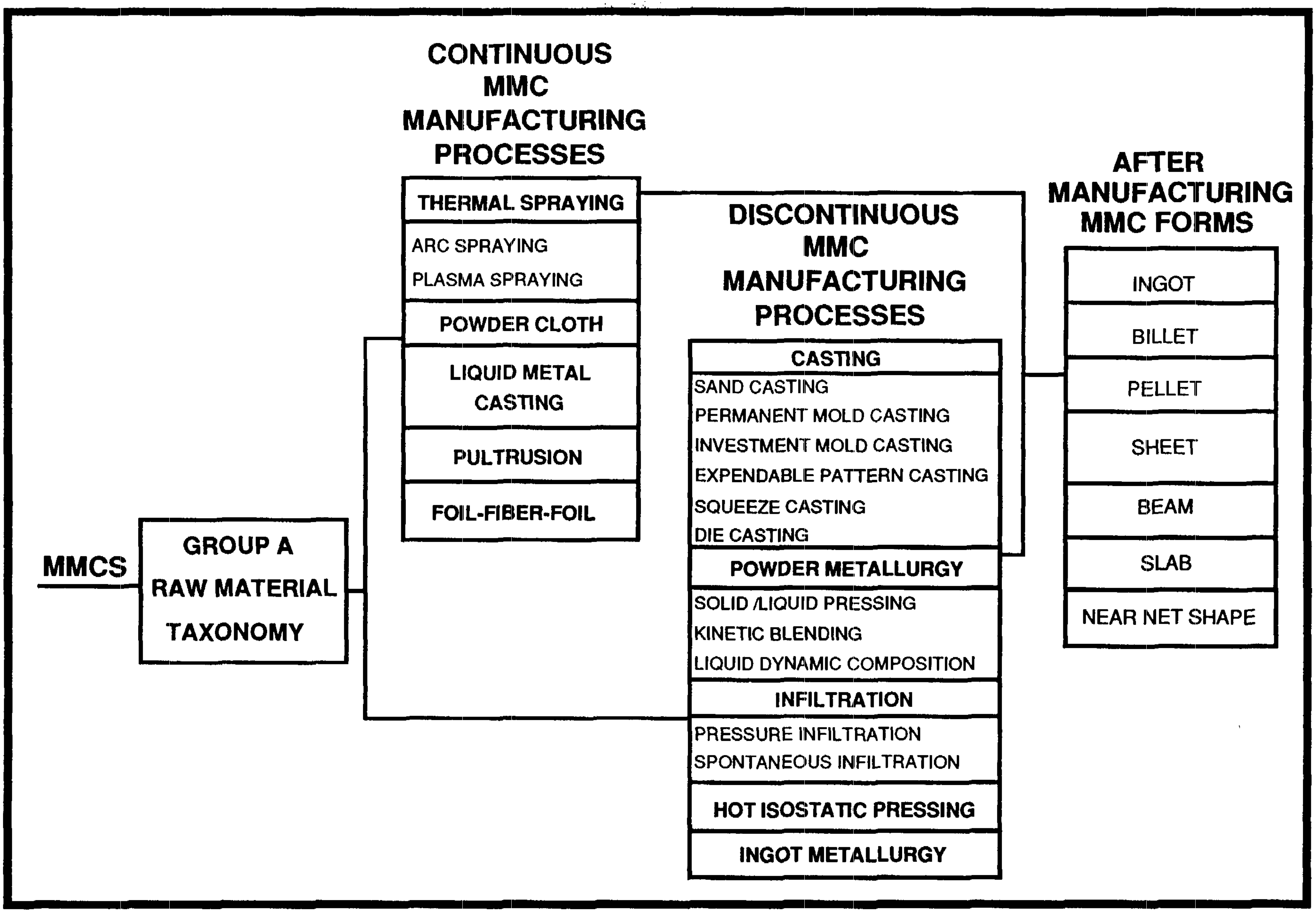

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Figure 6-8. Metal Matrix Raw Material Manufacturing Taxonomy Group B

METAL MATRIX SECONDARY FABRICATION TAXONOMY GROUP C

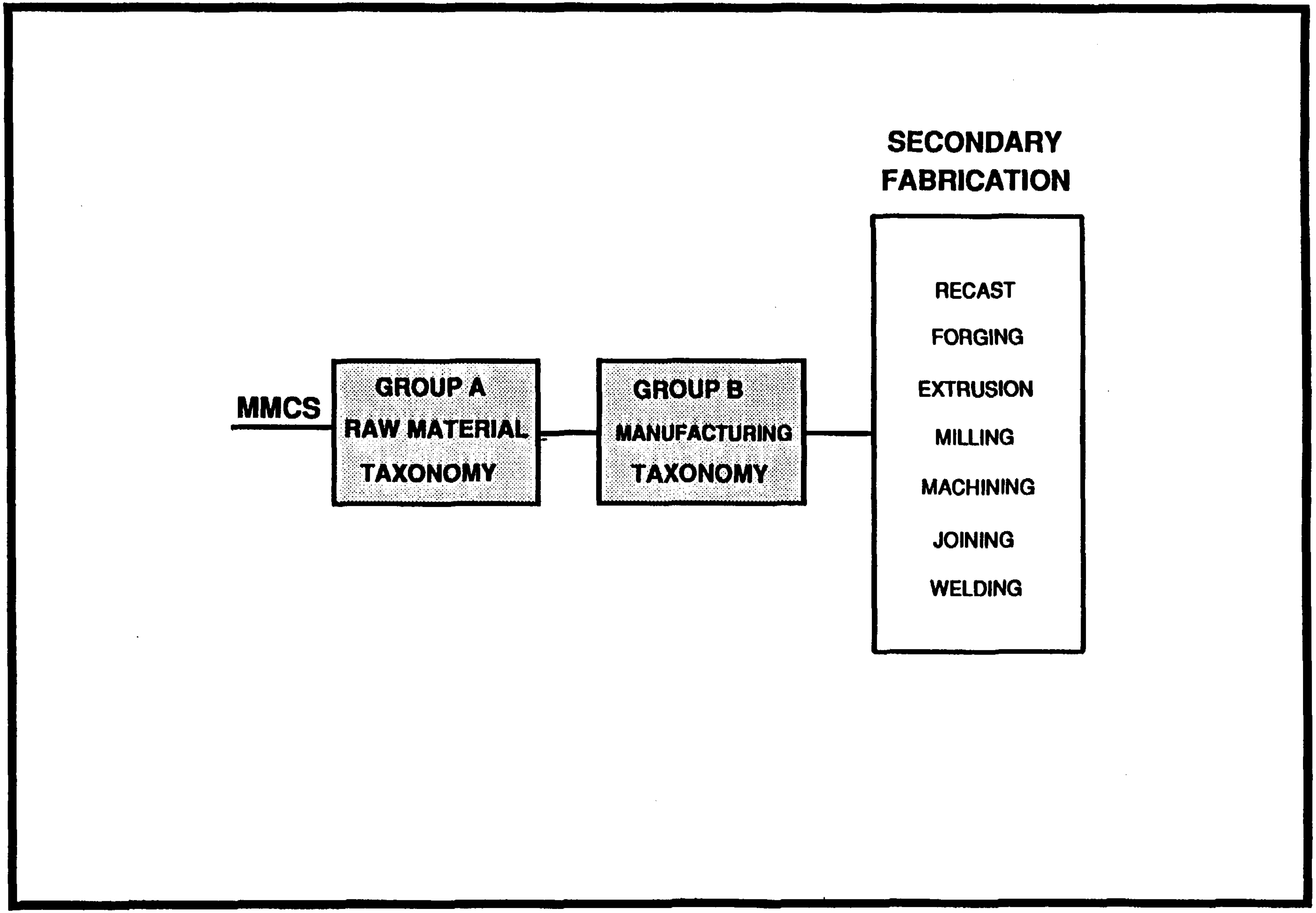

Figure 6-9. Metal Matrix Secondary Fabrication Taxonomy Group C

METAL MATRIX APPLICATIONS TAXONOMY GROUP D

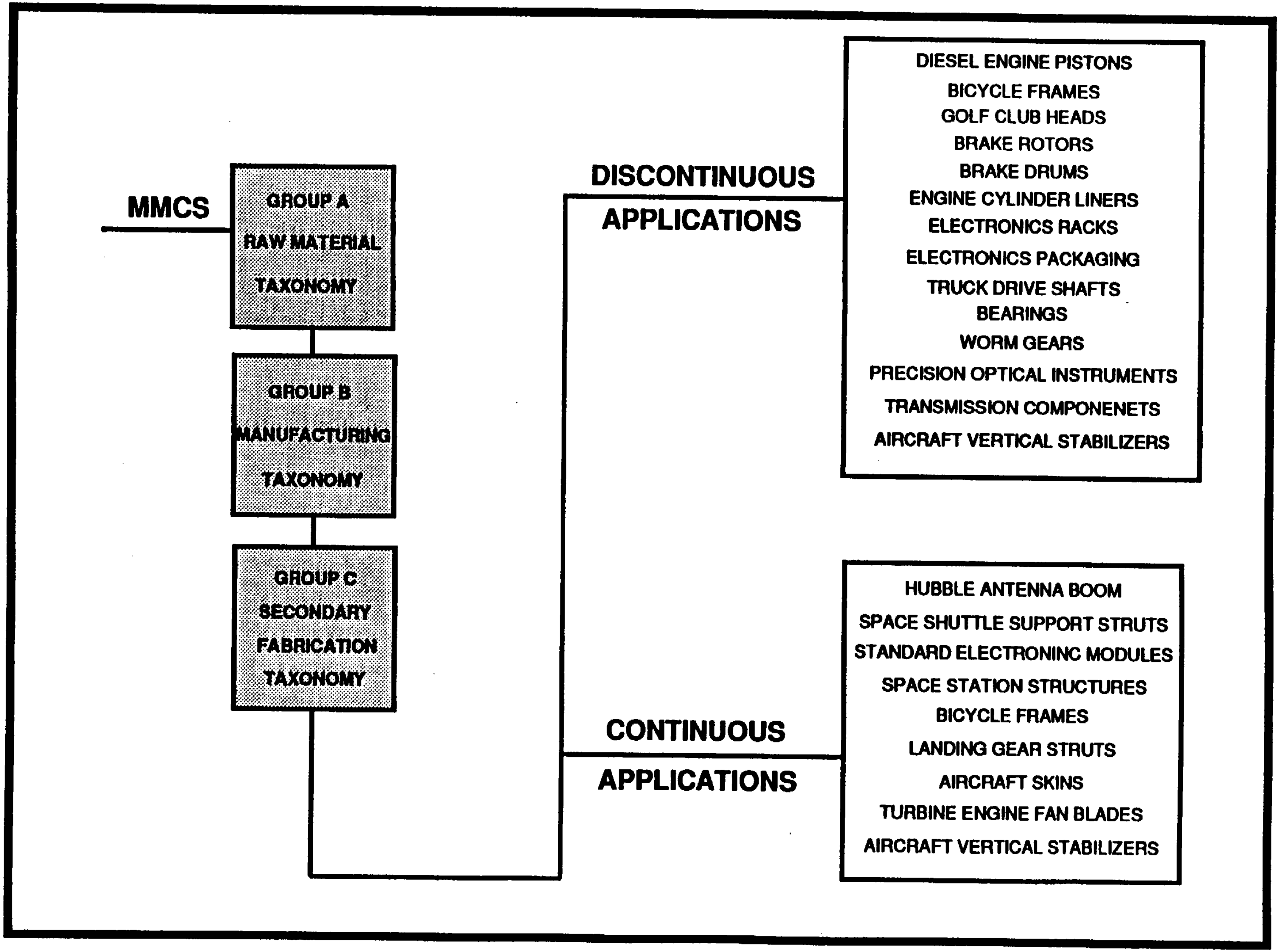

Figure 6-10. Metal Matrix Applications Taxonomy Group D

6.1.4.1 MMC Manufacturing

Many processes are employed to combine the matrix with the reinforcement. Certain composites dictate specific processes due to the properties of the matrix and/or the reinforcement as well as the desired properties of the composite itself, while other composites (again pending properties and applications) may be made by more than one process. For some MMCs, conventional metallurgical processes, such as casting, can be adapted; for other MMCs, specific processes have been developed (See Figures 6-7 and 6-8).

Before the matrix and reinforcement can be combined or processed, a fundamental understanding of the individual properties of each, along with their compatibility, must be considered. Since the reinforcements and the matrices are chemically distinct, the reaction between the two components before, during, and after processing must be considered as well. Undesirable or unknown reactions, triggered by the elevated temperatures during processing, operational conditions, or both, can degrade the composite and affect product life and performance. Overall compatibility between reinforcement and matrix requires a balanced reaction for correct bonding. A critical parameter of the bonding phase is the wettability of the reinforcement. Often, coatings are used to protect the reinforcement from chemical reactions with the matrix and improve wettability. For better bonding in aluminum, carbon fibers are coated with titanium diboride; for use in titanium, boron fibers are coated with boron carbide. Another consideration is the Coefficient of Thermal Expansion (CTE) match between the matrix and the reinforcement. A poor CTE match can cause stresses and thermal fatigue which could lead to microstructural cracking.

6.1.4.2 MMC Fabrication

The intermediary MMC product, after the composite fabrication process, comes in many forms. For example, Duralcan produces foundry ingots, rolling slabs, and extrusion billets. Other manufacturers produce their MMC products to net or near-net-shape, and as beams, pellets, plates, or sheets. The form which the MMC takes depends upon numerous factors, including the type of reinforcement (i.e., continuous or discontinuous), the application, the process used to manufacture the composite, and the composite properties desired (See Figure 6-8).

After a composite is made, the next step is usually some sort of secondary fabrication. Secondary fabrication methods include conventional metallurgy operations such as forging, extrusion and rolling, various machining operations, and joining operations like welding and brazing (See Figure 6-9). Many difficulties are being encountered in the secondary fabrication of MMCs. These difficulties are found in the milling of MMCs, which causes excessive wear and tear on the machining tools and difficulty in preserving fiber integrity within the composite (mostly in continuous MMCs). Although cutting forces can be lower with MMCs than with matrix alloys alone, tool wear with MMCs is invariably greater than with monolithic alloys, due to the ease of chip formation with brittle reinforcements. In addition, knowledge in welding and joining composite parts to composite and non-composite parts is very limited.

6.2 Continuous MMCs

This section, in parallel format to 6.1, describes the status of continuous reinforced MMCs: components and properties, manufacturing and fabrication processes, and advantages and disadvantages.

6.2.1 Continuous MMC Definition and Components

In continuous MMCs, the metal matrix acts as the binder or glue to hold the fibers together. Since the fibers are both stiffer and stronger than the matrix, the load is transferred from the matrix to the fiber to result in a system with dramatically improved properties when compared to the matrix metal. The fibers extend the entire length of the composite to allow the strengthening effect to occur along the entire length of a component.

Early investigation into MMCs addressed the development and behavior of continuous fiber reinforced matrices such as aluminum and titanium. Although results have been encouraging, extensive industrial application of these composites has been hindered by the high manufacturing costs and the high costs of the reinforcement fibers themselves. As a result, use of these materials has been limited almost exclusively to military and other highly specialized applications.[167]

Continuous fiber reinforced MMCs gain their greatly improved properties through the continuity of the fibers. The fibers can have various diameters and compositions. They range from graphite yarns and filaments to ceramic fiber and to metallic wire. They can be of single chemical origin or may be a composite themselves.

Continuous fibers are produced using various methods. The fiber choice and method of production are usually dependent upon MMC application temperature range. Fiber production methods for low temperature MMC applications (cryogenic through 600°F) include thermal decomposition, chemical vapor deposition, and inorganic polymer precursors. Production methods for medium temperature MMC fibers (600°F to 1800°F) include chemical vapor deposition and extrusion. For high temperature MMC applications (above 1800°F), currently available fibers are not suitable as reinforcements. Figure 6-11 presents a chart of processes and fibers produced.[393]

CONTINUOUS FIBER MANUFACTURING TECHNIQUES	
Process	**Fiber Type**
Thermal Decomposition	Graphite
CVD -Chemical Vapor Deposition	Boron & Silicon carbide
Inorganic Polymeric Precursors	Silicon carbide
Extrusion	Alumina or Alumina Silica

Figure 6-11. Continuous Fiber Manufacturing Techniques

6.2.2 Continuous MMC Manufacturing

The fabrication of continuous MMCs is less advanced than that of its discontinuous counterpart. Problems with manufacturing continuously reinforced MMCs include micro-structural non-uniformity, fiber damage, extensive interfacial reactions, and fiber to fiber contact. A major concern during manufacturing is maintaining the integrity and position of the fibers. Continuous MMC manufacturing usually requires two major steps. The first step involved generating a fiber-matrix preform; the second step involves converting or consolidating that preform to the desired component. In most manufacturing processes for continuous MMCs, consolidation of layers occurs to form the resultant composite. Some of the processes are foil-fiber-foil processing, thermal spraying, and powder cloth processing. A summary of processes, raw material forms, and advantages and disadvantages is presented in Figure 6-12.

For continuous composite forming, the fibers must be "wetted" with molten metal to form a strong bond between matrix and reinforcement. For example, some manufacturers consolidate continuous fibers between sheets of metal foil. At Textron, silicon carbide fibers and titanium filaments are woven together into a fabric. Layers of titanium foil are laid up with the fabric and enclosed in a vacuum bag, then heated and consolidated in a hot isostatic press.[392]

Thermal spraying includes processes such as arc spraying and low pressure plasma spraying. For both processes, molten matrix droplets are sprayed onto a single ply of the reinforcement, then wound upon a drum. The winding on the drum forms monotapes. These monotapes are then cut to size, stacked together, and either vacuum hot pressed or hot isostatic pressed to form the metal matrix composite.[392]

MMC Process	Matrix Form	Reinforcement Form	Process Advantages	Process Disadvantages
Powder Cloth Processing	Sheets made from powder	Fiber mat preform	readily available matrix powders	binder deficiencies, scale up for production is difficult
Foil-Fiber-Foil	Foil sheets	Woven fiber mat	no organic binders needed	high cost and low availability of foil, excessive waste
Thermal Spraying (Plasma and Arc)	Liquid droplets	Prepositioned fiber array	fibers more uniformly distributed, elimination of organic binders	some fiber breakage during spraying
Cast Tape	Powder	Sheet preform		organic binder difficulties
Liquid Metal Casting	Liquid	Preform	ability to produce complex shapes	reactivity of molten metal with fibers - hence, processing limited to low temperatures
Pultrusion	Solid	Fibers of Preform	lower temperature than Liquid Metal Casting removing many adverse fiber/matrix reactions, ability to produce cross section pieces	requires critical die design

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Figure 6-12. Continuous MMC Summary

In powder cloth processing, thin sheets of the matrix alloy are produced by blending a wetting agent, a fugitive binder, and matrix alloy powder. The reinforcement is produced as a fiber mat preform by winding continuous lengths of reinforcement fiber on a drum. The matrix sheets and fiber mats are cut to size and stacked together in alternating layers. The consolidation to form the composite occurs through vacuum hot pressing.[392]

6.2.3 Secondary Fabrication of Continuous MMCs

Most processing of continuous MMCs results in near-net-shape or net-shape products, hence eliminating most secondary fabrication. Since maintaining fiber integrity is critical to the performance of the composite, machining and reprocessing are not always viable. Usually the only secondary fabrication required is small machining or finishing, such as hole drilling.

6.2.4 Advantages and Disadvantages of Continuous MMCs

The primary advantage of continuously reinforced MMCs are their greatly improved properties over both metal alloys and discontinuously reinforced MMCs. These improved properties include high strength and the enhanced ability to withstand high temperatures. Another advantage is the directional tailorability of properties in continuous MMCs.

Disadvantages of continuous MMCs include the high cost of fibers and the high cost and complexity to manufacture. Ceramic and graphite fibers are brittle, thus making them difficult to fabricate into preforms. Monofilaments of both ceramics and metals are limited in use because their large diameters and inflexibility make weaving them into preforms extremely difficult. Problems with fiber and matrix interfacial reactions still constitute a major deficiency. Processing is elaborate due to the inherent nature of the composite and the fact that products are usually fabricated to near net or net shape.

6.3 Discontinuous MMCs

This section, in parallel format to 6.1 and 6.2, describes the status of discontinuous MMCs: components and properties, manufacturing and fabrication processes, and advantages and disadvantages.

6.3.1 Discontinuous MMC Definition and Components

Discontinuous MMCs are combinations of discrete reinforcements which are uniformly distributed throughout the matrix. This dispersion creates the primary strengthening mechanism in the composite by dislocation movement retardation. Discontinuous MMCs have improved properties over the monolithic matrix yet intrinsically tend to retain most of its fabrication and design properties.

Discontinuous reinforcements are primarily in the form of particulates, whiskers, or flakes, and are generally ceramics. Particulates, or particles, have maximum dimensions on the order of one micron, while whiskers have length to diameter ratios between 4 and 200, and are usually only a few hundred microns long. Discontinuous fibers have a larger reaction with and a greater reliance upon the metal matrix than do continuous fibers.

Whisker reinforced MMCs have been shown to have attractive combinations of strength and thermal stability relative to those of particulate reinforced MMCs. For these MMCs, however, extensive commercialization has been slow, primarily due to the high cost and producibility of currently available whiskers.[176]

6.3.2 Discontinuous MMC Manufacturing

The processing methods used to manufacture discontinuous MMCs can be grouped according to the temperature of the metal matrix during processing. Accordingly the processes can be classified into three categories: 1) liquid phase processes, 2) solid state processes, and 3) two phase (solid-liquid) processes.[167]

Some of the variations of the categorized processes include near net shape casting (sand casting, permanent mold casting, investment mold casting, expendable pattern casting, squeeze casting, and die casting), powder metallurgy (solid/liquid pressing, kinetic blending, liquid dynamic composition), infiltration (pressure, spontaneous), hot pressing then hot isostatic pressing, and ingot metallurgy. Most of these processes are proven and applicable for discontinuous MMCs. A summary of processes, raw material forms, and advantages and disadvantages is presented in Figure 6-13.

DISCONTINUOUS MMCs				
MMC Process	**Matrix Form**	**Reinforcement Form**	**Process Advantages**	**Company Using**
Melt Oxidation	Liquid	Preform	able to form complex shapes	Lanxide
Ingot Metallurgy	Liquid	Powder	lower cost to manufacture, good for high volume high stiffness and wear resistance applications	Duralcan
Powder Metallurgy	Powder	Powder	good strength and stiffness properties, near net shape forming	ACMC, DWA
Cospray	Liquid Droplets	Powder	uniform particulate distribution, more economical than PM	Alcan
Rapid Solidification Process	Flakes	Flakes	better strengthening of composite, low temperature processing so no degradation of matrix	Pacific Northwest Laboratories
Melt Infilitration	Liquid	Preform	piston with MMC insert cast to shape	Toyota (for diesel engine pistons)
Infiltration Casting	Liquid	Hybrid Preform	engine block cast with reinforced cylinder liners in place, no need for specialized tooling	Honda Motor Co.

Figure 6-13. Discontinuous MMC Summary

6.3.2.1 Liquid Phase Processes[167, 157]

In liquid phase processes, reinforcements are incorporated into a molten metallic matrix using a variety of proprietary techniques, followed by mixing and casting of the resulting MMC. Several approaches have been successfully used to introduce reinforcements into an alloy melt. These include (a) addition of particulates into the molten stream as it fills the mold; (b) injection of powders entrained in an inert carrier gas into the melt using an injection gun; (c) addition of small briquettes into the melt followed by stirring (these briquettes are made from co-pressed aggregates of the base alloy powder and the solid particulates); (d) addition of particulates into the melt via a vortex introduced by mechanical agitation; (e) dispersion of the particulates in the melt by using centrifugal acceleration; (f) pushing of the particulates in the melt using reciprocating rods; (g) injection of the particulates while the melt is being irradiated with ultrasound; and (h) zero gravity processing (using ultra-high vacuum and high temperatures for long periods of time).

In melt infiltration (a liquid phase process), a molten alloy is introduced into a porous preform, using either inert gas or a mechanical device as a pressurizing medium.

This approach is currently being used to fabricate the Toyota diesel piston, using a chopped alumina fiber/aluminum composite material.

In melt oxidation processing (i.e., the Lanxide Process™, also a liquid phase process) a preform, formed into the final product shape by a fabricating technique such as pressing, injection molding, or slip casting, is continuously infiltrated by a molten alloy as it undergoes an oxidation reaction with a gas phase (most commonly air). The primary advantage of this process is its ability to form complex, fully dense composite shapes.

Ingot metallurgy (a liquid phase process), used by Duralcan, incorporates (ceramic) particulates in a molten metal alloy by vigorous stirring, forming a slurry that is cast into an ingot. The reinforcement particles are thoroughly wetted by the matrix, and their distribution in the cast products is quite uniform. Ingot metallurgy MMCs are a lower cost composite and usually have lower strengths. These MMCs are ideal for high volume applications where stiffness or wear resistance are required attributes.

6.3.2.2 Solid Phase Processes[167, 157]

In powder metallurgy (a solid phase process) two discrete powders (a powder form of the matrix and a powder form of the reinforcement) are blended together, sometimes with the aid of a solvent slurry. This process, used by DWA Composites and ACMC, offers a method to manufacture near-net-shape parts for MMCs. The process usually incorporates HIP (Hot Isostatic Pressing), or it can utilize CIP (Cold Isostatic Pressing); there is also a combination technique called CHIP (Cold and Hot Isostatic Pressing). Powder metallurgy MMCs have higher associated costs but produce a higher performance composite with good strength and stiffness characteristics.

Another solid phase process which has been successfully used to consolidate quenched powders containing a fine distribution of ceramic particulates is called high-energy-high-rate processing. This approach involves the consolidation of a metal-ceramic mixture through the application of high energy in a short period of time. The applied energy can be either mechanical or electrical. Although encouraging results have been obtained, work is continuing to perfect and improve this process.

6.3.2.3 Two Phase Processes[167, 157]

Pacific Northwest Laboratories, through U.S. Army funding, has developed a low cost process to produce high performance MMCs. The process, termed RSP for Rapid Solidification Process, produces metal matrix composite flakes in a melt spinner. The flakes are then either canned and followed directly by extrusion or are consolidated into a billet form and then extruded. Advantages of this process are prevention of degradation of the matrix properties due to the low temperatures used, better strengthening of the composite, and better homogeneity within the matrix.

Another recently developed technique for composite forming called Cospray comes from Cospray Advanced Aluminum Materials (Alcan International, Charlotte NC). It can be categorized as a two phase process. It is similar to spray deposition, where a molten aluminum alloy is atomized by nitrogen into a fine spray of molten metal droplets. The composite is made when silicon carbide powder (the reinforcement) is added during the atomization process. One advantage of this process is that it allows uniform distribution of the reinforcing particles throughout the composite. In addition, Alcan claims that Cospray is more economical than powder metallurgy or castable aluminum composites and can utilize a wide variety of new aluminum materials that are impossible to make using conventional direct-chill casting.

In rheocasting, another two phase process, the reinforcement particulates are added into a metallic alloy matrix at a temperature within the solid-liquid range of the alloy.

6.3.3 Secondary Fabrication of Discontinuous MMCs

The difficulty in machining metal matrix composites is becoming more recognized. Silicon carbide is one of the most widely used reinforcements, especially in particulate form; its extreme hardness makes machining difficult and costly. The increased hardness of MMCs translates to quick and severe wear on conventional tools, leading to relatively short tool lives compared to use on monolithic alloys. High speed steel tools dull within seconds of use, and conventional and coated carbide tools have life spans measured in minutes when trying to machine MMCs. The primary mode of tool wear is through the abrasive contact between the tool edge and the reinforcements, where the reinforcements chip away tiny flakes of the tool edge. Since the discontinuous MMCs of primary interest contain silicon carbide reinforcement, cutting tools must be devised which cut cleanly, have little or no fragmentation, and withstand the abrasive wear.

Diamond, the hardest material known, has proven to be an answer to this problem. This material is used to form polycrystalline diamond (PCD) tools. Diamond is suitable only for machining non-ferrous workpieces. In use on MMCs, the tool life is usually 50 to 200 times greater than that obtained with conventional cemented carbide cutting tools. PCD drills and reamers offer similar longevity over tungsten carbide (WC) conventional tools. Unfortunately, for tapping, which due to physical constraints is already the most difficult machining operation, no PCD taps exist to date. Duralcan recommends a fairly low-cobalt, micro-grain WC, six-fluted tap for best results.[175] Since most commercial MMCs are aluminum or magnesium based, PCD tools make machining these materials possible without detriment to the tool or the workplace.

End users of MMC fabricated parts are finding it difficult to join these "composite" pieces using existing or conventional methods, especially when welding. The end users who are not MMC manufacturers are finding the problems of machining and joining even more daunting. These end users do not have the research experience in determining the correct joining procedures or machining tools, nor are they as knowledgeable as to the inherent properties of the MMC itself.

Duralcan has attempted to resolve part of this dilemma by performing extensive research and experimentation, deriving and teaching methods to weld and machine MMCs. For both of these aspects of fabrication, Duralcan publishes an informative technical and required tool guide for use with their silicon carbide/aluminum and aluminum oxide/aluminum composites.[12]

Duralcan has had much success with welding, as evidenced by their MMC drive shafts. The drive shafts require a forged aluminum yoke to be welded to the shaft. Duralcan has accomplished this with a gas metal arc process using cold wire feed. A fundamental reason for this success was the changing of the reinforcement from silicon carbide to aluminum oxide. Duralcan found this change useful due to the superior weldability of the aluminum oxide versus the silicon carbide. This was based on the fact that during welding with silicon carbide, if the silicon carbide is not kept cold in the weld pool, it will decompose and form aluminum carbide, degrading the composite. Duralcan states that for repairs required to correct surface defects, gas tungsten welding is the preferred process, and for large defects or structural welding of components, gas metal arc welding is the process of choice. Standard aluminum welding equipment is still the same, but the procedures involved in the welding process are not identical to those for aluminum alone. Joint preparation and welding parameters change, using the judgment and skill of the welder, to produce a properly welded joint.[12]

At DWA Composites, one answer to welding MMCs is to change the reinforcement. Substitutions of titanium diboride or boron carbide occur in place of the more conventional silicon carbide reinforcement when welding is required in the (end use) fabrication. Boron carbide is more expensive than silicon carbide but less dense, thereby producing a less dense and easier welded composite. DWA has found that aluminum, when used with boron carbide or titanium diboride, appears to be structurally weldable.[136]

DWA Composites has also had success in brazing and resistance spot welding of both continuous and discontinuous MMCs. Friction welding has produced joint strengths better than 90 percent of those of the base materials. Also, the results using tungsten arc welding with filler metal addition have been quite good. DWA notes that the industry has experienced problems in the use of electron beam and laser beam processes for welding MMCs when silicon carbide is the reinforcement. The main problem is the same as experienced by Duralcan, where there is a breakdown of the silicon carbide and aluminum carbide is formed. This is caused by too much localized heat.[136]

6.3.4 Advantages and Disadvantages of Discontinuous MMCs

The primary advantages of discontinuous MMCs are their material properties, their low density and their similarity to monolithic alloys in design, process, and fabrication. In many instances, the same or slightly modified metallurgical processes and fabrication techniques can be used with discontinuous MMCs. As use and implementation into systems increases, so will familiarity with all facets of the composite. The dilemma associated with use of discontinuous MMCs is that more use of MMCs is needed to gain more knowledge, but with a limited knowledge base there is strong reluctance to use these composites. With significantly more effort devoted to discontinuous MMCs through government funded programs and private industry initiatives, this dilemma is slowly starting to subside.

Disadvantages of discontinuous MMCs include increased material and fabrication costs and potential interfacial reactions between reinforcement and matrix. The cost of some reinforcements (primarily whiskers) and manufacturing of the composite are still inhibiting broader utilization. Interfacial reactions between reinforcement and matrix still need to be resolved. At present the technology for producing discontinuous MMCs is far ahead of its fabrication.

6.4 Other Types of MMCs

Recently there has been research in improved metal alloy reinforced composites. These new composites include Intermetallic Matrix Composites (IMCs), whereby intermetallics such as titanium-aluminides and nickel-aluminides replace the conventional metal matrix. These IMCs demonstrate much improved temperature capabilities over continuous MMCs. Unfortunately the high temperature capability is offset by two main deficiencies: brittleness at ambient temperatures and limited ductility at higher temperatures. Potential applications include the hotter regions of engine cores and structural materials for NASP type vehicles, where the ability to repeatedly withstand high temperature reentry is required.

Other composites under development are Metal-Metal-Composites, a metal matrix reinforced with metallic fibers. Problems arise in the reaction between the matrix and the reinforcement, resulting in a brittle intermetallic compound. Minimizing this reaction is a major obstacle to the production of Metal-Metal-Composites.

These composites suffer from the same deficiencies as continuous and discontinuous MMCs but on a larger scale, primarily due to their early stage of development. The lack of optimization of components, processes, chemistry, and the composite itself are progress impediments to these composites.

6.5 R&D in the MMC Arena

Levels of research and development (R&D) in the MMC arena have varied throughout the years. For most of the time that the MMC arena has been active, more emphasis has been placed on development than on research. As of late, however, members of the MMC community are stressing the material research end of R&D. Sources of funding for MMC R&D include the 6.1, 6.2, and 6.3A budget categories for the Services and ARPA, the Defense Production Act Title III program, the DoD Manufacturing Technology Program, the Small Business Innovative Research Program, and the University Research Initiative (URI), among others. Figures 6-14 through 6-17 depict the level of funding from the DOD Technology Base, the DOD Non-Technology Base, Contractor IR&D, and NASA for MMCs.

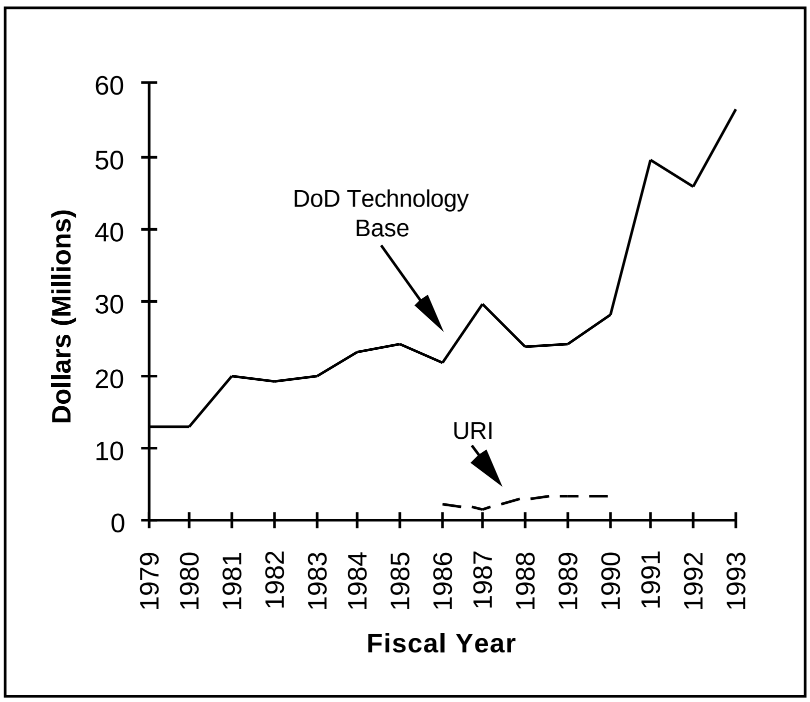

Figure 6-14. Funding for MMCs from DOD Technology Base
(Source: Office of the Director of Defense Research and Engineering)

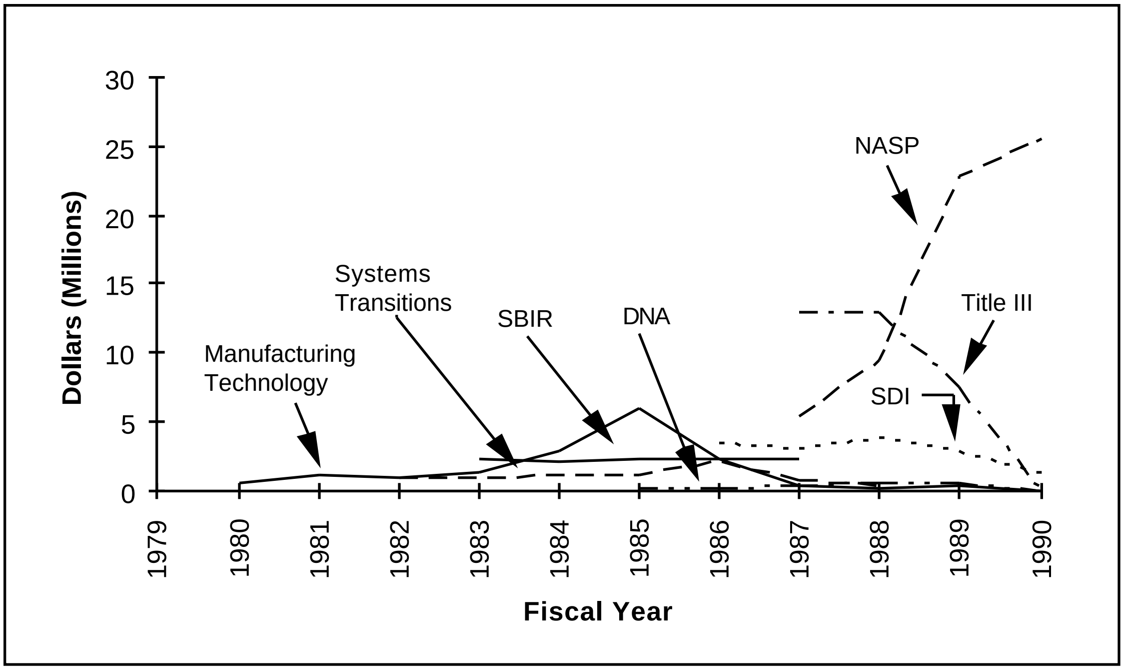

Figure 6-15. Funding for MMCs from DOD Non-Technology Base
(Source: Office of the Director of Defense Research and Engineering)

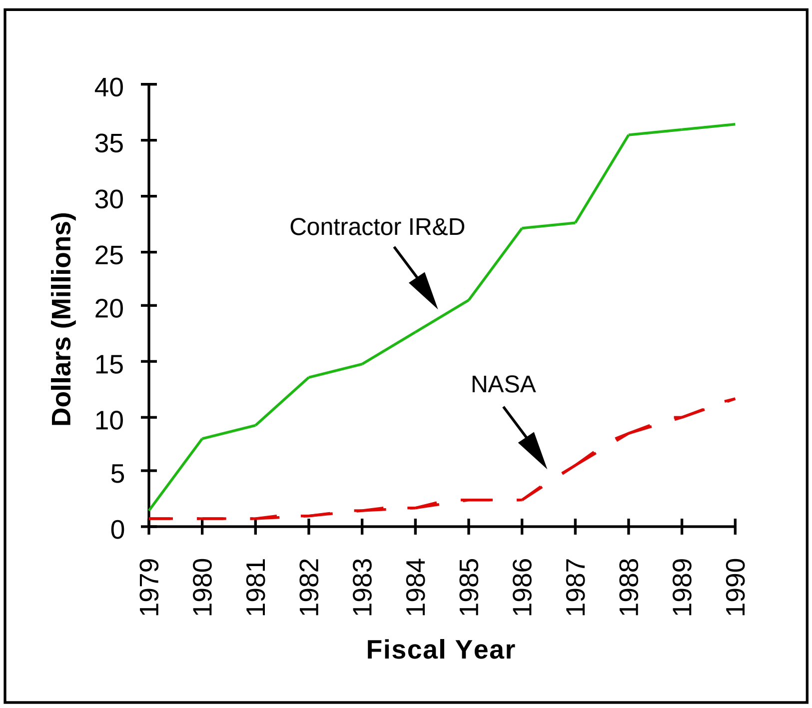

Figure 6-16. Other Government Sources of Funding for MMCs
(Source: Office of the Director of Defense Research and Engineering)

R&D in the MMC Arena		
Researcher	**Area(s) of R&D**	**Source of Funding**
Amoco Performance Products	Robust Processing MMC Initiatve Program to Produce Improved Property Thermal Planes for SEM E's (standard electronic modules - series E)	Navy
Center for Welding and Joining Research @ University of Colorado	Better Understand the Wetting of Ceramics by Liquid Metals	Ballistic Missile Defense Organization (BMDO)
Clemson University	Precipitation of MMC Systems	Turkish Government
Clemson University	Tribology of MMCs	National Science Foundation
Department of Materials Science and Engineering @ University of Florida	Understand and Develop New In-Situ Route to Process Structured MMCs and Intermetallic Matrix Composites (IMCs)	Office of Naval Research
Drexel University	Research the Interfacial Reactions of Metal-Matrix Composites During In-Situ Processing	Office of Naval Research
Ecole de Technologie Superieur	Hybrid aluminum MMC composites	Department of National Defence (DND)
Inco	Nickel coated fibers for use in MMCs; Hybrid MMC using Alcan MMC & nickel coated graphite fibers	Internal Funds and ISTC
McMaster University	Studies of mixing, solidification and particle distribution; high temperature properties of composites; basic studies of strengthening, fracture studies related to wear and machinability	Department of National Defence (DND)
Mechanics Division @ Clemson University	Continuous MMCs / Fracture Mechanics	Air Force
Metallurgical Materials Laboratory @ University of Maryland	Determine Interrelationship Between Microstructure and Strength in Titanium-Diboride Nickel-Aluminum (TiB2/Ni/Al) Composites	Office of Naval Research
Queen's University	Electrochemical routes for production of composites; control of interface reactions in metal matrix composites	Department of National Defence (DND)
Rockwell International Science Center	Determine Methods for Optimum Fabrication of Titanium Aluminide Composites, for Use in Engine Structures	DoD ManTech
University of British Columbia	Microstructural engineering of MMCs	Department of National Defence (DND)
University of California @ Santa Barbara	MMC Mechanism Based Design	University Research Initiative (URI)
University of Minnesota	Toughening Mechanisms in Titanium and Aluminum Composites Reinforce with Alumina Fibers	University Research Initiative (URI)
University of Toronto	Fatigue of MMCs, electron microscopy of interfaces	Department of National Defence (DND)

Figure 6-17. R&D in the MMC Arena

Some current areas of MMC R&D deal with understanding and improving properties, interfacial reactions, matrix optimization, fiber optimization, and manufacturing technologies. A fair amount of R&D in the MMC arena is being performed by universities across the country—some details of which are presented in Figure 6-17.

Clemson University (South Carolina) is involved with several research initiatives. Through funding from the National Science Foundation (NSF), Clemson University is performing research involving the tribology (frictional properties) of MMCs. This funding amounts to $45,000 per year. Clemson is also performing studies on the precipitation of MMC systems using funding from the Turkish government. In addition, the Mechanics division is studying continuous MMCs with a $40,000/year contract with the Air Force to examine fracture mechanics.[222]

The University of California at Santa Barbara, through the Center for Advanced Composites, is performing a study on MMC Mechanism Based Design. The study is supported primarily by a five year, $2.5 million DARPA University Research Initiative (URI) grant.[230] Another research effort supported by the DARPA URI is situated at the University of Minnesota. Research is performed to investigate and better understand the toughening mechanisms in titanium and aluminum composites reinforced with alumina fibers.[396]

The Office of Naval Research is funding various university based programs related to MMCs. A research program at the University of Maryland's Metallurgical Materials Laboratory was established to determine the interrelationship between microstructure and strength in titanium-diboride/nickel-aluminide (TiB2/NiAl) composites. A currently active program at Drexel University studies the interfacial reactions of MMCs during in-situ processing. The University of Florida's Department of Materials Science and Engineering, also with funding from the Office of Naval Research, is performing research to understand and develop new in-situ routes to process structured MMCs and intermetallic matrix composites. In addition, Research Opportunities, Inc. has a $50,000/year contract to explore the use of MMCs in electronic packaging.[396]

The Ballistic Missile Defense Organization (BMDO) is also a source of funding for university R&D programs. The Center for Welding and Joining Research at the University of Colorado is performing R&D to better understand the wetting of ceramics by liquid metals. This study effort will support the ability to tailor metal alloys for optimum infiltration of ceramic preforms.[396]

R&D at the Massachusetts Institute of Technology's Solidification & Metal Matrix Composites Lab involves the processing and mechanical behavior of MMCs and the manufacture and component prototype development of MMCs. These projects are being performed in a joint activity with the 3M Model Factory program, Ferrari & Fiat, and Ford.

The Defense Production Act Title III program is a DOD initiative that provides incentives to domestic industry to progress into high-risk markets. DWA Composites Specialties, Inc. is working on a Title III program for the Air Force, in conjunction with Advanced Composites Materials Corporation (ACMC), to expand existing production capability of all types of aluminum-based silicon carbide discontinuously reinforced aluminum (DRA) MMCs. ACMC receives funding for the development of high strength, whisker-reinforced DRA, while DWA Composites Specialties, Inc. receives funding for the development of moderate strength, particulate-reinforced DRA.[230] Rockwell International Science Center is performing research, under a ManTech program, to determine methods for optimum fabrication of titanium aluminide composites for use in engine structures. Texas Instruments is performing R&D, also under a ManTech program, to establish and implement processing methods for titanium aluminide and titanium alloy foil. Amoco Performance Products, Inc. is working on a Title III program to increase production of high modulus pitch-based graphite fiber.[395] They are also involved in a $2.7 million Navy funded Robust Processing Initiative.[222]

Inco (Ontario, Canada) has been working on developing nickel coated fibers to provide better fiber protection from matrix materials for use in composite materials. Fiber have included carbon, alumina, and silicon carbide. The focus of Inco's MMC activities has been with nickel coated graphite fibers in an aluminum matrix for use in wear resistant applications in automobiles. Inco is using Alcan's discontinuously reinforced MMC as the aluminum matrix for their activity. They are calling their material a hybrid composite consisting of an aluminum matrix with both graphite and silicon carbide reinforcement. Inco believes this material is easier to machine, easier to extrude, provides increased wear resistance coefficient of friction, increases thermal conductivity and has minimal expected increase in cost over Alcan's material.

A consortium of U.S. and Canadian companies is developing a new Canadian technology for melting metal at lower temperatures into a semi-molten form to produce MMCs. The goal of the consortium is to achieve a fundamental understanding of processes and interfaces. Members of this consortium include Texco Molding, Dow Chemical, Conalco, MIT, and Amptech. Funding is provided through multi-client research programs.[130, 394]

Future areas of interest for R&D include better understanding of fiber and fiber/matrix interface, thermal management applications, interfacial characteristics, fiber coatings, and reproducibility, and MMC use in electronic packaging. In addition, a national database containing R&D results may be established. This database will enhance efforts of composite standardization and expansion of the knowledge base required for design engineers to consider implementing MMCs into their systems.

7.0 Applications

The applications, or end uses, of MMCs are myriad. Actual applications range from a telescope orbiting the earth to golf clubs. Unfortunately, to date there has not been widespread acceptance of MMCs as a viable engineering material, so existing applications are few and in most cases are only "one-shot" applications. There is no full scale use of an MMC component at present. Several large scale applications exist, all using discontinuous MMCs. These applications include tire studs and bicycle frames made from Duralcan's material, MMC pistons made by Toyota, and the Honda Prelude Si engine block. Figure 7-1 presents some potential and actual MMC applications and the benefits realized.

Potential and Existing Applications / Benefits	Weight Reduction	Wear Resistance	Stiffness	Tailorable Thermal Conductivity	Increased Performance at Elevated Temperatures	Tailorable CTE	Corrosion Resistance	Resistance to Radiation	High Strength
Aircraft Skins	•				•				•
Bearings	•	•					•		•
Bicycle Frames	•		•						•
Boat Masts & Spars	•		•						•
Brake Rotors	•	•							
Electronics Packaging	•			•	•	•		•	
Electronics/Avionics Racks	•			•	•	•			
Engine Cylinder Liners	•	•							
Fastening Equipment in Chemical Environment- Bolts and Screws	•						•		•
Ground Vehicles	•								•
Landing Gear Struts	•		•						•
Medical Implants	•						•		•
Optical/Guidance Systems Structures	•		•	•		•			
Pistons	•	•							
Satellite Antenna Masts	•		•						
Sea Vehicles	•		•				•		
Space Structures	•		•	•				•	
Transmission Components	•	•					•		
Tubing in Nuclear Plants	•						•	•	
Turbine Engine Components	•	•			•				•
Worm Gears	•	•							•

Figure 7-1. MMC Application Benefits

7.1 Application Categorization

Application maturity is categorized as theoretical, prototype, and actual (in use). Theoretical applications are those which are in the concept stage, for which no prototype or only a few prototypes have been developed. Prototype applications are concepts taken to manufacture on a very small scale (single to a couple of units). Actual (in use) applications are those where manufacturing is near or at full scale for use in an end product. Applications are classified as Military, Aerospace, Automotive, Commercial and Other, or Recreational. The following sections discuss known applications within these application classes and in accordance with their current maturity (See Figure 6-10).

7.2 Military Applications

IDENTIFIED MMC MILITARY APPLICATIONS	
• Avionic Electronics	• Gun Barrels
• Armor for Military Vehicles	• Assault Bridges
• Armor Penetrators	• Rail-gun and Kinetic-energy Weapons
• Tank Track Shoes	• Ship Antennas
• Tank Track Pins	• Ship Propellors
• Torpedo Shells	• Mirror Substrates

Figure 7-2. MMC Military Applications

7.2.1 Theoretical Military Application

MMCs are of major interest for use in ground vehicles. Mirror substrates in larger fire control devices for tank based systems will benefit from the strength and stiffness of MMCs. The lighter weight of the vehicle gained through use of MMC components will allow more rapid deployment and improved mobility and maneuverability. Durability of the vehicles will increase by using multi-layered MMC armor, guns, sprockets, rollers, tank treads and tank tread pins. Increased vehicle life will be obtained through reduction in part breakdown and repair, thereby reducing logistic support requirements.

Continuous and discontinuous MMCs are under consideration for various applications in helicopter components. Discontinuously reinforced aluminum sheets would be substituted for titanium sheets in nacelle firewalls, while continuously reinforced aluminum would replace steel push rods and tubes, as well as filament wound polymeric composite drive shafts. These substitutions will allow for improved component strength and stiffness with the possibility of increased damage tolerance.

Besides air and land applications, MMC components may someday be found under the sea. Torpedoes could utilize either continuous or discontinuous MMCs to achieve weight reduction, improved maneuverability, and greater depth.[394]

7.2.2 Prototype Military Applications

With funding from the Army's Materials Technology Laboratory, Sparta Inc. (San Diego, Ca.) has developed and is testing MMC applications in the Exoatmospheric Reentry Interceptor System (ERIS) projectile.[147] MMC components include the cruciform and the bulkhead airframe, which were fabricated from continuously reinforced boron-fiber aluminum face sheets. Advantages of using MMCs as compared to using carbon-fiber epoxy baseline material are a 28 percent weight savings and an expected higher natural frequency in bending.

Sparta is also working on MMC applications for thermal management of electronic modules. Citing Air Force plans to raise circuit board power from 35 to 300 Watts, Sparta is looking at MMCs for heat rejection/heat exchangers in chip carriers and printed wiring boards.[147] Some of the work has implemented Amoco Performance Products' high-thermal-conductivity pitch-based carbon fiber. This fiber has been used in a copper and in an aluminum matrix. One of the goals is to minimize or eliminate the coefficient of thermal expansion (CTE) differences between the circuit boards, chip carriers, and computer chips.[222]

7.2.3 Actual Military Applications

To date actual military applications are few. Robins Air Force Base is using whisker reinforced aluminum from Advanced Composite Materials Corporation (ACMC) as repair patches on aircraft wings. This has been performed on a small scale, with the first repaired aircraft logging over 300 hours of flight since the repair with no noticeable problems. Also, through Robins AFB and ACMC, whisker reinforced aluminum escape hatches will be introduced into the C-141 aircraft. The first assembly test of the hatches at Wright Patterson Air Force Base was unsuccessful due to distorted components. ACMC is presently working to resolve this problem and will have three hatches ready for assembly by the end of September 1993.[222]

7.3 Aerospace Applications

IDENTIFIED MMC AEROSPACE APPLICATIONS	
• Compressor & Turbofan Blades	• Missile Guide Vanes (fins)
• Supersonic & Hypersonic Airframes	• Missile Body Components
• Landing Gear Components	• Spacecraft Boom & Strut Structures
• Vertical Tail Wings	• High Temperature Airfoils
• Engine Ducts	• Rotating & Static Engine Components

Figure 7-3. MMC Aerospace Applications

7.3.1 Theoretical Aerospace Applications

Potential airframe applications represent large volume materials applications for MMCs, especially for elevated-temperature airframes, as on supersonic and hypersonic aircraft. Pratt & Whitney is investigating rapidly solidified powders of titanium aluminide for use in the Aurora, a Mach 5 replacement for the SR-71 Blackbird.[393] Fuji Heavy Industries is also working to develop fiber reinforced aluminum and titanium for a Japanese Mach 5 vehicle.[393] MMC skins and spars will play crucial roles in supersonic and hypersonic aircraft.

Missile systems can benefit by utilizing MMCs through the higher strength to weight ratio, reduced flutter, increased range (due to lower missile weight), and increased speed resulting from the ability to withstand higher temperatures. Potential uses of titanium and superalloys may be superceded by MMCs. Substituting aluminum MMCs for titanium and titanium MMCs for nickel-base superalloys may present weight savings and dramatically reduce the overall missile cost. These substitutions are being explored. Particular missile components using MMCs include the bulkhead, tube, spars and stiffeners.[394]

Many gas turbine companies are conducting research in the continuous MMC arena for applications in compressor and turbofan blades for aircraft engines. Identified potential composites are silicon carbide/titanium and boron/titanium. Continuous MMC components appear to be the most viable, near term, in the gas turbine engine, predominately in rotating and static components. Such components include shafts, compressor rotors (or disks), hollow fan blades, frames and nozzle structures, ducts and cases. In hollow fan blades MMCs make possible vibration control of advanced swept aerodynamics, while in engine disks there is a potential for a 50 percent or more weight reduction. For shafts, the use of MMCs will allow for increased speeds.

There is much more potential for continuous MMCs for aerospace applications due to their improved properties over discontinuous MMCs; unfortunately the technology state of continuous MMCs does not support use at this time. Supersonic vehicles, such as the Advanced Tactical Fighter (ATF) and the Advanced Tactical Aircraft (ATA), could use MMCs in stiffener beams, fuselage stringers, fuselage frames, spars, longerons, pivot shafts, torque boxes, vertical stabilizers, wing skins, cover skins and landing gear.

Identified potential titanium MMC applications exist for various propulsion system components for the National Aerospace Plane (NASP) and the Integrated High Performance Turbine Engine Technology (IHPTET). For IHPTET, component weight savings from 30 percent to 50 percent are possible in the replacement of conventional titanium or nickel-base superalloy integral rotors with titanium reinforced MMC integral rotors. Using the titanium MMC for the two-spool turbofan could also reduce total engine weight by as much as 15 percent.

Boeing and McDonnell Douglas have submitted initial vehicle concepts to utilize MMCs in the construction of the High Speed Civil Transport (HSCT). The HSCT will be required to fly 6500 nautical miles at speeds of Mach 1.6 to Mach 3.2, while enduring temperatures of 400 to 600 degrees Fahrenheit. To achieve these requirements, MMCs will be utilized in propulsion as well as in structural components such as fuselage and wing skins, I-beams, spars, leading edges, and vertical and horizontal tails.[146]

Continuously reinforced titanium MMCs are being widely tested for rocket propulsion. Some of the continuous reinforcements are silicon carbide and aluminum oxide. Component applications include blades, vanes, and high thermal conductivity casings, and the primary thrust structure truss for the ALS Propulsion/Avionics Module. This last component is used to transmit main engine loads into the expendable part of the launch vehicle.

There is a variety of potential applications identified specifically for space, using both continuous and discontinuous MMCs. Most typical are components of satellites, telescopes, space stations, launch vehicles, and SDI structures. Light weight and high stiffness allow erectable trusses for a space station (tubes and fittings), and the ability to maintain precision structure during environmental changes maintains mirror alignment in an optical array. High thermal conductivity properties of MMCs make them applicable for space-based radiators. Ultrahigh-modulus graphite reinforced aluminum or copper possess these qualities and could be used to construct high performance body mounted or boom attached space radiators.

7.3.2 Prototype Aerospace Applications

To date, the largest manufactured MMC structures are four vertical tail stabilizers, which are being tested on Lockheed's prototype Advanced Tactical Fighter (ATF) aircraft. The stabilizers measured 10.5 feet long, five feet at the root cord, two feet at the tip cord, and approximately six inches thick.[147] Two of the four stabilizers had skins made from aluminum reinforced with 15 percent discontinuous silicon carbide whiskers, while the other two used aluminum reinforced with continuous silicon carbide fibers. In all four stabilizers, the continuous and discontinuous skins were attached to five continuous silicon carbide fiber/aluminum spars and 14 discontinuous whisker silicon carbide aluminum ribs. The continuous silicon carbide was supplied by Textron Specialty Materials, and the discontinuous silicon carbide was supplied by Advanced Composite Materials Corp.

Pratt & Whitney, GE Aircraft Engines, and Allison Gas Turbine are focusing efforts on producing "demonstration" engines. These engines are not designed for any particular aircraft, but to illustrate the incorporation of MMCs into engine components. These demonstrations are expected to help resolve disagreements regarding whether development should concentrate on rotating components like fan blades or static components such as struts in the exhaust nozzle.

Other prototype continuous MMC applications include using aluminum reinforced with graphite fibers in the antenna boom on the Hubble Space Telescope. The space shuttles utilize hundreds of continuous boron/aluminum MMC struts for frame support.

7.3.3 Actual Aerospace Applications

Existing aerospace applications are limited to a few specific areas. "Instrument grade" MMCs are being used for optical and guidance system gimbals and for inertial and ring laser gyroscope guidance systems. The Trident II missile uses MMC guidance covers.

Also in use are MMC missile fins (guide vanes), avionics racks, and some electronic packaging. Ball Aerospace has used 20 percent silicon carbide / aluminum MMC gimbals, which were cast by Cercast (of Montreal, Canada). The MMC was manufactured by Duralcan. Hughes Helicopters has also used MMC optical mounts cast by Cercast.

7.4 Automotive Applications

IDENTIFIED MMC AUTOMOTIVE APPLICATIONS	
• Car & Truck Drive Shafts	• Brake Rotors, Calipers, and Drums
• Pistons	• Timing Sprockets
• Rocker Arms	• Accessory Pulleys
• Push Rods	• Oil Pump & Crankcase Housings
• Intake Valves	• Engine Cylinder Liners
• Turbocharger Impellors	• Frame Components

Figure 7-4. MMC Automotive Applications

7.4.1 Theoretical Automotive Applications

For automotive applications, discontinuous MMCs seem the composite of choice. Many engine components, including wrist pins, rocker arms, turbocharger impellers, timing sprockets and accessory pulleys, intake valves, and oil pump and crankcase housings, are under development. Possible use outside the engine includes frames, bumpers, suspension components such as struts, clutch pressure plates, shift forks, gears, gearbox bearing housing, differential bearing housing, and transmission components.[394]

7.4.2 Prototype Automotive Applications

The U.S. automotive industry is developing various applications for discontinuous MMCs. Programs are presently underway at Ford and GM. No major programs exist for the developmental use of continuous MMCs by the automotive industry. Due to current prices, the Big Three do not consider them viable even for R&D. Initial prototyping is on brake systems, including rotors and calipers. Duralcan seems to be the principal supplier, along with Lanxide. This application is also being pursued by Allied Signal, Rockwell, and Mahle.

Numerous "Demonstrator Components" have been manufactured out of reinforced aluminum. These include silicon carbide reinforced pistons made by Dural, Martin Marietta, and Lanxide; an aluminum oxide reinforced piston crown made by T&N, JPL, Mahle and others; a silicon carbide reinforced drive shaft made by Dural and GKN; aluminum oxide reinforced valve springs, retainer cams and lifter bodies made by Lanxide; titanium carbide reinforced pistons and connecting rods made by Martin Marietta; a silicon carbide reinforced connecting rod made by Nissan; and an aluminum oxide reinforced connecting rod made by DuPont and Chrysler.

Graphite/aluminum bearings for connecting rods have been produced and successfully tested.

Ford has manufactured a limited number of the Taurus model cars with aluminum MMC brake rotors, to be test driven by company executives. Rear MMC brake rotors made by Duralcan have been tested successfully by one of the Big Three automotive manufacturers. Testing of the front rotors will probably dictate design changes to lower the operating temperature of the brakes. Potential changes in the chassis and modifications in larger car design may be necessary for the implementation of front MMC rotors.[130]

Although there are many advantages to the use of MMC components, especially in brake systems, there are some drawbacks. A MMC brake rotor can be 40-60% lighter than its cast iron counterpart, can dissipate heat much faster, and offers a potential reduction in noise. But the rotor will also wear conventional brake pads much faster, since it is reinforced with very hard silicon carbide fibers. Hence, collateral components need to be developed jointly when considering using MMCs for brake rotors. Most probably, brake pads containing silicon carbide particles will have to be developed in conjunction with the MMC brake rotors. This problem may be true for other MMC component applications as well and may dictate the development of MMC "component systems", versus single components.

7.4.3 Actual Automotive Applications

The MMCs in automotive use today are few and most often discontinuous. The first uses of MMCs in automotive applications were by Toyota, as early as 1983, with the introduction and use of aluminum-based MMC pistons in diesel engines. These pistons use a fibrous preform of alumina and alumina-silica to reinforce the piston ring groove. Even before Toyota, Alfa Romeo fitted Formula One racing car engines with graphite/ aluminum cylinder liners. These MMC-utilizing engines powered race cars victorious in the 1975 Formula One World Championship. Alfa Romeo Formula One engines with MMC cylinder liners experienced no seizure in races during the 1975-76-77 era and exhibited very high power ratings. Mitsubishi is also producing and using reinforced aluminum pistons for diesel engines.

In 1989, graphite aluminum drive shafts entered the automotive market on GMC and Chevrolet pickup trucks. The drive shafts, developed jointly by Hercules Inc. (Wilmington, Del.) and Dana Corporation (Toledo, Ohio), offer a 60 percent weight reduction versus a two piece steel assembly.[134]

Another unique MMC product application is a gray-iron brake drum with a series of equally spaced steel wires as the reinforcement. This brake drum is produced by Budd Co. at their Wheel and Brake Div. (Farmington Hills, Mich.). Budd Co. claims that the steel reinforced brake drum will provide 30 percent longer drum life over traditional gray-iron drums. As of June 1991, more than 10,000 had been shipped for use on CL 7 and CL 8 trucks and trailers. The steel reinforcing wire works like the silicon carbide fibers discussed earlier, increasing the rigidity of the drum and helping to prevent crack propagation caused by repeated heating and cooling of the drum.[175]

A very innovative technique is presently in use by Honda Motor Company. The cylinder liners in their 1991-through-1993 Honda Prelude Si engines are made from a MMC that is fabricated at the same time the engine block is cast. Honda takes alumina fiber (12 percent by volume) for strength, and graphite fiber (9 percent by volume) for lubricity, and combines them into a cylinder liner preform set in the engine block during casting. Benefits of the two fiber cylinder liner are reduced weight (versus using cast iron cylinder liners, as is done in Honda's other aluminum block engines), better wear resistance due to the alumina fibers, and improved friction resistance between the piston and the cylinder lining due to the graphite fibers. There is an increase of horsepower from 135 to 140 over the non-MMC engine block, with no increase in engine size, and better cooling.

7.5 Commercial and Other Applications

IDENTIFIED MMC COMMERCIAL and OTHER APPLICATIONS	
• Robot Components	• Gears and Bearings
• Computer Printer Components	• Precision Machinery Components
• Computer Disk Components	• Machinery and Machine Tools with High Speed Reciprocating Parts
• Computer Tape Drive Components	• Electronic Packaging
• Centrifuges	• Pump Housings for Chemical Processing
• Wheelchairs	• Furnace Components
• Battery Plates	• Generators
• Tire Stud Jackets	• Aerial Ladders - Fire Trucks
• Medical Implants	

Figure 7-5. MMC Commercial and Other Applications

7.5.1 Theoretical Commercial and Other Applications

A key specific property of MMCs, corrosion resistance, provides MMCs with crossover potential for hardware fabricated for applications such as bolts for use in chemical plant equipment. Other similar applications include tubing for nuclear power plants, heat exchanger panels in refining plants, nozzles for smokestacks, and bearings for high-speed conveyors.

Other identified potential applications run the gamut from the office to the construction site. These include natural gas pistons; small engine connecting rods; flame spray wire; copier end fuser caps; compression scrolls; truck tractor rails; equipment brake rotors; fire hose connectors; aerial ladders, fire trucks; battery plates; computer magnetic disks; computer tape drives; earth moving equipment; high speed machine tools, rotating shafts and rotating equipment; packaging machinery; robot arms; and turbines.

A potential application in the medical field is a very stiff and lightweight wheelchair constructed from MMC components.[393]

Another potential application is use of cast MMCs in NASA's Advanced Space Suit. Instead of fabric, parts of the upper torso would include a number of rigid sections. These sections can be hermetically sealed and show no outgassing in reduced pressure, hence making them "ideal" for this application.

7.5.2 Prototype Commercial and Other Applications

In the medical field, joint replacement implants are being investigated. The MMC titanium alloy implants, besides being stronger and lighter, are less reactive in the body and offer improved flexibility over their metal counterparts. However, approval for use through the Food and Drug Administration can take as long as five years.

MMCs can support a host of potential applications in the electronics field. Packaging materials support and protect integrated circuits and other electronic components. Properties that make MMCs attractive to the electronics industry include improved heat dissipation (high thermal conductivity), hermeticity, low thermal stresses, light weight, electromagnetic shielding and better vibration control. These properties lend themselves to applications for electronic, microwave, photonics and laser diode packaging. Particular component applications include printed circuit boards, package mounting plates, heat sinks, electronic enclosures and covers. Many companies have produced a variety of packaging products, from integrated chip (hermetic) covers to avionics racks and supporting structures.

7.5.3 Actual Commercial and Other Applications

Cercast (of Montreal, Canada) has had considerable success in their electronics packages, which are being sold under the names Stablite and Lite-var. These two products are aluminum composites, which offer the same basic properties as conventional metals at one-quarter to one-fifth the density. Stablite is a silicon carbide reinforced aluminum, while Lite-var is a graphite preform reinforced aluminum.[130]

7.6 Recreational Applications

IDENTIFIED MMC RECREATIONAL APPLICATIONS	
• Bicycle Frames	• Golf Clubs - Heads and Shafts
• Bicycle Sprockets	• Arrow Shafts
• Tennis Rackets	• Motorcycles
• Fishing Poles	• Boat Masts and Spars
• Skis	• Exercise and Playground Equipment

Figure 7-6. MMC Recreational Applications

7.6.1 Theoretical Recreational Applications

Potential MMC applications for recreation include motorcycles, skis, marine hardware and structural elements, fishing rods, playground and exercise equipment, bicycle sprockets, golf club shafts, and arrow shafts.[393, 394]

7.6.2 Prototype Recreational Applications

Textron has prototyped bicycle frames from 48 percent silicon carbide/aluminum continuous fiber.

7.6.3 Actual Recreational Applications

MMCs are used in bicycle frames and golf clubs. Specialized Bicycle Components Inc. (Morgan Hill, Ca.) markets the Stumpjumper M2 mountain bicycle. The bicycle's frame is made from extruded oxide reinforced aluminum made by Duralcan. Langert Golf Co. Inc. (Carlsbad, Ca.), is the first golf club company in the industry to utilize MMCs. Langert markets the "Fat Eddie Ceramic Wood" driver, which contains a MMC club head. The club head is a silicon carbide reinforced aluminum manufactured by Duralcan. It is one-third the weight of steel with equivalent hardness properties, allowing for an expanded sweet spot on the face of the club and a more forgiving performance for off center hits.[137]

Also of note, during the 1970's commercially available tennis rackets utilized boron/aluminum for the frames.[148]

7.7 Applications - Summary

The introduction of MMCs into actual applications has been sparse and fragmented. No true high volume applications exist to date. As stated earlier, a few large applications exist such as the Toyota diesel piston and the Honda prelude engine. Both of these applications are significant in that they do not attempt component replacement with MMCs, but utilize the advantages of MMCs to improve the existing component through selective reinforcement. This methodology of selectively reinforcing a part or component with MMCs might help to prove the capabilities of the composite while keeping initial costs down. The advantages of MMCs can be obtained without incurring the increased cost of a completely manufactured MMC component.

To promote further use of MMCs, some fundamental events must occur. The cost of the composite must be reduced, most probably by improving the manufacturing processes used to create the composite. A better chemical and physical understanding of MMCs must be developed so that designers can use the material with confidence. Finally, applications with MMCs designed into them from the onset will provide the greatest potential for performance improvements.

8.0 Technical Barriers to the Advancement of MMCs

Despite a U.S. MMC investment strategy that has spent 1/2 billion dollars in the past 15 years to improve our understanding of MMC fabrication and increase MMC producibility, major impediments exist to the technological advancement and further widespread application of MMCs. For the purposes of this report, these impediments will be divided between general impediments, those barriers that are applicable across the entire spectrum of MMCs, and technology gaps, those impediments related to a specific type of MMC or MMC process or component. Since many members of the MMC industry interviewed for this report indicated that most of the conclusions found in the September 1991 AIA/NCAT report "National Advanced Composites Strategic Plan" are still valid, this section draws heavily upon the AIA/NCAT publication for its content and recommendations.

8.1 General Impediments

The purpose of this section is to describe the impediments to MMC advancement that apply to most, if not all types of MMCs. The impediments described in this section are broader in nature than those that will be described under the Technology Gap section. These general impediments include cost, lack of commercial applications, lack of standardized design and analysis techniques, CTE mismatch between matrix and reinforcement, thermal management, nondestructive evaluation, and the ability to repair and recycle MMC products. Each of these is discussed in the following paragraphs.

8.1.1 Cost

Cost is the principal constraint to the pervasive use of MMCs. In addition to the high cost of processing and fabrication, MMC development costs tend to be high due to the technical complexity of the material. It is therefore essential that any MMC program planning activity provide guidance on how to streamline development costs and to bring down processing and fabrication costs. Discussions with numerous government and industry proponents, though, indicated that cost will continue to be problem number one for MMCs for the foreseeable future.[139]

The two main cost drivers affecting the final MMC product are raw materials and processing methods. Raw material costs of high performance metal alloys are traditionally high. The cost of the reinforcements is also high, with some continuous ceramic fibers running more than US $1000 per pound. Primary and secondary processing of these alloys to forms suitable for producing MMCs further increases the cost. This exorbitant cost has forced many potential MMC end-users, both military and commercial, to look for other alternatives to meet their high strength, low weight, and thermal management requirements.

8.1.2 Lack of Commercial Applications

As indicated in section 7.0, the current market for MMCs is concentrated in the high performance aerospace industry. Few large scale commercial applications, though, have been developed or evaluated. Transfer of technology to the commercial arena is a major driver for achieving high volume production runs and thus a reduction in manufacturing and processing costs.

In order to capture commercial applications, it is vital that the MMC industry be able to compete in these markets. Product improvements as well as cost reductions as discussed above are required. Although the advanced composites industry has a comprehensive technology base from which it can support process and product innovations, continuing efforts to sustain fundamental research and development and improvements in existing MMCs must be made.

In order to meet the material requirements that satisfy the operating conditions and temperatures for future applications (e.g., the proposed High Speed Civil Transport), new matrix alloys and reinforcements need to be developed. These new technologies will be costly to develop and employ expensive manufacturing processes in the initial stages.

8.1.3 Lack of Design and Analysis Techniques

A number of general impediments pertain to the design and analysis of MMCs. These impediments are described in this section and include the need for standardized testing procedures, reliable analytical modeling techniques, material databases, and Federal and industry standards.

8.1.3.1 Lack of Standardized Testing Procedures

Accurate and reliable material property testing is the first and foremost requirement for the successful design and analysis of MMCs. Testing of MMCs requires specific attention to the fundamental behavior of the microconstituents and how they interact on the macroscopic level. There are currently numerous test methods and private data bases in use throughout industry. This has resulted in considerable property variability appearing in the open literature. Standardized methods of testing and reporting results are a prerequisite to the establishment of composite properties for design and process modeling. The lack of standards represents a significant barrier to the transfer of test results from one structural application to another.

8.1.3.2 Lack of Reliable Analytical Modeling Techniques

Numerous analytical models are available for predicting the performance of MMCs, ranging from simple equations to numerical simulation (finite element analysis). Using these models, engineers have the ability to gain nominal insight into the numerous factors which govern the behavior of MMCs. The use of global assumptions in place of either constitutive equations or specific material behavior, though, bounds the reliability of these techniques. In addition, limited knowledge of fundamental deformation and damage mechanisms, as well as fracture and fatigue, lead to interpretational differences among researchers.

8.1.3.3 Lack of Widely Accessed MMC Material Databases

The lack of a comprehensive properties database is often cited as a barrier to the further implementation of MMCs. This is not surprising based on the large number of processing options and materials combinations being pursued. The cost of developing design allowable data is substantial unless a relatively high value application is present. Such applications, however, will be restricted until the necessary data development is completed. This circular dilemma is being addressed through government programs such as Title III.

A concise and comprehensive materials property data base is critical to the success of MMCs. Designers and engineers require a statistical foundation comparable to the monolithic materials. However, the designers' and engineers' requirements must be balanced against the need to protect the proprietary rights to competing MMC technologies and processes. Any MMC materials database to be developed must contain controls on the transfer of proprietary data while also allowing the free flow of non-proprietary ideas.

A common accessible data base does not currently exist for continuously reinforced MMCs. Because few material systems are in full production, few fiber/matrix systems have been subjected to a complete characterization. As the titanium-based composite system matures, more effort will be focused on generating design data. To allow cross-referencing and centralized access to data bases, industry standards for test specimen design, test methods, and data reporting formats must be finalized.

8.1.3.4 Lack of Federal and Industry Standards

Users of engineered materials have a wide range of expectations that are not easily met by emerging technologies. Development of MMCs is often driven by unique application requirements, whereby expanded market potential is uncertain beyond the initial application. In addition, during the initial design stage, material specifications and requirements may be unclear; making it difficult for material suppliers to respond effectively to market needs.

Design engineers' lack of experience with MMCs must be resolved in order to familiarize them with the benefits of the materials. MMCs can be uniquely tailored to meet application requirements, but this requires a level of expertise, as well as the availability of design databases that are lagging. Inexperience can lead to failure in part fabrication and the non-qualification of the material as a candidate of choice.

8.1.4 Coefficient of Thermal Expansion Mismatch Between Matrix and Reinforcement

Currently available MMC reinforcement fibers do not satisfy the goals of high coefficient of thermal expansion to match those of potential matrices. Fiber/matrix chemical compatibility, low density and high temperature strength and modulus are also issues involved in the combining of matrix and reinforcement. Fiber candidates are in the process of being identified. Promising fiber processing techniques include floating zone, single crystal, fiber growth technique, chemical vapor deposition, physical vapor deposition methods, and a high rate, hollow cathode magnetron sputtering process.

8.1.5 Nondestructive Evaluation

Nondestructive evaluation (NDE) is a critical step in the development of metal matrix products. Industry's NDE database on processing anomalies results from three primary techniques: 1) radiography for detecting and characterizing a variety of fiber discontinuities such as broken, displaced, and crossed fibers, 2) ultrasonic scan for detecting lack of consolidation, delamination, and porosity, and 3) penetrant for detecting surface skin cracking. To date there has been some destructive verification of the above described defects on actual part configurations.

Further MMC NDE development is required in the following areas:

1) Defect verification and categorization,
2) Acceptance criteria,
3) Test standardization, and
4) Test automation.

Defect verification and categorization is an important continuing effort since new and different part configurations may yield defect types unique to the specific part. Acceptance criteria is a joint effort between design, structural, and NDE engineers using analytical data to define realistic acceptable defect information. The standardization of test techniques to verify detection of rejectable defects is particularly critical to production scale processing.

In addition to the above techniques, advanced NDE methods such as infrared imaging, holography, acoustic emission and computed tomography also require further development.

8.1.6 Repair

As with all aerospace structures, damage to MMC structures is expected to occur sometime during their lifetime, whether it is the result of offensive attack in the military arena or simply an overload/fatigue cracking or delamination in civil or military applications. Like monolithic materials, the addition of a patch repair by riveting or bolting is a viable option. In most cases, however, similar to the case of resin based composites, drilling holes in the base material will cause stress risers (thus weakening the structure) and alternative approaches are required. Very little work has been conducted in the area of metal matrix repair.

There are two basic types of damage conceived for MMCs. These are where (a) the matrix is delaminated or separated from the fibers (which themselves remain intact), or (b) the fibers are broken. For both cases significant development efforts are required. In (a), repair techniques are required to re-bond the metal to the reinforcement. If the part can be easily removed and returned to a repair facility then pressure and heat can be applied either in a matched die press or in a hot isostatic press. By these processes, the metal is rebonded in a manner similar to the original fabrication technique. On-site repairs will require locally heating the repair area without creating severe material distortions and oxidation of the metal. One technique to be evaluated is local enhanced energy spot welding to fuse small areas of delamination. Severe areas of delamination possibly can be injected with a resin/metal powder mixture with subsequent heating to volatilize the resin binder. Fusion of the powders can be accomplished using focused infrared, induction or plasma torch heating techniques. The development of Transient Liquid Phase Bonding metal powders will assist in reducing the level of required heat. A localized inert environment can be achieved using inflated plastic enclosures.

In (b), where damage to the fibers has occurred, material additions are required to strengthen the damaged area. If the component can be removed and returned to a repair facility, then a patch repair can be brazed, welded or diffusion bonded to the surface using techniques similar to those used in the original fabrication procedure. On-site material reinforcement can be added by building up layers of a pliable composite monolayer over the damaged area. These monolayers are approximately five mils in thickness and are sufficiently pliable to be 'mated' under vacuum pressure. If each monolayer is coated with a layer of eutectic braze alloy, then, within the vacuum bag environment, the monolayers can be brazed to each other and to the base component using local heating techniques.

8.1.7 Recycling of MMC Scrap

Concerns have been expressed regarding the segregation and recycling of scrap generated during the processing of MMCs. The percentage of scrap is dependent upon the process and also varies from company to company. Some information is becoming available on remelting and casting composite scrap, or recovering the matrix alloy by injecting certain gases in the melts of recycled material to remove the reinforcement. This area requires more research effort; otherwise, persisting concerns about scrap and recycling could become a major barrier in the widespread use of MMCs. In the future, requirements of recyclability may have to be included in the design of composite alloys.

8.2 Technology Gaps

A number of technology gaps presently exist in the development of both continuous and discontinuous MMCs. These impediments are divided by MMC type and are technically more detailed than the general impediments described above.

8.2.1 Continuous Fiber Reinforced MMCs

The purpose of this section is to describe those technology gaps that presently exist in the matrix/reinforcement interface of continuous MMCs, the development of reinforcements for continuous fiber reinforced MMCs, and the processing and manufacturing methods used for continous MMCs.

8.2.1.1 Matrix/Reinforcement Interface

The matrix alloy is the base component of the composite and is reinforced with fibers occupying up to 45 percent by volume of the material. The metal stabilizes the fibers in position, distributes the loads between fibers and where necessary protects fibers from environmental damage. Candidate metal alloys are useful over a given temperature range, and as indicated previously, can be divided into low temperature, medium temperature, and high temperature.

The principal technology gap attributed to the matrix alloys for continuous fiber reinforced MMCs is the lack of a tailored interface with the fiber. Alloy modification in conjunction with fiber surface development is required to minimize unwanted reactions and foster reductions in local stresses.

Additional matrix alloy development is required to address the issue of thermal expansion stresses imposed on the matrix. Matrix alloys with high yield strength are required to minimize plastic deformation that results in matrix cracking and hysteresis. Detailed computer modeling studies will aid in defining matrix alloy characteristics.

The status of high temperature continuous fiber reinforced metal matrices can be classed as embryonic, requiring sizable development efforts to be established before applications can be considered.[139] Several low density, high temperature candidate matrix alloys have been identified. Significant research and development is required on those and other alloys to provide sufficient ductility and oxidation resistance. These developments are required in conjunction with advanced fiber development where CTE mismatch can be reduced, and hence deleterious thermal stresses minimized. New (modified) alloys are also required to be produced in the forms required, i.e., foil, powder, and wire.

8.2.1.1.1 Fabric

A fabric of woven fibers is the principal preform used to-date, being a convenient method for collecting the fibers together into a handleable sheet. Graphite, alumina and other small diameter fibers (tows) are easily woven into conventional uniaxial, bi-directional and multi-axis fabrics. Since monofilaments, due to their intrinsic stiffness, cannot be woven into multi-axis fabrics, they are limited to uniaxial fabrics utilizing pliable metal cross weave ribbons in the 'fill' direction.

Monofilament fabrics are presently limited in size due to the lack of wide looms suitably modified for weaving the large stiff fibers. Advanced fabrication methods are required to produce cross weave ribbons from the brittle titanium aluminide and other intermetallic alloys.

8.2.1.1.2 Foil

Thin layers of metallic foil can be interleaved between layers of fabric and hot pressed together to form the MMC. This assembly procedure is called the foil-fiber-foil technique. Typically, the foil is between two and four mils in thickness and is produced by conventional mechanical rolling techniques, or, in some cases, by chemical thinning methods. Equipment is currently in place for production of continuous foil from conventional aluminum magnesium and titanium alloys.

Titanium aluminide alloys and other high temperature intermetallic alloys, due to their low ductility, are extremely difficult to roll. Advanced rolling equipment is currently being installed to evaluate advanced rolling processing. However, the size limitations are still an issue. Foil joining techniques are also required.

8.2.1.1.3 Thermal Spray

As an alternative to the use of 'fabric' and 'foil', thermal spray methods are used to produce sheets of collimated fibers immersed in the metal matrix alloy of choice. This is currently achieved by winding the fibers side-by-side onto a circular drum and then over-spraying with liquid metal. The metal penetrates between the fibers (ensuring fiber separation) and locks the fibers together into a handleable metal-fiber sheet preform. Two methods of thermal spraying have been developed for composites: plasma spraying, utilizing high radio frequency energy to melt metal powder feedstock, and ARC spraying, stoking an arc between two metal wires. In each case, a high velocity inert gas drives the molten droplets onto a pre-positioned array of fibers.

It is generally accepted that for titanium aluminides, and very high temperature intermetallic alloys, their forms (powder and wire) and associated processes require considerable development in order to produce quality material with required properties. Present processes are limited to batch production methods and are expensive. Continuous tape production systems analogous to resin composites are required.

8.2.1.1.4 Cast Tape

Cast tape is another alternative to the foil/fiber and thermal spray preforms; this method locks the collimated fibers together in a sheet preform with a mixture of metal powder and an organic (resin) binder. The resin binder, being a low char yield compound, is burned off and evacuated during the tool heat up cycle.

Further development of organic binders and composite molding procedures are required to ensure full and complete volatilization of resin during consolidation, without deposition of residual char with the composite. This may be impracticable for large thin sections requiring vacuum extraction through very small passages.

8.2.1.1.5 Coated Fibers

Metal coating techniques are typically used for facilitating the addition of metal into bundles of small diameter carbon fibers. In addition, metal pre-coated monofilaments are used to ensure fiber separation in fatigue-critical applications. Fibers are coated with copper by electroplating methods. For other alloys, physical vapor deposition methods such as sputtering are used.

Since electroplating is not applicable to all metals, sputter coating is a viable procedure for all low, medium and high temperature alloys available in the target form. Further development is required to increase metal deposition rates and establish large scale production systems.

8.2.1.2 Reinforcements

A number of technology gaps exist in the development of reinforcements for continuous fibers reinforced MMCs. These gaps are described in this section.

8.2.1.2.1 Fibers

The major technology gap with respect to most reinforcement fibers is cost and producibility. The fibers are produced in small quantities compared to the typical industrial scale. Demand levels have not yet justified the development or utilization of efficient large scale production methods.

Another technology gap with respect to fibers, as discussed above for the matrix, is attributed to the lack of a tailored interface with the matrix. Surface modifications in conjunction with matrix alloy development are required to minimize unwanted reactions and to further reductions in local material stresses.

8.2.1.2.2 Coatings

The major technology gaps in the area of coatings relate to coating properties and cost. Fiber coatings which protect the fiber from chemical attack or mechanical damage can result in non-optimum interfaces with the matrix. The interfaces might be weak, leading to low stress fracture for certain loading directions, or can adversely affect matrix structure by, for example, enhancing phase changes. A primary goal is to engineer coating structures and compositions to optimize composite properties. Cost reduction is also an acute problem, particularly with alumina coatings.

8.2.1.3 Processing/Manufacturing Methods

A variety of methods are currently used for consolidating the fiber reinforced metal composites. These include various forms of liquid metal casting as well as solid state processes that require the application of high pressure at high temperatures.

For the liquid metal casting process, molten metal is forced into a fibrous fabric preform by action of a differential gas pressure, or alternately in a pressureless infiltration process, by wetting of the fibers. The process has the potential for fabricating near net-shape components with complex geometries, at relatively low cost. The key technology issue is developing a fiber surface or coating that protects the fiber during processing, reduces reactivity, and provides a wettable surface.

Liquid metal infiltration is a special form of liquid casting, where bundles of dry fibers are passed continuously through a bath of metal, exiting through a shaped orifice to form constant cross section shapes such as rods, bars and angles. Graphite and SiC fibers have successfully been used to form shapes. Due to the extreme reactivity of molten metal with fibers, liquid metal casting generally is limited to low temperature metals such as aluminum, copper, and magnesium.

Maintaining uniform reinforcement distribution, good matrix bonding, and lack of voids are key processing and manufacturing issues requiring further development of molding equipment, processes and wettable fiber surfaces. Large scale production equipment and methods must also be developed to reduce cost.

8.2.1.3.1 Pultrusion

Pultrusion is an extension to the liquid metal infiltration process. Fibers or preforms are first coated with metal and then drawn through a hot drawing die to form tubes, rods, wire and other shapes. The metal is maintained in the solid state, requiring only a heating furnace and a shaping die. Die design is critical because the axial tensile forces of pultrusion must be converted to radial compressive forces in order to promote bonding. The advantages of pultrusion over liquid metal casting are that the pultrusion method produces shapes at a lower temperature, thereby removing many adverse fiber matrix reactions and enhancing bonding. Fabrication of MMC shapes can currently be conducted at temperatures up to 2192 degrees F allowing a broad range of alloys to be used. Many graphite and silicon carbide/aluminum shapes have been produced.

The principal technology gap in pultrusion relates to the lack of demonstrated capability for production of medium and high temperature composites and requires further development of material processes (e.g., coated fibers) and die technology. In addition, presently available prototype equipment requires further development to produce continuous, low cost product shapes.

8.2.1.3.2 Diffusion Bonding Techniques

In order to produce complicated MMC shapes from titanium and other high temperature alloys, solid state diffusion bonding (hot pressing) techniques have been developed. Using the foil-fiber-foil and plasma spray preforms, panels and simple shapes are produced employing vacuum hot presses or heated ceramic die presses with vacuum sealed steel bags enclosing the composite materials. (Vacuum extraction systems are employed to remove organic binders.) While this procedure is useful for consolidating MMC parts, it is limited to relatively simple part geometries and component sizes that are within the hydraulic ram pressure and die capabilities.

The hot isostatic press (HIP) technique uses one-sided ceramic or steel tools to form complex shape parts. The metal and fiber preforms are placed into the mold, and positioned for formation of the desired thickness and shape. Subsequently a metallic bladder is placed over the composite area and vacuum sealed to the base tool. Subjected to heat and pressure in a HIP, the metal is forced around the fibers and consolidated against the shaped die surface. Many shapes have been fabricated by this process, using material such as boron/aluminum and SiC/titanium.

The diffusion bonding processes have successfully produced a variety of shapes and configurations. The technology gaps are in the area of cost, repeatability and capacity where items such as material handling, tooling, HIP utilization will require significant attention. Intelligent processing techniques now under development are designed to address these gaps.

8.2.1.3.3 Secondary Processing

The lack of ductility of the high performance reinforcing fiber limits the degree of subsequent forming of the consolidated material. In addition, machining and forming of the MMC can be very expensive. Hence net shape molding is generally the accepted practice for fabrication of fiber reinforced metal shapes. Where a relatively simple geometric shape is required, however, subsequent forming of flat consolidated metal matrix panels may be both technically sound and cost effective.

As with the net shape molding method discussed previously, secondary forming techniques have been successfully demonstrated. Manufacturing technology efforts are now required to develop the full potential of the processes and reduce costs to increase applicability. As commercial applications are identified, the development of appropriate secondary processing data bases, modeling and testing techniques become critical.

8.2.2 Discontinuously Reinforced MMCs

Discontinuously reinforced MMCs are available in a range of product forms, including both conventionally wrought products and cast products. Limitations are primarily in the size of products currently attainable. At the commercial level, discontinuously reinforced aluminum products dominate the market. As with the continuously reinforced MMCs, the gaps are discussed in the following paragraphs. They include matrix alloy development, discontinuous MMC reinfocement technologies and processing and manufacturing methods.

8.2.2.1 Matrices

The matrix exerts primary control over the characteristics of discontinuously reinforced MMCs, and in this regard plays a greater role than in continuous fiber materials. There is increased recognition that improved performance can be achieved in composite-specific matrices, as evidenced by the registration of a number of composite-specific matrix alloys with the Aluminum Association. The development of Al-based composites is now being driven by commercial requirements, whereas high temperature materials have been prompted by IHPTET and HSCT initiatives.

The primary technology gap impeding discontinuously reinforced metal matrices is the development of composite-specific matrix alloys. These gaps are discussed below by formation process: wrought products and cast products.

8.2.2.1.1 Wrought Products

A number of wrought product forms have been demonstrated for discontinuously reinforced MMCs. For example, a SiC whisker/Al sheet has been fabricated for the ATF tail program. Many other forgings and extrusions have been made. In-situ TiC/Al wrought products are available on an experimental basis. For high temperature applications, Martin Marietta's XD-CU is available experimentally in sheet form.

In the area of wrought products there is a need for improved understanding of deformation processing effects on materials. In addition, larger scale starting materials to better fit into conventional fabricating operations for improved efficiencies are required.

8.2.2.1.2 Cast Products

The use of cast liquid metal matrices can reduce the cost of processing since one can achieve either intermediate shapes for further deformation processing or net shape products. However, cast liquid metal processing provides additional challenges for matrix alloy selection. Reactivity is a critical concern. For example, SiC is thermodynamically unstable in liquid Al, and hence will degrade unless exposure times are very short or the matrix alloy contains a substantial amount of Si. Even more thermodynamically stable reinforcements, such as alumina, react with aluminum alloys. It should be noted that in-situ formation of the reinforcement overcomes these reactivity issues due to the stability of the reinforcement phase.

For lower temperature cast matrices such as aluminum, the primary need is for the development of high performance matrices to accept the new thermally stable reinforcements. For higher temperature cast matrices, incompatibility between available reinforcements and matrices needs addressing, as does the formulation of advanced composite systems, where development is focused on the reinforcing phases and matrices as a unified system.

8.2.2.2 Reinforcements

The reinforcements used in discontinuously reinforced MMC's are generally ceramic in nature and can either be added to the matrix as discrete elements or formed in-situ in the matrix. Reactivity with the matrix during fabrication and service, CTE difference with the matrix, and cost/performance in the finished product are the critical reinforcement selection criteria used. Reinforcement technology gaps are discussed in the following paragraphs and are organized as particulates gaps, whiskers gaps, and in situ reinforcement gaps.

8.2.2.2.1 Particulates

Particulate reinforcements are primarily SiC and alumina of greater than 1 micron in size, as these materials represent a good compromise between density, property improvement, and cost. Other particulate products, including boron carbide, graphite, TiC, and TiB_2 have been studied. Due to their equiaxed shape, the particulate reinforcements provide fairly isotropic property improvements. Modulus increases of 35-60 percent are provided in the range of reinforcement volume fractions typically used for structural applications. To increase the applicability of particulate reinforcements, though, higher strength particulates are needed.

8.2.2.2.2 Whiskers

Whisker reinforcements, generally less than 1 micron in diameter with initial aspect ratios of 50:1, offer potentially improved properties over particulate reinforcements.

To date, the only improvements over particulate materials that have been realized are increased stiffness in the working direction (due to whisker alignment and higher strength). Although research, such as that on streamlined extrusion dies, has demonstrated that higher whisker aspect ratios can be achieved in final deformed products, the need for commercial scale-up for this process must be demonstrated. As with most things associated with MMCs, whisker costs must be reduced. In addition, modified processing approaches are required to improve whisker strength.

8.2.2.2.3 In-Situ Reinforcement

An alternative reinforcement process is the in-situ formation of the reinforcing phase. In-situ reinforcement overcomes some of the processing difficulties of the traditional approaches. Specifically, a wide variety of reinforcements of controlled size, shape, and reinforcement level have been produced in a range of metal and intermetallic systems. While there has been substantial government funding and commercial interest in this technology, in-situ reinforced products are currently less developed than the traditional particulate and whisker reinforced materials.

In the area of in-situ reinforcement there is a need for the continued development of reinforcement chemistry and processing for optimum properties. This development will assist in expanding the manufacturing technology knowledge base and contribute to the composite material databases as they are developed.

8.2.2.3 Processing/Manufacturing Methods

A wide range of processing and manufacturing methods for discontinuously reinforced MMCs have been developed by a variety of producers. These include ingot casting, net shape casting, and secondary deformation processing and are discussed in the paragraphs below. All basically involve blending of the reinforcement and either elemental or prealloyed powders, a consolidation including cold pressing, degassing, and hot consolidation (either under pressure or in a vacuum), or some subset of these steps. Particularly in aluminum-based alloys, the consolidated billets typically are subjected to further deformation processing in order to enhance structural properties.

A systematic study of the effects of processing/manufacturing methods to establish the process-structure-property trade-offs is sorely needed. The goal of such an effort would be to reduce costs and increase the size capability for processing/ manufacturing products.

8.2.2.3.1 Ingot Casting

The attraction of ingot casting is the potential for producing billets capable of being fabricated on the large scale equipment currently employed for monolithic alloys. This approach will capture economies of scale. Efforts by Duralcan are underway to produce both round and rectangular ingots. In the ingot casting process, ceramic particles are injected directly into molten metal and blended by mechanical means. Melt viscosity limits the volume fraction of the reinforcement to approximately 25 volume percent. Direct in-situ processes generally are limited to low-loading composites. Martin Marietta's XD is a hybrid approach in which high loading in-situ-derived master alloys are used to produce MMCs.

The scale-up of the casting process to larger sizes presents challenges: the effects of the solidification rate on the ingot cell size, and attendant particle-pushing to the last regions to freeze. In addition, since matrix-reinforcement reaction is a critical issue in some systems, larger ingots will have longer solidification times and therefore more exposure of the reinforcement to the molten metal. New casting methods need to be developed to improve the homogeneity of distribution in large scale MMC ingots.

8.2.2.3.2 Net Shape Casting

Casting-to-shape offers an economical approach to achieving part configurations at minimal secondary processing cost and maximum material use. Depending on part thickness and casting method, improved microstructures can be achieved through increased solidification rates and imposed pressure, for example, in the pressure die casting process. In addition, some improvements in casting can be achieved due to the thixotropic nature of the MMC melts. Much effort is being expended in introducing discontinuously reinforced MMCs consisting of conventional casting alloys and SiC to foundries for casting into net shaped parts. The automotive industry, in particular, is interested in this process. To gain wider applicability, though, other casting methods need to be developed to improve properties in thick section net shape parts.

8.2.2.3.3 Secondary-Deformation Processing

Many discontinuously reinforced metal composite products require deformation processing via rolling, extrusion, or forging to achieve the final shape. Issues in secondary processing include equipment capabilities, die wear due to the abrasive nature of the reinforcements, and the influence of deformation conditions on microstructure. A better understanding of how deformation processing influences microstructure and properties in these materials is sorely needed.

8.3 Summary

Increased demand in both the commercial and aerospace markets is blocked by the cost of MMC materials and the non-availability of material standards, specifications and databases, as well as the lack of operational experience. The technical complexity of MMC materials and the existing technology gaps also contribute to the lack of demand.

To meet the goals of increased productivity and reduced product costs, both government and industry proponents believe it will be necessary to maximize the return on investment. This will require changes in how the government divides its dollars and how industry views competitiveness. In a period of uncertain defense budgets, it is vital that scarce resources be allocated in a manner that avoids duplication of effort and improves manufacturing skills. There is a perception in the aerospace community that MMCs are too expensive and cannot be fabricated with any degree of reliability. This has resulted in a very low level of funding at the material supplier level directed at improving manufacturing technology and reducing costs. The markets for high performance composites have usually been "one-of-a-kind", as dictated by DOD requirements with short lead times, limited fundamental research, and minimum coordination.

The government and industry MMC proponents believe that the technology gaps can be filled only by a coordinated effort covering basic science, engineering development, manufacturing technology, and field testing. In developing advanced materials, basic science is often neglected due to a perceived need to bring a new product rapidly to the marketplace. Lacking a sound scientific foundation, the in-service performance of the product can be disappointing. Recent studies indicate that support for basic science by both government and industry is declining in the U.S. and may be contributing to the erosion of our competitive position in world markets. A coordinated effort between universities, our national laboratories, and industrial science centers should be structured to effectively utilize resources and avoid duplication of efforts. Major emphasis needs to be placed on development programs covering reinforcements, matrices, and processing that can bring new ideas from the laboratories to create engineered structures.

In addition, government and industry proponents believe that resources must be allocated to manufacturing science and technology at the material supplier level to develop production capabilities for processing new fibers, consolidating composite material, and evolving more effective secondary forming and joining methods. These programs are necessary to gain experience, raise confidence levels, and stimulate designer usage. Demonstration programs involving component fabrication and field testing can be very effective in ensuring suitability but are also very expensive. Thus it is essential that any material system to be demonstrated is fully mature and can be produced reliably with effective quality controls.

Reflecting the implementation of a national strategy, cooperative, generic programs supported by both industry and government hold the best promise for achieving MMC development goals. These could take the form of NASP-type consortia where major aerospace industry players divide up the core technologies and avoid duplication of effort. Another example is the 3M-DARPA "factory" concept that involves material suppliers, end users, and the government in a cooperative venture. An MMC applied research center where R&D programs and property evaluations are carried out by suppliers and users is another possibility.

The above sections identify the critical technological needs that must be satisfied in order to broaden the role of metal matrix composites and make them a contributor to national competitiveness. It is important to realize, though, that increased support for science and technology programs is necessary but not sufficient for success of this initiative. Existing policies and practices in government and industry must also be addressed. These policies and practices are presented in Section 10.

9.0 Market Assessment of the MMC Sector

For the purpose of assessing the MMC marketplace, the process of inserting an MMC into an end product is divided into four stages (See Figure 6-6 and the accompanying discussion). This process consists of raw material production, MMC production, MMC fabrication, and the sale of an end product. Raw material producers are at the front of this process. Because these companies synthesize more primitive raw materials to provide the starting products for MMC production, these companies are referred to as raw material producers rather than raw material suppliers. There are two categories of raw material producers: matrix producers and reinforcement producers. The second step in the process of creating an MMC end use product is performed by MMC producers. Here there are two categories as well. Some MMC producers combine matrix and reinforcement raw materials to produce MMC raw material in the form of extrusion billets, foundry ingots, or rolling slabs that are sent to secondary fabricators for transformation into a final product. Other MMC producers create either net or near net shape parts that are inserted into the secondary fabrication process. These products require less secondary fabrication than MMC raw material. In the third step of the process, secondary fabricators convert MMC raw materials or MMC parts into usable product forms. For instance, secondary fabricators may receive an MMC billet, extrude the billet to create MMC tubes, and then weld the tubes together to form an MMC bike frame. Each of these secondary processing activities may be performed by a different company. The final step in the process of inserting an MMC into an end product is selling end products containing MMC materials to end users. For the purpose of this report, these end users are categorized into various user markets.

This section focuses on MMC producers who manufacture material in the form of billets, ingots, rolling slabs and near net shapes and MMC end users who generate a demand for MMC materials. Specific MMC producers are identified and their capabilities are discussed and quantified where possible. In addition, MMC end user markets are identified and quantified where possible; factors driving these market demands are discussed.

While raw material producers and secondary fabricators are important to the MMC marketplace, these entities are not the focus of this report. The interaction of these entities with the MMC producers and end users is discussed at a high level. Any relevant information collected through the course of this study is presented as well. When MMC production capability and MMC product demand are balanced to provide a thriving marketplace, raw material availability and secondary fabrication may provide significant limitations in the continued success of the MMC marketplace.

In addition to discussing the MMC marketplace cycle, this section discusses potential dual use applications that may help ensure the survivability of the North American defense industrial base. The discussion includes current defense industrial base needs related to MMCs, potential future defense industrial base requirements, and commercial technologies that could be leveraged to support these needs.

9.1 Domestic/North American MMC Producers

This section provides an overview of companies currently supplying MMC materials. Figure 9-1 presents a distribution of MMC producers in North America. These MMC producers are Duralcan/Alcan, Amercom, DWA, Advanced Composites Materials Corporation, Textron, 3M, Alcoa, Lanxide, Ceramics Kingston Ceramiques, California Consolidated Technologies, Rolls Royce, Fiber Materials Incorporated, and Martin Marietta. The companies identified throughout this section represent a non-exhaustive listing of the North American companies supplying MMCs; the companies do represent the <u>major</u> companies currently supplying MMC material. Products, market focuses, applications and other issues influencing company marketing strategies and efforts are presented in this section.

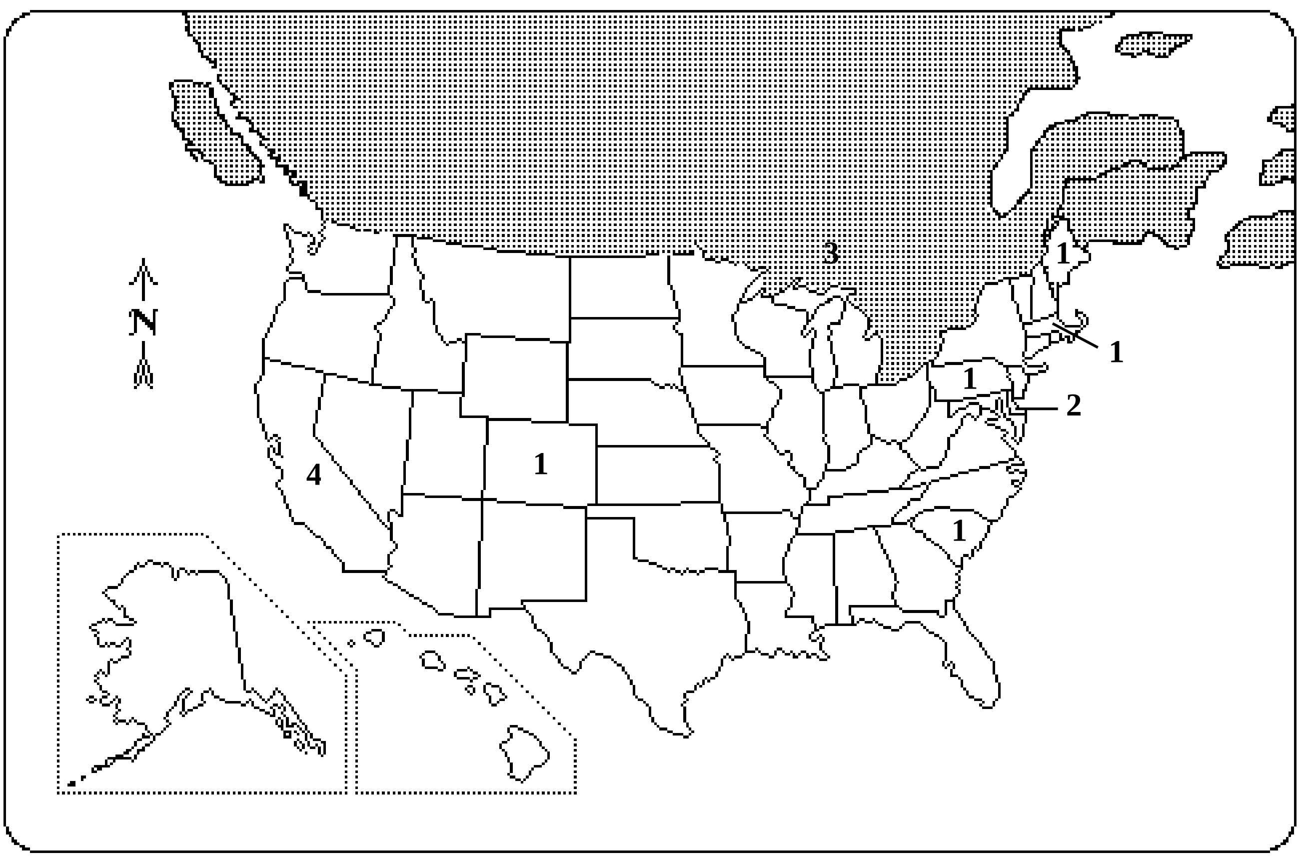

Figure 9-1. North American Distribution of MMC Producers

Figure 9-2 quantifies current and potential production capabilities of several domestic MMC producers. Because they regard the information proprietary, some of the companies were unwilling to provide current sales figures (either in volume or dollars). Others were not willing to estimate sales because no current market for their material exists and material produced is provided to companies for characterization, testing, or other R&D activities.

Company	Material	Sales Vol/ Year (lbs or units/year)	Production Capability (lbs or units/year)
Duralcan/Alcan	Low Volume Particulate Reinforced Metals	1,000,000 lbs	25,000,000 lbs
Amercom	Boron Aluminum Graphite Reinforced Metals	400 lbs/Space Shuttle Minimal	3600 sheets (32 in x 122 in) 200,000 units
DWA	Particulate Reinforced Aluminum Graphite Reinforced Metals Monofilament Comps	Proprietary	150,000 lbs 1000 - 5000 lbs 3000 - 5000 lbs
ACMC	Whisker Reinforced Aluminum	Proprietary	150,000 lbs
Textron	Fiber Reinforced Metals	800 lbs 100% T&E	2000 lbs
3M	Fiber Reinforced Metals	Minimal 100% T&E	Minimal
Alcoa	Low Volume Particulate Reinforced Metals High Volume Particulate Reinforced Metals	15,000 lbs 1000 parts	500,000 - 800,000 lbs 10,000 - 30,000 units
Lanxide	Low Volume Particulate Reinforced Metals High Volume Particulate Reinforced Metals Fiber Reinforced Metals		500,000 lbs
CKC	Whisker Reinforced Metals	Minimal 100% T&E	Minimal

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Figure 9-2. Domestic MMC Supply Capabilities

9.1.1 Duralcan/Alcan[130,438]

Alcan, a Canadian company, purchased their current discontinuously reinforced cast MMC technology in 1986 and created Duralcan, USA. Since that time, Duralcan has taken a unique approach to marketing this technology. They are strictly a raw material producer of low cost MMCs, with little interest in producing MMCs in net or near net shapes. Duralcan products come in the form of extrusion billets, ingots and rolling slabs. Their customers include extruders, foundries, and machinists. Duralcan has developed their technology and current production capabilities using internal funds; Duralcan has not received any government funding supporting their technology.

Duralcan has focused their marketing efforts on applications that require high material volume. They believe the automotive industry offers the best potential for high volume applications. Duralcan is focusing their efforts on developing brake rotors for all cars and drive shafts for light trucks as well as other applications within the automotive industry. Duralcan material has been used to make rear brake rotors and drive shafts that are currently being tested on several vehicles. Specialized Bicycle Components Inc., a bicycle manufacturer, has been producing mountain bike frames with Duralcan material for three years. In the first two years, Specialized sold approximately 17,000 MMC bike frames; they are expecting to sell between 20,000 and 30,000 frames this year. Duralcan understands that this type of application will not provide the tonnage they desire, though it is providing publicity for their material as well as solid support for their continued development of other markets. Duralcan's tire stud business in Finland has provided a consistent and substantial market for their material. Even with this application, Duralcan does not reach their desired tonnage, but it does help support further development efforts. In addition to the areas discussed above, Duralcan's material is currently used in gas piston rings and flame spray for wear and corrosion resistance.

While Duralcan has not been involved in any military applications, they have expressed a willingness to enter this area. They are currently involved in a consortium activity to qualify their material for MIL-HDBK 5, general use in aerospace application. Duralcan believes involvement in military applications is very expensive due to the qualification process and time lag necessary to develop a market.

Duralcan is probably the leading producer of MMC material in the world today. Duralcan estimated their current sales volume to be around 1,000,000 lbs/year. They have a production capacity of approximately 25,000,000 lbs/year. Duralcan's position at the forefront of the industry would appear to be enviable, though it is also an expensive position due to Duralcan's efforts to educate the community on the use and fabrication of discontinuously reinforced cast MMCs. Duralcan is spending internal funds to educate and train foundries, extruders, machinists, and others to work with their material. While this investment benefits Duralcan, it also potentially benefits all of their competitors.

9.1.2 Amercom[438]

Amercom is a U.S. owned MMC manufacturer of continuous fiber reinforced MMCs. They are the only NASA qualified producer of boron/aluminum, which is used for tubes on the space shuttles. Approximately 400 lbs of this material is used on each space shuttle. This material has also been used for heat sinks and compression pins in tank rounds. Boron/aluminum offers probably the highest compressive strength of any material, although it is very expensive and is slowly being replaced by graphite/epoxy, which is cheaper, quicker, and easier to produce.

Recently, Amercom has been focusing their efforts on developing graphite fiber reinforced MMCs with aluminum and copper matrices using Amoco's K1100 graphite fiber. Amercom feels they can produce approximately 200,000 graphite reinforced MMC units, or SEM-E type components, a year. At this time, they are producing a minimal number of components for test and evaluation purposes only. These composites provide excellent properties for thermal management applications in both commercial and military markets. The major benefit these materials provide in thermal management applications is weight savings. Because of this, Amercom is marketing their material based on component cost versus traditional cost/pound. Amercom feels they need to improve and scale up their processing capabilities to establish their graphite reinforced MMCs in the marketplace. The primary applications Amercom is examining for their material are for SEM-E boards and other heat sinks. Amercom has not succeeded in producing these products at a competitive price; however, Amercom is working with Texas Instruments in an attempt to establish a market for their material, in order to lower their costs through economies of scale.

9.1.3 DWA[438]

DWA is a U.S. subsidiary of British Petroleum. DWA is one of only a few MMC producers that is involved in both continuous and discontinuous MMCs. In the continuous arena, DWA is looking at monofilament composites as well as graphite reinforced metals. In the discontinuous arena, they have a Title III program to develop a discontinuously reinforced aluminum with SiC particulate reinforcement. Figure 9-2 details DWA's production capability for each of these materials. DWA's production capabilities for all the materials they produce currently exceed the demand for these materials. DWA recognizes the need to shift more from military to commercial markets.

For their graphite reinforced metals, DWA is looking at thermal management applications and lightly loaded structures on space crafts. DWA has produced some graphite/aluminum composites that have been used in the Hubble space telescope. DWA is attempting to qualify their graphite aluminum composites for use on military satellites. For their monofilament composites, such as boron/aluminum and SiC reinforced aluminum and titanium, DWA is looking at applications within NASA and the Integrated High Performance Turbine Engine Technology (IHPTET) program.

DWA's $9M Title III program is the focus of their current activities. This program is allowing DWA to address the market barriers that exist today for discontinuously reinforced aluminum (DRA). More detail on Title III programs in general can be found in Section 10. The market areas that DWA is examining for their DRA materials are aerospace, recreational, automotive, and wear applications. DWA is somewhat skeptical about the potential success of their material in automotive and recreational application due to cost constraints. Aerospace applications offer tremendous potential. DWA's DRA has been used as a replacement for graphite/epoxy to produce extruded electronic racks, and it has replaced beryllium in the Trident II guidance system covering forging. In addition, DWA's DRA is being looked at for space truss tube extensions and for chip carriers on commercial and military satellites. At one time, DWA produced machine pistons and connecting rods for racing cars using DRA. The components were tested and showed considerable performance improvements. However, efforts for long term applications are continuing, based upon life cycle cost and performance, and not by direct replacement costs.

9.1.4 ACMC[222]

The Advanced Composites Materials Corporation (ACMC) is a U.S. subsidiary of a Japanese owned company. They produce whisker reinforced MMCs. In addition, they produce their own whiskers through rice hull pyrolysis. ACMC uses a powder metallurgy process to produce MMCs in billets, sheets, forgings, extrusions, and near net shapes. The main thrust for ACMC is a $24M Title III program. This program has enabled ACMC to validate their MMC material and scale up their manufacturing capability with goals to reduce material cost and establish a market for their material. The target production capability for ACMC's Title III program is 150,000 lbs/year.

Through the Title III program, ACMC has identified and established several military applications. ACMC has supplied MMC sheets for wing patches on the C-130. At least three aircraft have used ACMC's material for permanent wing repairs; the first aircraft repaired has logged over 300 flight hours with no problems. Ten prototype escape hatches have been delivered for use on C-141s. If these hatches pass static testing, the Air Force plans to purchase approximately 30 hatches per year. The C-141 has also flight tested main landing gear actuator struts produced by ACMC. Electronic racks produced by ACMC offer weight reductions in the TR-1 aircraft. Other applications include a prototype rudder for use on the F-15 and a lower spring bungee link pivoting wedge for future flight test on the B-1.

In addition to the military applications presented above, ACMC has produced MMC bicycle frames for Raleigh mountain bikes. ACMC has also been in contact with the automotive manufacturers and is exploring potential applications in this market. ACMC has developed some optical grade MMCs that use high volume loading of SiC for use in precision mirror optics, platforms and associated optical hardware.

9.1.5 Textron[442]

Textron Specialty Materials is a domestic developer and manufacturer of high strength, lightweight, advanced composite materials and components for aerospace, industrial, and commercial markets. Textron produces boron and silicon carbide fibers as well as MMCs reinforced with these fibers. Recently, their focus has been on the development and production of SiC fiber reinforced titanium for use in high temperature applications such as gas turbine components and various aircraft structures. Currently, Textron has a pilot plant that has a production capacity of 2000 lbs/year, a production rate of 800 lbs/year, and a production expansion capacity to 10,000 lbs/year. In addition Textron has done work on SiC fiber reinforced aluminum and boron reinforced aluminum.

The titanium MMCs with SiC fiber reinforcements offer corrosion resistance, high compressive and tensile strengths, high stiffness, high temperature performance and light weight as compared to other materials. The National Aerospace Program (NASP) is looking at these materials for high temperature, structural applications. The Navy is interested in these materials for their light weight and corrosion resistance for use in landing gear on the F-15 and other carrier aircraft. High temperature gas turbine engine components offer extensive applications for these materials as well. Textron is only producing MMC components for test and evaluation purposes. The material has shown impressive properties, but consistent quality and cost remain major obstacles for this material.

Textron feels SiC fiber reinforced aluminum has considerable potential in both military and commercial applications. This material is less expensive than the titanium MMC they produce and the processing associated with the aluminum MMC is more flexible. Textron has worked with Cercast in Canada on investment casting of SiC fiber aluminum MMC components. They have had favorable results, but funding constraints have limited the advancement of this technology. Potential applications for this material include gun barrels, tank tread pins, shuttle components, missile fins, structural aerospace components, and recreational components such as bike frames.

Textron feels there is enormous potential, both commercial and military, for their materials. The establishment of a market and the funding to establish their production capability have been their biggest obstacles.

9.1.6 3M[436]

3M has been active in the MMC arena for five years. The Advanced Research Project Agency (ARPA) is supporting 3M's development of a model factory to produce continuous aluminum oxide fibers for use in continuously reinforced aluminum and titanium. The DOD has invested over $75 million on this program. The primary market identified for these materials is in aerospace engines. 3M feels the aerospace market is in turmoil at this time, but they believe the commercial market will stabilize and the military market may not.

Cost and producibility of fibers are the major barriers facing 3M's MMC capability. In addition, MMC producibility is an obstacle. The lack of a stable marketplace, in particular a commercial demand, will hinder the advancement of 3M's continuous MMCs.

9.1.7 Alcoa[439]

The Aluminum Company of America (Alcoa) is a U.S. owned company currently producing three or four different MMC components with plans to increase their level of activity in the MMC arena. Alcoa's primary MMC products are helicopter components for European aerospace companies (Deutsch Airbus, Aerospatiale). Alcoa believes the future for MMCs, both financial and volume, is in the automotive industry. They have been working with Audi for ten years on introducing MMC engine components. Alcoa has identified many iron engine components as potential targets for MMC replacement. Alcoa is working with Ford to prove the cost effectiveness of an MMC connecting rod; the MMC connecting rod has been shown to be technically viable, offering a 46 percent weight reduction and improved performance.

Alcoa produces two types of MMCs, low volume particulate reinforced aluminum and high volume particulate reinforced aluminum. These MMCs are produced using a solid state billet oriented process and a vacuum die-casting process to infiltrate near-net shape preforms, respectively. Alcoa is capable of producing MMCs reinforced with as much as 75% SiC particles. This level of reinforcement allows Alcoa to pursue demanding applications such as thermal management. Alcoa estimated their low volume reinforcement MMC production capacity at about 500,000 to 800,000 lbs/year and their high volume reinforced MMC production capability at about 10,000 to 30,000 units/year. They projected their sales volume to be approximately 15,000 lbs and 1000 parts for the year.

Alcoa feels their MMC technology is critical to their longevity. At present they have a large aluminum aerospace market. If polymer composites become acceptable for aerospace applications, Alcoa feels their aluminum market could be severely affected. This makes the development of an MMC market imperative to Alcoa.

9.1.8 Lanxide Corporation[441]

The Lanxide Corporation is a U.S. owned company (45 percent owned by Alcan) that develops and commercializes MMC products based on their patented PRIMEX™ and PRIMEX CAST™ processing techniques. Lanxide uses a unique commercialization strategy of setting up joint manufacturing ventures with exclusive marketing rights to all Lanxide technologies. Currently Lanxide has seven joint ventures. Lanxide Electronic Components is 50 percent owned by Lanxide and 50 percent owned by DuPont. This venture is primarily focused on the use of MMCs in electronic packagings, substrates, and supports. Lanxide Armor Products is 60 percent owned by Lanxide and 40 percent owned by DuPont. This venture uses both ceramic matrix composites (CMC) and MMCs to produce land vehicle, aircraft and personnel armor. DuPont Lanxide Composites is 70 percent owned by DuPont and 30 percent owned by Lanxide. This venture focuses on CMC use in aerospace applications with some MMC uses in aerospace structural components. Lanxide KK is 65 percent owned by Lanxide and 35 percent owned by Kanematsu, a Japanese company. This venture has exclusive product commercialization rights in Japan for all Lanxide technologies. Two new ventures are Lanxide Sports International and Lanxide Precision Equipment, both of which are looking at MMCs for high stiffness applications. Lanxide is currently looking to establish a joint venture for the automotive marketplace.

Lanxide's PRIMEX™ process is conducive to manufacturing both continuous and discontinuous MMCs. The focus of Lanxide's efforts have been on discontinuous MMCs. Their processing technology allows them to create a variety of MMC materials with varied levels of reinforcement and material characteristics to support unique application needs. Lanxide's process creates very stable bonds between dissimilar materials.

In the automotive market, Lanxide is looking at brake calipers and brake caliper bridges, brake rotors, connecting rods and piston pins, and cylinder liners. All of these components are considered unsprung weight on an automobile and potentially offer substantial opportunities for weight reduction. One of the armor applications Lanxide is examining is large sheets of heavy armor that are more damage tolerant than ceramics, lighter weight, lower cost, stronger, stiffer and harder than metals. Lanxide is also making macrocomposites of dissimilar materials to build high performance armor arrays. The two primary products of the electronics venture are standard electronic module (SEM) cores for military and aerospace applications and carrier plates for semiconductors and hybrid circuits. One of the newest markets Lanxide is examining is precision equipment and optics. For optical applications MMCs provide tailorable CTEs to match nickel. For precision equipment, MMCs offer low density, high thermal conductivity, and comparable stiffness to replace cast iron. Lanxide is finding this to be a difficult market because material selection for these products is imbedded into prime contracts and the prime contractors prefer to use their own material.

9.1.9 Ceramics Kingston Ceramiques (CKC)[130]

CKC is a privately held Canadian corporation chartered to develop and manufacture new materials, components, and systems based on the use of new material. CKC is a small company with approximately 15 graduate engineers and scientists. Their current MMC activity is in the development of SiC whisker reinforced TiAl, $MoSi_2$, Ti, and Nb_5Si_3 composites produced using powder metallurgy. These composites are developed and sold as experimental materials for various aerospace, engine, and high speed aircraft applications. CKC is currently producing a nozzle reinforced with SiC whiskers for scrubbers in smoke stacks.

9.2 MMC End User Markets

MMC end users have been categorized into the following markets: automotive, recreational, electronics/thermal management, aerospace, armor, precision equipment, and others. For each of these markets, this section discusses applications, the properties driving MMC use for these applications, potential MMC materials to be used, and, where possible, some quantitative analysis of the current and/or potential demand for MMCs in these applications and markets. Establishing a demand for MMC material is crucial to establishing an MMC industrial base capability. MMC production capability and supporting capabilities (e.g., raw materials and secondary fabrication) may present technical challenges, but these challenges will not be overcome without a demand for the material. Government programs and military needs constitute a considerable market for MMCs, in particular, high performance MMCs. Specific government activity is embedded within the following markets.

9.2.1 Automotive

The automotive market represents the largest potential material volume market for low cost MMCs. With an estimated yearly world production of 45 million automobiles (including cars and light trucks), this market offers enormous material volume figures. The most promising near term automotive application for MMCs is rear brake rotors. Approximately six lbs of MMC material is used for each brake rotor, resulting in a potential demand of over 500 million pounds just to support MMC rear brake rotors.[438] There are numerous other components that also offer tremendous potential for MMC use. If in five years there is an average of 25 lbs of MMC material on all automobiles, this will represent a one billion pound per year market.

The technological advantage of MMCs that is driving their usage in automobiles is low weight. The benefits associated with weight reduction in automobiles are dependent on where the weight is removed from the car. Weight reduction in engine components and, in particular, rotating engine components, provides the most substantial benefit. The next most beneficial area for weight reduction is the drive train and suspension. Unsprung weight such as the brakes and transmission provide the next level of benefit with the chassis offering the least benefits from weight reduction. Weight reduction in automobiles can result in improved engine efficiency, reduced noise, reduced emissions, and improved fuel economy.[440] Some of the potential components and the justification for MMC use in these components are summarized in Figure 9-3.

System	Component	Justification
Engine	Piston Crown	High temperature, fatigue, creep, wear
	Pistons	Wear resistance, weight reduction, high temp
	Piston Ring Groove	Wear resistance, weight reduction
	Rocker Arm	Weight, stiffness
	Valve	High temperature, fatigue, creep, wear
	Wrist Pin	Specific stiffness, wear, creep
	Cylinder Block (Liner)	Wear and seizure resistance, low friction, weight
	Connecting Rod	Specific stiffness, weight
	Bearings	Weight, reduce friction
Suspension	Struts	Damping, stiffness
Driveline	Shift Forks	Wear, weight
	Drive Shaft	Specific stiffness, fatigue
	Gears	Wear, weight
	Wheels	Weight
Housings	Gearbox Bearing	Wear, weight
	Differential Bearing	Wear, weight
	Pumps	
Brakes	Disk Rotors	Wear, weight
	Calipers	Weight

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Figure 9-3. Potential Automotive MMC Use

Automotive manufacturers are currently assessing the cost effectiveness of using MMCs. MMC components such as brake rotors, drive shafts, connecting rods, and cylinder liners are being tested on automobiles today. So far, these components meet or exceed current performance requirements while offering lower density materials than currently in use. In addition, these materials have been tested and shown to improve performance in racing cars.

Because the automotive industry is so price sensitive, any cost increase in the production of the car must be well justified in reduced life time cost or improved performance. Secondary processing capabilities and material recyclability are two concerns of the automotive manufacturers.[440]

9.2.2 Recreational

The potential for MMC components in the recreational market is extensive. MMC applications include bike frames and other bike components, golf clubs and tennis rackets. The main properties driving the use of MMCs in these types of applications are low weight and high stiffness, resulting in improved performance. Duralcan's MMC material is being used to produce bike frames for mountain bikes produced by Specialized Bicycle Components, Inc. Other MMC producers are addressing this market as well. Golf club heads are also being looked at by several MMC producers. Discontinuously reinforced aluminum is the most common material being marketed to the recreational industry. With approximately 25 million bicycles sold a year and maybe half of them being produced for the high end consumer ($600 + price range), the potential demand for this market is considerable. The average MMC bike frame weighs between three and four lbs. This represents a potential market between 37.5 and 50 million lbs of MMC material per year.[438]

This market is different from others because material cost is less of an issue. The end products being produced are primarily specialty, high performance products that have enormous markup costs associated with them. Consumers of these items are often willing to pay higher prices for improved performance. The number of applications associated with this market is enormous. As MMCs become more widely used and their benefits are demonstrated and communicated, it is believed that recreational equipment manufacturers will begin to contact MMC producers and fabricators with recommendations for new applications.

9.2.3 Electronics/Thermal Management

The electronics/thermal management market for MMCs is focused on products requiring low density materials with high thermal conductivity, low or tailorable CTE, high stiffness, and high temperature capability. High volume percent discontinuously reinforced aluminum and graphite fiber reinforced metals are the primary MMC materials that provide these properties. Diamond particulate reinforced aluminum is also being considered for some of the more demanding electronic applications. Applications for these materials within this market are electronic packages, circuit board heat sinks, carrier heat sinks, and structural electronic products, such as racks and chassis.

One MMC producer estimated the total potential market for all electronic applications to be as much as 50 million pieces per year.[439] Currently the market consists primarily of test components with few in use applications. MMC material produced under the Title III programs being conducted by DWA and ACMC has been used to produce electronic racks.[439] These racks are currently flying on military aircraft. In addition some MMC producers are producing SEM-E type components, but the quantities are very small. This market comprises both commercial and military end users. Commercial applications include high speed computers and small electronic packages. Military applications are focused around the Navy because the Navy produces more than half of all electronic components for military use.[438] MMC use in aircraft to reduce weight and reduce or eliminate the need for active cooling of electronics is likely. The majority of representatives in the MMC marketplace involved with military applications believe thermal management applications for electronics offer the greatest near term potential for continuous MMCs.

The Cercast Group in Canada has developed two families of investment cast MMC products for electronic packaging material: Lite-Var and Stablite. These components offer the same basic properties as conventional metals at 1/5 to 1/6 the density. Cercast has been using MMC material from Alcan to produce these products.[130]

9.2.4 Aerospace[129]

MMCs are of considerable interest to the aerospace industry because of their enormous potential for the production of lightweight, structurally efficient components. This market addresses critical defense needs and applications. The material properties driving these applications are high stiffness, high strength, good wear resistance, and improved elevated temperature properties compared to the matrix alloy. These material attributes offer designers improved structural efficiency, improved structural reliability, and reduced maintenance when compared to carbon fiber reinforced composites. Aerospace engines (in particular gas turbine engines), airframes, spacecraft, and guided weapons, represent the primary aerospace application areas for MMCs. Together these areas represent an extremely large market potential. Predictions have indicated that the aerospace MMC market could be worth over $200 million by 2000. The commercial aspect of this market has been estimated at less than $50 million.

According to engine manufacturers, conventional aerospace engine materials are reaching their performance limits, and new materials are required to achieve significant advances in gas turbine engines. MMCs are being considered as a potential material to support these advances. Potential MMC applications in aerospace engines are fan disks, compressor casings, turbine disks, compressor blades, and stator vanes. Fiber reinforced titanium is the primary material targeted for these applications. This material offers strength/weight improvements over nickel superalloys at temperatures up to 1500 degrees F. The advancement of this material in these applications is considered to be critical to the Integrated High Performance Turbine Engine Technology (IHPTET) program which is working to develop a more efficient gas turbine engine to meet future aerospace applications.

MMC use for airframes is being considered for military and commercial aircraft. Commercial activity has been limited. The majority of the funding for research into MMC airframes has come from the DOD. Aerospace manufacturers have conducted design and manufacturing analyses that have shown a potential weight savings of up to 60% for some components. Fiber reinforced aluminum was originally the material of choice for these applications, but recently discontinuously reinforced materials have been considered. The Wright Laboratory Materials Directorate (WL/ML) has concentrated on developing an advanced structural material from either SiC monofilament or SiC whisker reinforced aluminum. The program has proven the feasibility of the materials in I-beams for vertical stabilators on the Advance Tactical Fighter (ATF). The cost effectiveness of these materials for these applications is still being determined. The only commercial activity related to MMC use in airframes has been conducted in Europe. The Airbus division of British Aerospace is developing manufacturing technology to allow a planned introduction of cost effective civil aircraft applications. Several potential civil airframe applications have been identified. The National Aerospace Plane (NASP), a DoD and NASA sponsored program, requires structural material with high temperature potential and light weight. Like the IHPTET program, NASP is looking at using continuously reinforced titanium to meet requirements. The High Speed Civil Transport (HSCT) program also requires light weight materials with high temperature performance requirements. This program is looking at both continuous and discontinuous MMCs to meet its needs.

Space applications for MMCs have been focused on the production of thermally stable space structures. These structures have been produced from graphite reinforced aluminum and can be produced to have near zero CTE. Other potential applications for MMCs in spacecraft is in re-usable spacecraft such as the space shuttle. Boron aluminum tubes produced by Amercom are used as support structures in the shuttle cargo bays. Future vehicles, such as NASP, with expected speeds of up to Mach 25, will result in skin temperatures between 1500 and 3000 degrees F. SiC reinforced titanium is seen as critical for these applications. MMC antennas have been produced for use on the Hubble as well as some satellites.

Stiffness designed components, such as fins, represent the most suitable applications for MMCs in guided weapons. Many MMC fins have been produced but purely as test components at this time. MMCs have been introduced into some nonstructural applications in guided weapons. The Trident missile uses discontinuous SiC reinforced MMC for guidance components previously produced from beryllium. Tailorable CTE and lower cost were the drivers for this application. MMCs have been investigated to replace microwave packaging components made from Kovar. These applications are limited but MMCs do meet some critical needs and offer potential cost reductions related to guided weapons.

9.2.5 Armor[441]

MMC use in armor applications is being driven by the need for light weight materials that offer high stiffness, a higher damage tolerance than ceramics, low cost, and large shapes. Armor applications for MMCs include armored vehicles, aircraft armor and personnel armor. The demand for MMCs in armor applications is limited to military armored vehicles and some personnel armor. The potential benefits that the material can provide are extensive.

Lawrence Livermore National Labs developed a manufacturing process to bind boron carbide particles in an aluminum matrix to produce an MMC for armor applications as well as other applications. This material is currently being used for lightweight armor in U.S. Air Force special operations aircraft. While this application could cut the aircraft weight by up to 3000 lbs, its use is limited due to its high cost of $20/lb. Lanxide has developed two materials for armor applications. They are currently testing these materials to determine performance characteristics and market viability.

This market will be slow to develop due to limited military combat vehicle acquisition programs. Suppliers of this material will need to prove the cost effectiveness of this material and actively sell it to military programs responsible for system upgrades and acquisitions.

9.2.6 Precision Equipment[441,222]

A new potential market that is emerging for MMCs is in precision equipment applications. Precision equipment applications in general have common needs, including light weight, high stiffness, long-term dimensional stability, low CTE, high thermal conductivity, high strength, high wear resistance, and high vibration damping. The continuing increase in the demand for improved precision, accuracy, quality, and productivity is beginning to push beyond the capabilities of current materials. MMC material properties such as high stiffness, low weight, and long term dimensional stability can provide improved accuracy, repeatability, speed, and payload capacity. The specific applications for MMCs associated with precision equipment are in machine tools, robots, motion control equipment, optical mirrors, platforms and associated hardware, photolithography machines, and coordinated measuring machines.

At this time Lanxide and ACMC appear to be the only MMC producers who are addressing this market. The potential demand for MMC material in this market is enormous. Precision equipment is used in both commercial and military applications world wide. If MMC use in this market is proven feasible and cost effective, the market represents a considerable increase in the potential demand for MMC material.

9.2.7 Other

The Army conducted a study to look at the use of MMCs for tank track pins. Textron provided the technology to support the requirements, but cost effectiveness prevented MMC use in this application.[442] The Army has looked at using MMCs for other applications, including gun barrels and tank mirror substrates. MMCs have not been successful in penetrating any of these applications but they do offer considerable potential.

The Navy is looking at MMCs for numerous marine applications. MMC use in ship engines offer corrosion resistance and low magnetic signatures in addition to other benefits associated with MMCs. Various ship structures such as masts, hulls and machinery are also potential applications for MMCs. A very important application that is receiving considerable attention is the use of MMCs for landing gear of the F-15 and other carrier aircraft. This application is driven by the materials lightweight and corrosion resistance. Submarine and torpedo applications are looking at using MMCs to enable increased depth through lighter weight and increase compression strength.[387]

9.3 Foreign MMC Marketplace

A significant level of foreign interest exists in the MMC marketplace. Japan and Europe appear to be the only current MMC producers other than the U.S. The former Soviet Union was very active in developing MMCs for defense applications; the current status of these programs and technologies is not known. MMC use potential extends around the world, though the focus for MMC producers and secondary fabricators is on North America, Europe, and Japan. Europe and Japan offer enormous potential for all MMC producers. Foreign markets offer some benefits over domestic markets as well as some market potential that is not available in North America. This section considers both foreign MMC production capabilities and foreign market demand potential. Appendix F provides a non-exhaustive listing of companies throughout the world that are working on MMC technologies. It includes a brief description of the programs and research activities they are involved in. Figure 9-4 shows the distribution of MMC manufacturers throughout the world.[73,443,437]

As previously stated, foreign production capability and research activity for MMCs is focused in Japan and throughout Europe. In Japan, MMC production and research has focused on the automotive industry. Recently, Japanese research interests have included the potential of MMCs for aerospace applications. Numerous Japanese companies and institutions are involved in MMC activities. In the low cost MMC arena, which entails material similar to Duralcan's, there are no identified competitors in Japan. Some companies around the world are purchasing Duralcan material, processing it, and reselling MMC components under their own name. These companies are simply secondary fabricators of Duralcan material, but can be mistaken for MMC producers. For the higher strength MMCs produced using powder metallurgy, material similar to DWA's and ACMC's, Kobe Steel is probably the leading producer in Japan.[438]

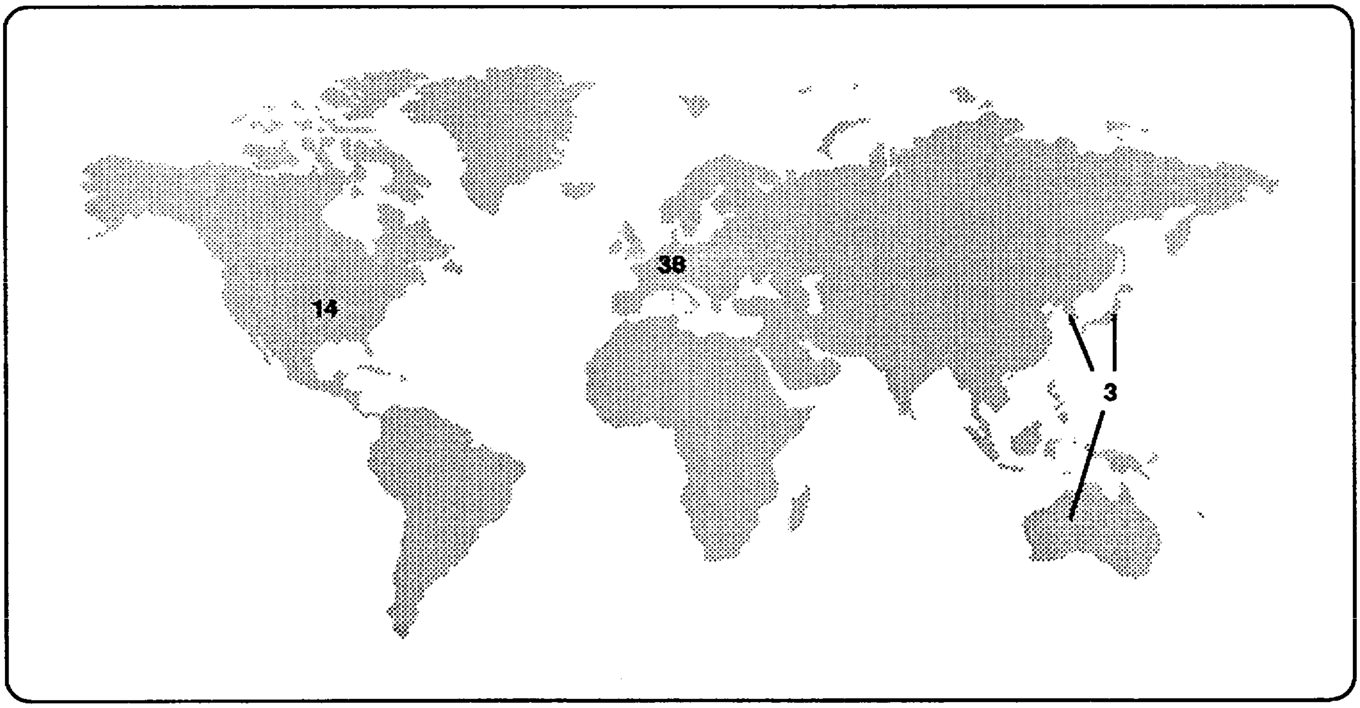

Figure 9-4. World-wide MMC Supplier Distribution

Like the Japanese marketplace, European MMC research has been extensive. Numerous companies are working on establishing MMC production capabilities to support automotive and aerospace applications. Hydro Aluminum in Norway has a material similar to Duralcan's, though they are sitting on the technology until a demand is established.[438] Comalco, an Australia-based company, is in the same position as Hydro Aluminum.

Producers of MMCs for high performance materials in aerospace, electronic, and other demanding applications appear to be less advanced than domestic MMC producers. On the other hand, the current level of interest and the number of companies working with MMCs appears to be greater than that associated with North America.

Foreign demand potential for MMC material and MMC components is considerable. In addition, it appears foreign demand will be realized ahead of domestic demand due to more aggressive applications of MMCs and fewer liability concerns. Japan is currently using MMCs in some automobiles. European automobile manufacturers are looking to use MMCs in the near future. Duralcan has identified several foreign automotive companies that have expressed interest in using MMCs. Duralcan feels these companies will be using MMC automotive components before U.S. automotive manufacturers. The European aerospace industry is actively looking at MMC usage. It is believed that foreign commercial aerospace companies are much faster to use new materials due to less stringent qualification procedures and liability issues. Foreign MMC demand will probably be beneficial to MMC producers and secondary fabricators, though if U.S. companies, such as Ford and Boeing, are too slow in accepting MMC components in their products, they may lose market share to foreign companies, such as Honda and Airbus Industrie. The railroad industry represents a market that is prevalent in foreign countries, Japan and Europe in particular, but not a really viable industry in North America. MMC usage for engine, structural, brake, and other components exist in the railroad industry.

9.4 Raw Material Producers

MMC producers are dependent on matrix and reinforcement raw material producers to supply necessary quantities of material, at reasonable cost, with required quality and consistency. Raw material producers supporting MMC production include matrix producers and reinforcement producers. Section 6 discussed the basic materials that make up these raw materials. Cost, cost stability, supplier availability, and production capability are the main issues affecting the relationship between the raw material producers and the MMC producers.

Price and price stability of MMC matrix materials are primary concerns. Price affects material selection. For example, many MMC producers feel magnesium would be an ideal matrix material; however, the price is too high to allow magnesium based MMCs to be competitive. Aluminum is the most common MMC matrix material; in this case, price stability is the major concern. For example, automobile manufacturers are concerned about using aluminum in automotive components and having little assurance that the price of the aluminum will remain constant. Until matrix producers, primarily aluminum foundries, can promise a stable price for aluminum alloys, it will be risky for MMC producers to establish a stable price for their material.[440]

The use of SiC whiskers in MMCs has been limited due to the high cost associated with growing these reinforcement materials and a perception that there is a limited supply of the whiskers. These reinforcements provide improved properties over particulate reinforced MMCs without the added cost associated with processing continuously reinforced MMCs. Whisker reinforced materials can be processed like all other discontinuously reinforced materials. This study identified three SiC whisker manufacturers in North America: ACMC, Ceramics Kingston Ceramiques (CKC), and Advanced Refractory Technologies (ART). Currently ACMC is producing whiskers to support whisker reinforced aluminum being produced for their Title III program. General Motors has been supporting ART for the past six years to develop their whisker production capability to support GM in producing whisker reinforced MMCs for automotive applications.[439] CKC has been producing and selling whiskers and whisker reinforced metals for testing and characterization.[130] Each of these whisker manufacturers is attempting to reduce the cost of whiskers.

SiC fiber manufacturers are faced with the most substantial barriers. Currently Textron has the only established production capability to produce CVD SiC fiber. At this time, Textron is unwilling to sell this fiber to composite manufacturers.[442] 3M, Amercom, and Atlantic Research are developing fiber production capabilities to support both fiber sales and fiber reinforced MMC production. The production and handling costs associated with these fibers and their incorporation into a MMC are so large that there are few markets willing to support their use. Until a technique is developed to produce these fibers at a reasonable cost, their use will be limited.

Graphite fibers appear to be the most common fibers used in continuous MMCs. Amoco has a patented technique for producing these fibers and is currently the leading U.S. producer. Inco is working on developing a nickel coated fiber technology. This technology addresses the problems associated with interactions between fibers and matrix materials during MMC production. Inco is working with a die caster and two automotive manufacturers to develop this technology. They are also looking at producing nickel coated graphite particles for integration with Duralcan's material.[130] Both of these technologies are still in their developmental stages.

9.5 Secondary Processing

Secondary processing supports the transition of MMC raw material and near net shape MMC components to end use products. First level fabrication technologies that support MMC raw material processing include all types of casting, extrusion, and rolling.

Second level fabrication technologies such as finishing, machining, welding, and joining support all materials produced by MMC producers. The industries that support these technologies are well established and have experience in performing these processing techniques on traditional materials. Due to the advanced properties associated with MMCs, traditional secondary processing techniques must be modified to work with these materials. These modifications often increase fabrication time and cost. MMC producers and first level fabricators are attempting to produce components that are as near net shape as possible to eliminate costly second level fabrication.

Educating the industries conducting secondary processing will be essential if future demand requirements increase. Secondary fabricators are unwilling to invest in developing the necessary technologies to work with MMCs until they recognize that a demand exists. Because Duralcan is the leading producer of MMCs, they are investing internal R&D funds to educate secondary fabricators to work with their material in the hope of establishing the necessary capabilities to support and promote their material.[438] As the demand for MMCs increases and MMC producers begin increasing their material production, secondary fabricators will need to learn how to work with the material to support the industry.

9.6 Potential for Dual Use

MMC dual use can be addressed from two perspectives. The first is use of MMC material in both military and commercial markets, regardless of the end product the material ends up in. Examples include the use of DRA produced by DWA for bike frames and for electronic racks in military fighter planes. From this perspective, MMCs are produced to support both commercial and military products with the attendant economies of scale. The second perspective focuses on the use of end products consisting of MMC material in specific applications that exist in both military and commercial markets. An example of this is the use of MMCs for brake rotors in both military and commercial vehicles. From this perspective, the economies of scale are obtained at the end item part of the process. All forms of dual use relating to MMCs are important to ensure a stable industrial base for critical military MMC applications. It is unlikely that military MMC demand alone can support the MMC marketplace; therefore dual use in all steps of the MMC lifecycle process will be required to support the different marketplace entities. The following paragraphs discuss the dual use potential for MMC producers and for end products producers. In addition, transition capabilities of MMC producers and secondary fabricators are discussed.

Material dual use is driven by the properties associated with different materials. This section will segregate MMC materials into low volume (<30 percent) discontinuously reinforced metals, high volume (30-70 percent) discontinuously reinforced metals, graphite reinforced metals, and fiber reinforced metals.

Low volume discontinuously reinforced metals provide performance improvements over traditional pure matrix materials such as aluminum, as well as reduced density over iron and steel. Performance enhancements over aluminum are improved stiffness, improved strength, and improved wear. The main factor driving their use as a replacement for steel and cast iron is reduced density. This type of material is also being considered as a low cost replacement for titanium. The primary markets for these materials are automotive and recreational. In addition, these materials will have some applications in the aerospace industry and some miscellaneous applications.

High volume discontinuously reinforced aluminum offers improved material benefits over low volume discontinuously reinforced aluminum. The driving factors behind this material's use are its high thermal conductivity and low and tailorable CTE. Markets associated with these materials are some of the more demanding applications in the automotive and aerospace markets as well as many applications in the electronics industry requiring thermal management and high temperature applications

Graphite reinforced metals provide excellent thermal management properties, such as tailorable CTE with a potential for near zero CTE and high thermal conductivity with very low densities. These materials offer beneficial properties for electronic and high temperature applications. They can potentially eliminate active cooling requirements and reduce component weight, providing considerable system benefits, especially in aerospace applications.

The benefits associated with fiber reinforced composites are still being identified. Like all other MMCs, reduced density is key. These materials are unique in their ability to provide anisotropic properties. They can be designed to provide material properties based on design needs. For instance, if a structure requires very high compressive strengths, a fiber preform to support this requirement can be constructed; if high thermal conductivity is required, then fibers can be arranged to support this design need. In general, these materials provide high material toughness, high resistance to critical failure, and low density. They compete with titanium and other high performance metals.

Transition capabilities will be important to the MMC producer's ability to produce the necessary amounts of material to support demand requirements. These transition capabilities are related to the ability to change matrix and reinforcement raw materials and MMC raw material composition levels to produce specific material properties. MMC producers can vary particulate reinforcement materials and fiber reinforcement materials fairly easily. In addition they can vary particulate size and fiber tow sizes. Volume concentration can be varied, but the extent of this capability is based on processing techniques and varies between MMC producers . Each of these variations can produce significant changes in MMC material properties to support property requirements.

End product dual use is simpler to characterize. It consists of potential applications or products that can be used in multiple markets. Automotive, aerospace, and electronic applications represent the bulk of this dual use potential. All of the potential MMC automotive components previously discussed could be produced and used for either military or commercial vehicles with no effect on the raw material producers, MMC producers, or secondary fabricators. This is similarly true in many of the potential aerospace applications for MMCs. Aircraft skins, high temperature engine components, and structural components in aircraft all represent potential end product dual use applications. Electronic applications such as SEM-E components, heat sinks, and high temperature packaging materials all have potential applications in both military and commercial markets. These areas have no direct influence on MMC producers but they can help generate increased demand for MMC material production. Material demand will increase as more end product dual use applications are identified and exploited. This dual use demand will help ensure that MMC producers maintain their production capability to support critical military applications.

9.7 Marketplace Issues

The current MMC marketplace is faced with issues beyond the technical issues discussed in section 8 and the regulatory issues to be discussed in following sections. The market can be segregated into two groups, with each group possessing different market strategies as well as unique market barriers. One market group comprises MMC materials that offer foreseeable benefits in both military and commercial applications. These materials include all discontinuous MMCs and graphite reinforced MMCs produced for thermal management application. Application potential for these materials appears to be extensive; current focus has been on electronic packaging, automotive applications and some recreational applications.

The other market group comprises material with limited or no foreseeable commercial applications. These materials consist of the high temperature continuously reinforced metals. Commercial applications for the high temperature materials exist in some commercial aerospace applications, although these applications will not exist until considerable cost reductions take place. The focus of this market is on the high temperature military applications, such as NASP and IHPTET.

The dual use market would benefit considerably from increased government funding and interest in actual demonstrations of products in electronics/thermal management and the automotive industry. Government participation in this area can defray the startup costs of proving the benefits of MMCs for these applications and developing the production capacity needed to achieve economies of scale. Due to the cost and risk associated with the development and use of the high temperature materials, the military unique applications will require nearly 100% support from the government to advance these technologies. Areas such as secondary processing, matrix/reinforcement bonding, and market awareness that are common to both markets should receive special attention due to the dual benefits advancements in these areas could provide.

Creating market awareness and developing a commercial demand is essential to establishing MMCs as a viable industry. Commercial demand, particularly in high volume markets, offers not only sales and profits, but the resources to reinvest in overcoming existing technical barriers. Attention should be focused on establishing identified commercial markets, such as automotive and electronic packaging/thermal management. These areas require the least amount of investment to help bring MMCs to market. In addition both of these markets offer high volume potential as well as dual use potential.

Foreign competition is a growing concern for the MMC industry. The majority of the foreign interest has come from Europe and Japan. Japan has focused on establishing a demand for MMCs in cars by incorporating MMCs into selected models. Europe has shown extensive interest in MMC technology. Their interest has been in the automotive industry as well as the aerospace industry. Airbus Industrie has been considering incorporating considerable amounts of MMC material on their aircraft. Japanese or European success in establishing a high quality and reliable MMC automotive engine component prior to U.S. automotive manufacturers will create an advantage in maintaining a viable MMC industry. In addition, due to their more mature technology, U.S. automotive manufacturers may prefer foreign produced MMCs over domestic MMCs due to lower cost, improved quality, and improved reliability. This could further inhibit the development of a viable domestic MMC industry.

Related to foreign competition is the increasing number of MMC producers that are being purchased by foreign companies. This represents a considerable threat to the viability and availability of a North American MMC industrial base. DWA and ACMC are two examples of former U.S. companies that have been purchased by European and Japanese companies, respectively. DWA and ACMC are also the two companies currently receiving Title III funding to develop an MMC capability to meet defense and possible commercial needs. Transfer of these companies to foreign interests may represent the loss of the U.S. investment in developing a domestic MMC industry.

10.0 Science and Technology Base Infrastructure

In both the U.S. and Canada, there is a complex and interconnected infrastructure in place in the federal government that deals with the science and technology base. This often entails close coordination and interplay between several different organizations. In the case of advanced materials, committees and programs have been established that directly address this area; some of which specifically focus on MMCs.

10.1 U.S. Federal Science and Technology Base Infrastructure[301, 431, 351]

A brief snapshot of the different key U.S. agencies involved in science and technology base issues in this arena is provided in Figure 10-1. A description of the functions of each agency involved in advanced materials is provided in the following chart.

ORGANIZATION	FUNCTION
Executive Branch	
Department of State	Manages international agreements; negotiates technology-related trade issues
Defense Advisory Group	Facilitates reduction of impediments to defense exports
Office of the U.S. Trade Representative	Involved in technology-related trade issues
Council of Economic Advisors, Cabinet Councils, Competitiveness Council	Concerned with economic competitiveness
National Space Council	Addresses space policy
Office of Management and Budget	Oversees budget aspects
National Academy of Sciences National Research Council	Conducts materials research through its National Materials Advisory Board
National Critical Materials Council	Advises President on national materials policy; develops national Federal program plan for advanced materials R&D
White House Office of Science and Technology Policy	Coordinates science and technology policy
Committee on Materials Federal Coordinating Council	Coordinates Federal R&D programs for Science, Engineering and Technology (FCCSET)
FCCSET Subcommittee on Materials	Spearheads Advanced Materials and Processing Program

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Figure 10-1. Key U.S. Agencies Involved in Science and Technology Base Issues

ORGANIZATION	FUNCTION
Department of Commerce (DOC)	Maintains list of R&D consortia
DOC's National Institute of Standards and Technology	Assists private sector initiatives on advanced technology; promotes cooperative R&D efforts and pooling of skills
DOC's International Trade Administration	Provides economic data and analysis on materials markets
DOC's Patent and Trademark Office	Issues patents; registers trademarks
Department of Defense (DOD)	Funds R&D; participates in Project Reliance
Department of Energy	Funds R&D; focus on materials research
Department of Interior, Bureau of Mines	Funds new materials research; examines impact of substitutions
National Science Foundation	Supports research, education, and formulation of national policies
National Aeronautics and Space Administration (NASA)	Develops aerospace technology
Legislative Branch	
Congress	Conducts lawmaking and budget appropriations; has oversight authority to convene special hearings for examining program activities of executive branch
Standing Committees	Conduct program or budget review hearings for Federal materials science activities

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A more detailed description of this infrastructure is provided in Appendix A. A brief overview of those U.S. groups and programs that do or could play a key role in the direction of MMC development are provided in this section.

10.1.1 Office of Science and Technology Policy

The White House Office of Science and Technology Policy (OSTP) plays a strategic role in integrating science, technology and foreign policy issues. It is responsible for coordinating science and technology policy throughout the Federal Government. The Director of OSTP also chairs the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), which coordinates the Federal R&D programs and other multi-agency science and technology activities.

10.1.2 FCCSET's Advanced Materials and Processing Program[7]

Within FCCSET's Committee on Industry and Technology, there is a Subcommittee on Materials. This subcommittee spearheads the Advanced Materials and Processing Program (AMPP), which represents the first coordinated Federal approach to materials science and technology. Prompted by the recognition of the need for a stronger overall Federal commitment to materials R&D and growing concern about foreign competition (which already has had a significant impact on manufacturing and national competitiveness), the goal of the AMPP is to address the needs and opportunities in materials to increase the effectiveness of the Federal R&D program in materials science and technology, taking advantage of opportunities for significant technical breakthroughs. By optimizing interagency R&D planning and properly appropriating resources among projects, the gap between innovation and application of advanced materials can be bridged. Composites is one of the nine broad classes of materials on which the AMPP has focused. By placing emphasis on key technological developments of MMCs, this program could effectively advance the current state of MMC technology and better position MMCs for applications in defense programs.

10.1.3 Department of Commerce

The Department of Commerce (DOC) has established a Strategic Partnership Initiative to help technology pull-through from R&D to commercialization and to assist in the development of multi-industry teams that create and commercialize large-scale technologies. These vertically integrated teams are composed of non-competing firms representing manufacturers, suppliers and users of the technology to be developed. Harley Davidson is currently involved in an initiative on aluminum MMCs under this program.[300]

The Department of Commerce's National Institute of Standards and Technology (NIST) assists private sector initiatives to capitalize on advanced technology through cooperative R&D efforts with industry, universities, and Government laboratories.

NIST administers the Advanced Technology Program, which is aimed at assisting businesses in developing pre-competitive generic technologies through joint ventures. This program funds advanced technologies that, though they generally have broad-based impact, are often characterized by high technical risks that inhibit an adequate level of private sector funding. This program could offer significant opportunities in the MMC area, since MMCs appear to fit the criteria of this program. NIST also has established five Regional Manufacturing Technology Centers which provide small businesses with information and expertise on manufacturing technologies and practices and matching funds.

10.1.4 The Department of Defense (DOD)

The DOD is of course a lucrative source for funding of MMC R&D, spending almost 1/2 billion dollars per year for materials and structures R&D. Of this, approximately 1/3 is spent on composites. A major portion of the R&D funding is provided under the 6.1, 6.2 and 6.3A budget categories. All of the Services participate in the DOD Project RELIANCE, which aims at restructuring the working relationships between the Services to promote greater efficiencies and effectiveness by increased Tri-Service interdependency. A formal Tri-Service Materials Focus was formed in 1992 to provide new emphasis on joint planning, implementation, coordination and oversight of Tri-Service Materials Science and Technology Programs. The Joint Laboratories (JDL) Technical Panel for Advanced Materials (TPAM) is assigned this mission. Heightened awareness of the potential benefits of MMCs within this group could prove beneficial in funding strategic MMC technology programs.

The Advanced Research Projects Agency (ARPA) is a separately organized agency within the DOD that serves as DOD's central research and development organization with primary responsibility to maintain U.S. technological superiority. A significant amount of funding for MMC research has been provided by ARPA. ARPA also has funded a pre-competitive technology consortium, the Advanced Composites Technology Consortium, to demonstrate the feasibility of achieving breakthrough rapid manufacturing technologies in intermediate and high temperature composites. ARPA initiatives funded in 1993 by Title IV Defense Conversion appropriations that should be of interest to the MMC community are the Technology Reinvestment Program, Advanced Materials Synthesis and Processing, and Agile Manufacturing and Enterprise Integration.[349]

Some of the other funding programs in which the DOD is involved include the University Research Initiative (URI), Small Business Innovative Research (SBIR) program, the Manufacturing Technology (ManTech) program, and the Defense Production Act (DPA)Title III program. The URI and the SBIR have both been used for funding of MMC research. ManTech is designed for funding the development of a new or improved process technology, but since this program currently emphasizes an identified production application prior to participation in the program, MMC companies sometimes find they are restricted from receiving funding. Numerous MMC programs, though, have been funded through ManTech, including manufacturing science for titanium aluminide composite engine structures; titanium matrix composites for engine components, exhaust nozzle components, mode struts and ring inserts; and innovative manufacturing of titanium aluminide and titanium alloy foil. The DPA Title III program is designed to establish or expand domestic production capacity for materials that are critical to DOD. Currently, there are two MMC projects being conducted under this program - one to DWA Composite Specialties, Inc. for moderate strength Discontinuously Reinforced Aluminum (DRA) and one to Advanced Composite Materials Corporation for high strength DRA.[45, 58, 70, 302, 303, 319 317]

Another avenue for MMC cooperative projects is Cooperative Research and Development Agreements (CRADAs). As part of the Stevenson-Wydler Technology Innovation Act (1980) and the Federal Technology Transfer Act (1986), legislation was enacted to enable federal laboratories to enter into CRADAs with private businesses and other entities to assist in the transfer of technology developed at the federal laboratories to the marketplace. Through CRADAs, companies or groups of companies can work with one or more federal laboratories to pool resources and share risks in commercializing technologies.[304, 308, 309]

By law, each federal laboratory is required to establish an Office of Research and Technology Applications (ORTA) to actively identify and assess potential technologies and ideas from their own laboratories for domestic technology efforts. These ORTAs are all part of the Federal Laboratory Consortium, which helps enable each ORTA to provide assistance and make referrals to appropriate sources of technology among the federal laboratories. An FLC Locator Network assists by matching potential collaborators with laboratory resources. Such a network could prove valuable to MMC producers for establishing contacts and engaging in collaborative efforts.[305, 306, 307]

Within the DOD, there are numerous organizations that have been chartered to address different issues involving advanced materials and MMCs. Of particular interest to the MMC community is the work of the Metal Matrix Composites Information Analysis Center (MMCIAC). It serves as the DOD's central source of engineering and technical data and R&D information on MMCs. The technical subject areas covered include all data and information on continuously and discontinuously reinforced MMCs, laminates, and hybrid composites that contain MMCs, applied to Defense systems and hardware. MMCIAC services include responses to technical and bibliographic inquiries; production of handbooks, databooks, state-of-the-art reports, critical reviews, technology assessments, and newsletters; and performance of special technical area tasks. Specific subject areas covered include MMC properties; key R&D concepts, results, and trends; fabrication, processing and applications; processing equipment; measurement, testing and quality control; test equipment and evaluation methods; corrosion/deterioration detection, prevention and control, and other environmental effects on MMC and systems; sources, suppliers and specifications for MMCs of concern to the DOD; operational serviceability and repair; MMC component design criteria; MMC industrial subsystem and system applications; theoretical performance computations; and assessment of international R&D technology to determine its impact on MMCs.[14]

10.1.5 The Department of Energy

The Department of Energy (DOE) Office of Transportation Materials has recently developed a Lightweight Materials for Transportation Program Plan to realize the benefits of lighter weight vehicles. This program will support R&D activity at industrial sites through competitively bid subcontracts and could offer significant potential for MMCs. It will enable companies to develop technology by using their capabilities and accessing supporting technology at national laboratories, universities, ongoing program activity at NASA, DOD, DOT, and NIST, leveraging industry resources through integrated team approaches.[215]

10.1.6 The National Aeronautics and Space Administration[322]

The National Aeronautics and Space Administration (NASA) materials R&D support aeronautics and space applications. Their research emphasized advanced materials that will improve the performance, durability, economy and environmental compatibility of civil and military aircraft. NASA's Advanced Composites Technology Program is one of the major national programs aimed at advanced composites for airframes. NASA has a cooperative arrangement with industry that is similar to CRADAs. Mandated by both the 1958 Space Act and the President's National Space Policy (1989), these Space Act Agreements can be used to provide mutual leverage of government and industry resources in the cooperative pursuit of R&D efforts. Since many of the MMC potential applications involve aerospace, this type arrangement could prove beneficial for a joint R&D MMC effort. NASA has also established Regional Technology Transfer Centers to assist clients in locating, assessing, acquiring and commercializing technologies from NASA.

10.1.7 The National Science Foundation[7]

The National Science Foundation (NSF) supports basic research and education to improve the synthesis of advanced materials and promote development of novel processing and manufacturing methods. NSF recently launched a five-year plan to enhance research in synthesis and processing of new materials. It funds R&D efforts by providing grants and graduate fellowships, support for its centers, and support for National User Facilities. This foundation could prove a great source of information on advanced materials.

10.2 Canadian Federal Government Science and Technology Base Infrastructure

As in the U.S., there are several departments involved in various aspects of the science and technology base, requiring close coordination and communication among components. The main players and programs are briefly described below. A more in-depth discussion of the Canadian infrastructure and programs is provided in Appendix A.

10.2.1 Department of National Defence[334]

The R&D program of DND is geared towards applying advances in science and technology to improve the operational capabilities of the Canadian forces. Interest in MMCs from the DND perspective directly relates to how MMCs can be applied to weapon systems to enhance their performance. R&D is carried out by DND's six Defence Research Establishments, as well as by companies and universities under R&D contracts. An important part of CRAD initiatives with industry is funded through the Defence Industrial Research (DIR) Program, which assists companies seeking support for defense research projects aimed at improving the research and technological capabilities of the Canadian Defense industry. DND funding of MMC R&D with industry has been accomplished through the DIR, as well as through R&D contracts with the Defence Research Establishments.

10.2.2 External Affairs and International Trade Canada (EAITC)[339]

EAITC has many roles, including identifying export opportunities for Canadian industry; establishing and maintaining Canadian participation in bilateral and multilateral cooperative defense trading agreements; managing Canada's space agreements; and administering the Defense Development Sharing Program (DDSP). The DDSP makes it possible for Canadian firms to do R&D work for the U.S. Armed Forces. These R&D efforts are jointly funded by the U.S. and Canada and performed by Canadian prime contractors. The Canadian share of this program is funded under the Defence Industry Productivity Program (DIPP), a program that is designed to develop and maintain strong defense-related industries across Canada in areas that are characterized by high commercial, technical and financial risk. Funding is available for R&D, source establishment, capital assistance, and market feasibility determination. DIPP funding is a potential vehicle for funding of MMC research. This program is jointly administered with Industry Science and Technology Canada.[34]

10.2.3 Industry Science and Technology Canada (ISTC)[352]

ISTC facilitates cooperation among private and public sector partners, develops industry and science policies, and collects and disseminates information. The ISTC maintains a business opportunities sourcing system - a computerized data base on Canadian companies, their products and markets in support of domestic and international marketing. An initiative of the Advanced Materials Directorate of ISTC, the Strategic Technologies Program, helps industry establish alliances with other Canadian firms, foreign firms, universities, or research institutes to conduct R&D or technology application projects in leading-edge technologies. One of the three strategic technologies eligible for funding under this program is advanced industrial materials. This program is another potential source of funding for MMC R&D.[333]

10.2.4 Government Services Canada (GSC).

The Science and Professional Services Directorate of GSC provides a centre for federal government R&D contracting. GSC, in cooperation with Industry and Science Canada, operates the Unsolicited Proposals Brokerage Service which receives and brokers R&D proposals to potential government sponsors. The service addresses both federal government R&D priorities as well as science and technology objectives of government departments.

10.2.5 Natural Sciences and Engineering Research Council[353]

Another possible funding avenue for MMC R&D is the University/Industry Grants Program. Administered by the Natural Sciences and Engineering Research Council, this program encourages cooperation between universities and industry on R&D programs.

11.0 Technology Facilitators

Facilitators that aid the U.S. and Canada in advancing the technology base include joint U.S./Canada programs and agreements, common participation in international organizations, specific U.S. facilitators, and specific Canadian facilitators. These are discussed in the following paragraphs.

11.1 Joint U.S./Canada Programs and Agreements

Capitalizing on the long history of defense economic development, the U.S. and Canada have several agreements/programs in place that help facilitate cooperative arrangements in the science and technology arena between the two nations. These agreements plus Memoranda of Understanding between the Canadian Department of National Defence, the U.S. Services, and the Department of Defense total some 2500. Further details on some of the key agreements that help set the foundation for cooperative efforts in MMC R&D are provided below.

11.1.1 U.S./Canada Defense Production Sharing Arrangement[348]

Under this arrangement, Canadian companies are allowed to compete for U.S. defense contracts directly, or as subcontractors to U.S. defense contractors, on the same basis as U.S. companies, with few exceptions. It is embodied in the Defense Supplement of the U.S. Federal Acquisition Regulations (DFAR 225.870). General terms include:

- U.S. Buy American Act is waived,
- Duty free entry, and
- If a Canadian company is a prime contractor, the contract is generally made through the Canadian Commerical Corporation (CCC).

Canadian companies can be U.S. Planned Producers and, in many areas, are considered by the U.S. as U.S. domestic sources for military equipment.

11.1.2 U.S./Canada Defense Development Sharing Program (DDSP), DFAR T201.2

The DDSP is designed to:

- Help maintain the Defense Production Sharing Program at a high technological level by making it possible for Canadian firms to do R&D work for the U.S. Armed Forces.

- Use the industrial, scientific, and technical resources of the U.S. and Canada in the interest of mutual defense and to ensure Canada a fair opportunity to share in the R&D and production of high technology military equipment and materiel of mutual interest to both countries.

- Help make possible the standardization and interoperability of a larger amount of the equipment necessary for the defense of North America.

The Defense Development Sharing Program consists of R&D projects that are performed by Canadian prime contractors, are designed to meet specific DOD R&D requirements, are managed and directed by the DOD, and are jointly funded by the U.S. and Canada. The Canadian share of this program is funded under the DIPP. The U.S. Government authority is DFAR Appendix T-2011.2.

11.1.3 Joint Certification Program[27]

This program certifies contractors of each country for access, on an equally favorable basis, to unclassified technical data disclosing critical technologies controlled in the U.S. by DODD 5230.25 and, in Canada, by the Technical Data Control Regulations. Policy oversight for this program is provided by the U.S./Canada Security and Technology Sharing Subcommittee of the Defense Development/Defense Production Sharing Arrangements Steering Committee. Through this program, certified Canadian contractors are able to:

- Respond quickly to DOD/Canadian contract opportunities where specifications involve technical data which can only be released to certified contractors.
- Attend DOD/Canadian-sponsored restricted access conferences where export-controlled data are presented.
- Visit DOD/Canadian contractor installations to obtain unclassified militarily critical technical data without prior DOD approval.

11.1.4 The Canada/U.S. Free Trade Agreement[21, 110, 341]

This agreement, which came into effect January 1, 1989, assures duty-free access to those companies meeting a new rule of origin, eliminates many tariffs, and establishes a mechanism for trans-border trade dispute resolution.

11.1.5 The North American Free Trade Agreement (NAFTA)[355, 356]

The NAFTA, when implemented, will reduce trade barriers and improve the flow of goods, services, and information by eliminating all tariffs on industrial and agricultural goods produced by the NAFTA partners, improving access to the services markets, and phasing out restrictions in the North American auto market to create new U.S. export opportunities, while establishing tough rules of origin that ensure that only vehicles with substantial North American parts and labor benefit from NAFTA tariff cuts. Defense trade is not covered under this agreement.

11.1.6 United States - Canadian Security Agreement

The exchange of classified information and materials on a government-to-government basis is safeguarded through this agreement.

11.1.7 Master Data Exchange Arrangement

This arrangement provides a means of sharing existing information without the need to negotiate a joint project.

11.2 Common Participation in International Organizations

Both the U.S. and Canada actively participate in international organizations and programs involving science and technology considerations. Two of these key groups that actively examine the materials sector and whose members include both the U.S. and Canada are highlighted below.

11.2.1 The Technical Cooperation Program (TTCP)[108]

The TTCP is a unique international defense collaboration program that provides a forum for participating countries to learn about each others' defense research and development programs so that national programs can be adjusted and planned accordingly. Through this process, unnecessary duplication is avoided, actions to identify and close important technology gaps are promoted, and each country is assured the best technical information available for advice to their governments on all matters related to defense research and development. TTCP also coordinates programs of mutual interest where special capabilities, facilities, personnel and geographical or environmental regions can be used to greatest advantage. The exchange of materials, equipment, test items and scientific staff are encouraged. Materials technology is addressed within Subgroup P, Materials, of this organization. Technologies such as metallic, ceramic, organic materials and non-destructive evaluation are covered.

11.2.2 Versailles Project on Advanced Materials and Standards (VAMAS)[115]

VAMAS works through international cooperation on standards research and harmonization toward accelerating the introduction of advanced materials into manufactured high technology structures and products.

11.3 U.S. Facilitators

In addition to the programs and agreements mentioned in the previous sections, there are a number of specific facilitators offered by the U.S. and Canada that enhance current R&D efforts and technology transfer.

Current and proposed U.S. legislation is geared towards offering industry many incentives to becoming more involved in research and development activities. Some existing policies also serve to enhance cooperative efforts with Canadian industry. A list of

U.S. acquisition regulations with direct application to Canadian company market access is provided as Appendix B.

11.3.1 President Clinton's Technology Policy[389]

President Clinton's proposed technology policy would greatly enhance the current science and technology environment. It revolves around four major themes:

- Strengthening America's industrial competitiveness and creating jobs,
- Creating a business environment where technical innovation can flourish and where investment is attracted to new ideas,
- Ensuring the coordinated management of technology all across the government, and
- Forging a closer working partnership among industry, federal and state governments, workers, and universities.

Under this plan, the ratio of civilian and dual-use R&D to purely military R&D is significantly higher than in the past.

Increases in funding for advanced manufacturing R&D are proposed. Manufacturing R&D will receive particular emphasis from the DOC's Advanced Technology Program, ARPA and other federal agencies. All laboratories managed by DOD, NASA, and DOE will be subject to a review to determine whether they can make a productive contribution to the civilian economy, with the aim of devoting at least 10-20 percent of their budgets to R&D partnerships with industry. Removing obstacles to CRADAs and facilitating industry-lab cooperation will be a priority. The Office of Science and Technology Policy will be reinvigorated and the FCCSET strengthened.

On the U.S. trade front, the new policy aims to strengthen high technology industries by fostering a trade policy that encourages open but fair trade, contributes to U.S. access to foreign science and technology, and promotes science and technology cooperative projects that enhance U.S. access to foreign sources of science and technology and provide the basis for marketing U.S. goods and services.

To improve conditions for private sector investment and create jobs, the Administration has proposed:

- Making permanent the Research and Experimentation Tax Credit to sustain incentives,
- Creating incentives for long term investments in small businesses,

- Creating incentives for investment in equipment - The Administration will propose a temporary incremental investment tax credit for large businesses and a permanent credit for small businesses,

- Reforming anti-trust laws to permit joint production ventures - The Administration will forward legislation to Congress to extend the National Cooperative Research Act of 1984 to cover joint production ventures,

- Supporting agile manufacturing - This allows independently owned companies to form instantaneous partnerships with firms that have complementary capabilities in order to exploit market opportunities (virtual enterprises or virtual corporations),

- Creating a national network of manufacturing extension centers,

- Seeding regional technology alliances - This will promote the commercialization and application of critical technologies in which there are regional clusters of strength to encourage firms and research institutions within a particular region to exchange information, share and develop technology, and develop new products and markets,

- Increasing research on civil aviation technologies, and

- Establishing a "clean car" task force linking research efforts of relevant agencies with those of U.S. auto manufacturers.

The Administration pointed out that many commercial manufacturers refuse to do business with the DOD due to the volume and complexity of procurement laws and regulations, and those that do often segregate their defense production. The Center for Strategic and International Studies states that this often "results in higher prices to DOD (even when lower-cost commercial alternatives exist for the same requirements), loss of a broad domestic production base, and lack of access to commercial state-of-the-art technologies." Reform of procurement policies will be a priority of the Administration to:

- Give priority to commercial specifications and products for government purchases or government-contracted development,

- Facilitate commercialization of advanced technologies by having agencies invest in and procure them, where economically feasible, and

- Incorporate leading edge technologies by having agencies invest a portion of their procurement budget in innovative products and services.

The Administration wants to ensure adequate and sustained funding for university research grant programs at NSF, NIH and other research agencies. It also proposes conducting a review of laws and regulations to determine whether changes are needed to increase government-industry communication and cooperation. The National Economic Council will monitor implementation of new policies and coordinate technology policy with the policies of the tax, trade, regulatory, economic development, and other economic sectors.

11.3.2 New Legislation[347, 351]

New legislation further underscores the involvement of Canadian firms in the U.S. national technology and industrial base. Other legislation that has been passed focuses on stimulating R&D partnerships and technology transfer. Much emphasis is being placed on dual use products. These programs could prove especially viable for funding MMC projects, given that MMCs are an emerging advanced material with the potential of both commercial and military applications.

11.3.2.1 1993 Authorization Act Language

In this act, it is stated that Canadian firms are to be considered part of the U.S. national technology and industrial base.

11.3.2.2 Technology Reinvestment Project

Authorized under the Defense Conversion, Reinvestment, and Transition Act of Fiscal Year 1993, this project is aimed at stimulating "the transition to a growing, integrated, national industrial capability which provides the most advanced, affordable, military systems and the most competitive commercial products." Working in collaboration on this effort are ARPA, the Department of Energy/Defense Programs, NIST, NSF, and NASA. This project will be administered by the Defense Technology Conversion Council. The strategy of this program is to invest Title IV funds in the development of technologies which enable new products and processes, the deployment of existing technology into commercial and military products and processes, and the integration of military and commercial research and production activities. Outlined as areas of focus in the Technology Development Activity Area for materials/structures manufacturing are product oriented computation and modeling, affordable processing and manufacturing, and insertion of advanced materials (replacing standard materials) into components or systems to improve performance or reduce costs.

Eight programs are specified in the law for the funding of this project: Defense Dual Use Critical Technology Partnerships, Commercial-Military Integration Partnerships, Regional Technology Alliances Assistance Program, Defense Advanced Manufacturing Technology Partnerships, Manufacturing Extension Programs, Defense Dual Use Assistance Extension Program, Manufacturing Engineering Education Grant Program, Manufacturing Experts in the Classroom, and the Small Business Innovative

Research Program. In addition, several other programs are likely to provide support. All of these programs are discussed in the following paragraphs.

DEFENSE DUAL-USE CRITICAL TECHNOLOGY PARTNERSHIPS

This $100 million program provides for partnerships between DOD and two or more firms to encourage R&D in dual-use critical technology. This program promotes cost sharing research.

COMMERCIAL-MILITARY INTEGRATION PARTNERSHIPS

This program is similar to the Defense Dual-Use Critical Technology Partnerships, though emphasis is placed on the commercial viability of the technologies. Partnerships can be between DOD and private firms or non-profit organizations.

REGIONAL TECHNOLOGY ALLIANCES ASSISTANCE PROGRAM

This program will provide assistance to regional technology alliance centers to promote the use of defense-critical technology for military and commercial purposes.

DEFENSE MANUFACTURING EXTENSION PROGRAM

This program is designed to help small and medium sized firms with manufacturing innovation and processes to upgrade capabilities.

DEFENSE DUAL-USE ASSISTANCE EXTENSION PROGRAM

This program is geared to help companies dependent on defense business expand into the dual use marketplace through various types of assistance, including loan guarantees to small businesses.

DEFENSE MANUFACTURING ENGINEERING EDUCATION PROGRAM

This program will enhance the ability of educational institutions to serve regional manufacturing firms. It provides grants in manufacturing engineering and management.

SMALL BUSINESS INNOVATIVE RESEARCH (SBIR)

Sponsored by the SBA, this program requires agencies to reserve some R&D funds for small businesses using a simplified award process. It was established by the Small Business Innovative Research Act in 1982. The objective of this program is to stimulate technological innovation, strengthen the role of small business in R&D, encourage participation of minority and disadvantaged persons in technical innovation, and increase the commercial application of Federally funded R&D. The Army, Navy, Air Force and ARPA participate in the program through the DOD Office of Small and Disadvantaged Business Utilization and their respective Offices of Small and Disadvantaged Business Utilization. SBIR funding typically is used for projects in their early development phases. DOD funding for SBIR projects totaled about $250 million in 1992, about 54 percent of the overall Federal SBIR program.

OTHER DEFENSE INDUSTRY AND TECHNOLOGY BASE PROGRAMS

Though not specifically spelled out in the 1993 Appropriations Act, the Defense Conversion Commission presumes this funding will be in support of the Agile Manufacturing and Enterprise Integration Program, the Advanced Materials Synthesis and Processing Program, and the U.S.-Japan Management Training Program.

ESTABLISHMENT OF A NATIONAL DEFENSE TECHNOLOGY AND INDUSTRIAL BASE COUNCIL

This newly created council will advise and coordinate industrial base programs; programs to achieve reinvestment, diversification and conversion objectives; and changes in acquisition policy. Members of this group would include the Secretaries of Defense, Energy, Commerce and Labor.

ESTABLISHMENT OF A NATIONAL DEFENSE MANUFACTURING PROGRAM

This program, to be developed and implemented in accordance with the National Technology and Industrial Base Plan, would provide centralized guidance on matters related to manufacturing technology and dual-use efforts.

ESTABLISHMENT OF AN OFFICE OF TECHNOLOGY TRANSITION

This office, which would fall under the auspices of the Office of the Secretary of Defense, will ensure that technology developed for DOD is integrated into the commercial sector where appropriate.

11.3.3 Stevenson Wydler Technology Innovation Act of 1980[272, 304]

This act was the impetus for major change in the interactions between federal laboratories and private industry, giving laboratories the specific mission of transferring new technologies and requiring them to establish Offices of Research and Technology Applications (ORTAs) to effect transfers.

11.3.4 Federal Technology Transfer Act of 1986[251]

This act amended the Stevenson-Wydler Act and provided incentives to encourage industry, universities and federal laboratories to work cooperatively. It granted permission for departments to authorize laboratory directors to enter into cooperative research and development agreements (CRADAs) with universities and the private sector.

11.3.5 National Cooperative Production Amendment, Public Law 103-42

Signed by President Clinton on June 10, 1993, this law expands joint-venture privileges beyond the R&D stage and proposes allowing joint-venture product manufacturing. This amendment gives manufacturing/production joint ventures similar treatment under the antitrust laws as now accorded R&D joint ventures and reduces financial liability if a joint-venture partnership is found to violate anti-trust laws.

11.3.6 DFARS Subsection 213.205-18

A 1992 change to this section allows companies to use Independent Research and Development and Bid and Proposals (IR&D/B&P) funds for projects that have the potential to enhance the industrial competitiveness of the U.S. and to increase the development of technologies useful for both the private commercial and public sector. These funds were traditionally used to create new products and technologies, but this revision expands this to the development of commercial products.

11.3.7 Unclassified Material Sent to Canada[22, 332]

Unclassified material being sent to Canada, not controlled by the DOD, is normally handled through the mail system.

11.3.8 Unclassified DOD/Controlled Technical Data[22, 332]

Under the International Traffic in Arms Regulations (ITARs), Part 126.5, Canadians are not required to have an Export License for unclassified defense articles or unclassified materials, with some exceptions (fully automatic firearms, nuclear weapons and designs for naval nuclear propulsion, submersibles and certain categories of aircraft listed in Munitions Category List VIII(a)). This includes unclassified munitions list equipment and technical data. Canadian companies registered with the Joint Certification Office are authorized release by the DOD of its export-controlled technical data.

11.3.9 Unclassified Technical Data Disclosing Critical Technology[27, 332]

Canadian contractors registered with the Joint Certification Office are allowed to take responsibility for safeguarding "Unclassified Data Disclosing Critical Technology".

11.3.10 Information Exchange Agreement[22, 352]

Canadian firms can be certified for the receipt and use of information which is classified or controlled because of export restrictions on the technology.

11.3.11 Duty Free[33]

Canadian defense supplies imported by U.S. companies carrying out defense contracts are duty free.

11.4 Canadian Facilitators

On the Canadian front, the Canadian government has in place policies that offer a conducive climate for joint ventures between U.S. and Canadian companies. Some of these policies are outlined below.

11.4.1 U.S. Exemption Under Canadian Export Control Law[352]

Export of DND-controlled technical data that are subject to the TDCR sent to U.S. contractors certified under the U.S./Canada Joint Certification Program does not require an export permit or license from the Export Control Division at the Department of External Affairs.

11.4.2 Imported Materials

Canadian Order-in-Council PC 1970-1913, implemented by Revenue Canada memorandum D8-9-1, has simplified matters for Canadian manufacturers requiring imported materials for U.S. defense work.

11.4.3 Canadian Government Sales Tax[352]

This tax does not apply to goods, both for military and commercial use, exported from Canada to the U.S., provided the goods have not been used in Canada. These provisions are spelled out in the Excise Tax Act.

12.0 Technology Barriers

Joint U.S./Canada activities in developing the technology base in general and MMCs in particular are inhibited by barriers specific to governmental policy as well as by economic and competitive barriers. This section discusses these barriers: first, those common to both the U.S. and Canadian industry and then, those unique to U.S. and Canadian industry individually.

12.1 U.S./Canadian Barriers[146, 147, 117, 53, 20, 375]

Many barriers to the development of MMCs are industry specific and therefore apply to both U.S. and Canadian companies. These are discussed below.

12.1.1 Large Capital Investment Required; Lack of Investment Incentives

A very high ratio of capital investment to sales revenue is required for the commercial scale manufacture of advanced materials, generally $1 of invested capital for $2 to $4 of sales revenue. This is about double the cost of the typical contractor. This investment is usually made almost totally by the industry without any long-term market commitment, either from the government or from the commercial marketplace. Coupled with this is the fact that the commercial banking system takes a conservative approach to lending and has become quite restrictive in assessing renewal of present commitments and in reviewing new requests. The development and potential plant recapitalization costs that are required to develop and implement advanced materials are major obstacles. In the initial testing and evaluation stage, production volume requirements for the materials are limited, and the facilities often sit idle for extensive periods. And, if the government is the potential customer, the risks of the investment are heightened by the nature of the competitive bidding process. In addition, there is little financial relief for such an investment via tax incentives, accelerated depreciation rates on capital, and/or an appropriate return on investment commensurate with the high economic risk. In a recent DOC Critical Technology Assessment of the U.S. advanced composites industry, 38 percent of the firms reported losses in 1991 and 54 percent reported operating at less than 59 percent capacity. Small businesses, or small business units in larger corporations that must compete for internal resources, are especially affected by these considerations.

To remain competitive, companies will need to invest more in technology and product development. The current level of incentives for technology investment could be improved to help stimulate efforts in this area. A 1991 Canadian National Services Conference Report cited the need for more risk capital, pointing out that Canadian bankers and venture capitalists are seen to be risk averse. Representatives of small and medium companies said it is virtually impossible to obtain equity capital through the stock markets. The National Advisory Board on Science and Technology, in a February 1992 report to the Canada Consulting Group, emphasized that the high cost of capital in Canada especially hampers company efforts to grow, diversify, and invest to stay competitive.[368]

12.1.2 MMC Producers' Profit Margin Consideration

U.S. MMC producers' focus is, and has to be, on the bottom line. Managers have shorter-term perspective on return on investments, seeking to maximize short term investments to keep investors happy. This is due in part because investors would rather invest in short-term returns. Longer term investments demand higher returns. Short term profitability is key, and hence, many corporations have been reluctant to support their MMC operations through extended development cycles.

12.1.3 Government's R&D Focus on Technology Push

The U.S. government's R&D efforts have focused on pushing the material performance envelope to support extreme performance requirements in defense systems. Little emphasis has been placed on enhancing manufacturing processes for existing MMCs that could lead to a commercially viable product. The commercialization process, or market pull-through, has received little focus, and there has been little commonality in the areas of research, so leveraging of government funding is difficult. In addition, government funding typically does not emphasize demonstration and insertion programs.

12.1.4 Long Incubation Time Between Need Identification and Product Commercialization

Product commercialization of advanced composites can take three to 15 years, depending upon the complexity of the application and the maturity of the target market. There is also the potential for unforeseen technical difficulties. The Office of Technology Assessment report on advanced materials estimates that it takes nearly 20 years between development and commercialization of advanced materials. A similar study by the Air Force showed an average of 15 years between development and Air Force adoption. Coupled with that is the uncertainty of continued Government funding and the lack of a cohesive national strategy. There is no long term commitment. The impact of major defense cuts, delays and cancellations, as well as the inevitable downsizing of the defense industrial base, only heightens the problem.

12.1.5 Government Policies and Regulations

Defense procurement regulations are cumbersome, complex, and require much paperwork. This is time consuming and increases costs. These regulations also hinder the integration of the civilian and defense industrial bases. Many companies that manufacture similar commercial and military items make them in separate facilities to comply with legal and regulatory requirements. This also ensures that the cost involved in complying with Government regulations do not inflate the costs of commercial items. This sea of policies and regulations mandated for conducting business with the government has sometimes fostered a confrontational rather than a cooperative environment for conducting business and reduces the productivity of R&D.

Government procurement policies define and limit profit to a fixed percentage above costs. This reward system, based solely on typical low capital-intensive industries but applied equally to high capital-intensive industries, drives participants to maximize costs. Before companies even consider embarking on a major initiative, profitability and return on investment are weighed.

Government specifications that a contractor is required to meet before a material can be used in an application have proven to be a significant barrier, especially in regard to aerospace applications. For instance, if a company had MMC blades which were ready to engine test, they must wait for an engine to test them on. If the blades pass, approval for use can be sought. But, if the blades fail, the company must wait until the next new engine is available for testing to retest the new blades.

Establishing CRADAs with the U.S. federal government also takes time and involves onerous contractual specifications. Industry-government consultation is further constrained by the Federal Advisory Committee Act.

12.1.6 Lack of a Cohesive Planning Process

Industry and government R&D planning is disjointed - there is no complementary arrangement between the programs or dialogue between decision makers. The U.S. has no single agency concerned with the development of materials science in the private sector and at universities. This is in direct contrast with France, the Federal Republic of Germany, Japan, and the United Kingdom, each of which has one or two agencies that coordinate materials R&D by industry and universities. There is no formal ongoing communication concerning the formulation and implementation of technology policy and government R&D programs and few decision makers are aware of the benefits of advanced materials and the properties they offer. Many procurement officials simply accept polymer composites without even addressing the potential of MMCs. Partially due to lack of insight and partially due to fact, the government R&D program is considered continually changing. This makes progress over the long term difficult since work has no continuity. Programs which have appeared to be high priority government programs one year end up as zero-ed line items the next.

12.1.7 Intellectual Property Rights

According to the United States Advanced Ceramics Association, "the government's desire to acquire rights to technology developed with government funds discourages government contractors from inventing with government funding due to the resultant restricted ability of the contractor to benefit commercially from such inventions". Oftentimes, contractors are required to share in the development costs of a program and give up some or all of their rights to the technology developed. The filing of a patent application prior to a government contract does not safeguard against having the invention deemed a subject invention. This results in discouraging contractors from pursuing their best technical ideas with the government, thereby reducing the number of inventions realized by federally funded R&D. Moreover, it is likely that only the highest risk ideas (i.e., those with least probability for success) and the lowest risk ideas (i.e., those with small opportunity for invention) will be explored by government contractors. This can affect the quality of invention achieved through government funding. In addition, when government funding reaches the design stage of a program, funding at the materials development level often runs out.

Private company concerns about losing rights to their own technology when working with the Government may actually cause the Government to become isolated from exposure to and application of certain technology which may be critical to government needs. This concern may prevent private companies from using their most viable technology because of their fear of the loss of rights.

There is also the risk of high technology piracy. According to the U.S. International Trade Commission, in 1986, American industries lost between $43 billion and $61 billion in sales from the illicit copying of U.S. inventions. Inadequate protection abroad of our patents, copyrights, trademarks, and trade secrets makes this piracy possible. An international code of effective laws and enforcement, possibly through the General Agreement on Tariffs and Trade (GATT), is needed.

12.1.8 Protection of Proprietary Information

Another consideration is the proprietary nature of much of the R&D effort. Most of the material vendors are small businesses with proprietary manufacturing processes they would like to protect. Because most of the companies do not want to share their unique manufacturing processes, joint research initiatives are hindered and there is no widely accessible data base to characterize the basic properties of MMCs.

12.1.9 Import Controls

Import controls have proven to be another hindrance. DWA has cited these controls to be a real problem for them. They have had opportunities to put MMC parts on European planes, but Europe would not allow U.S. produced parts on European planes.

12.1.10 Classified Data

Transmission of classified data between the U.S. and Canada must be approved through government-to-government channels. An Export License for classified and some unclassified materials is required. The U.S. State Department, Office of Munitions Control, regulates the export of defense articles and services.

12.2 U.S. Barriers

Some barriers are unique to the U.S. These are described below.

12.2.1 ManTech Program Restrictions[53]

The government shares the risk of developing a material through its MANTECH program. However, since this program usually requires an identified production application prior to participation, some MMC companies have been unable to receive funding through this program.

12.2.2 Antitrust Considerations[53]

The formation of consortia is advantageous because they spread risks and resource requirements and join the capabilities of participants. However, the formation of industrial consortia is constrained by U.S. antitrust considerations.

12.2.3 Munitions Control Act, ITAR[340]

Because MMCs are covered by the Munitions Control Act, the exchange of information with other countries is considerably limited. This has slowed MMC technology development, especially at the university research level where many of the graduate students are foreigners, and hence, unable to participate in MMC research. The result is that many schools have withdrawn from this area, with a consequent loss in the nation's ability to train new people. Foreign users are especially wary of these restrictions, fearing that the U.S. government could cancel or reject relevant export licenses. This is hampering the efforts of MMC suppliers attempting to export.

Alcan was recently granted an appeal to remove the DOD ITAR/OME restriction from their MMC process and place it under DOC restrictions, which only include trade restrictions to unfriendly nations. Recent rulings of the Defense Trade Control at the Department of State concerning MMC commodity jurisdictions licensing determinations have tended to list MMCs not specifically designed or modified for use in defense to be governed by the DOC Control List.

12.2.4 Small Business Set-Asides[348]

While Canadian companies can be subcontractors to U.S. small businesses, they cannot themselves qualify as small businesses under this legislation. Where Small Business Set-Asides are specified in the Request For Proposal process, Canadian suppliers that are registered as planned producers on that product (with the Canadian Commercial Corporation) are allowed to compete as a prime contractor.

A Canadian, however, may own a U.S. small business without jeopardizing the U.S. company's ability to qualify for set-asides.

Similar set-asides occur in:

- Labor surplus areas,
- Small disadvantaged businesses,
- Depressed industries, and
- Women-owned businesses.

12.2.5 The Berry Amendment (DFARS 225.70)[348]

This amendment restricts food, clothing, synthetic fabric, and specialty metals. Depending on how broad an interpretation is used, this could potentially be applied to certain MMCs.

12.2.6 The Bayh Amendment (DFARS 25.7008)[348]

This precludes use of DOD appropriations for award to any foreign corporation, organization, person or entity for R&D in connection with any weapon system or other military equipment if there is a U.S. corporation, organization, person, or entity equally competent and willing to perform at a lower cost.

12.2.7 Byrnes-Tollefson Amendment (DFARS 225.7006)[348]

This amendment precludes Canadians and other foreign suppliers from providing ships/vessels or major components thereof.

12.2.8 U.S. National Disclosure Policy[348]

The U.S. Government has a national disclosure policy under which technology and weapon systems not to be disclosed to foreign countries are identified. These cannot be disclosed without authorization from the National Disclosure Policy Committee.

12.2.9 Classified Contracting[332]

Gaining U.S. facility Security Clearances and Personnel Security Clearances can take several months to complete.

12.2.10 U.S. Visas[332]

U.S. visas are required for Canadian contractors working in the U.S., even in support of their own equipment.

12.2.11 Declining Skill Base

The present skill base in advanced materials is not sufficient to meet the future R&D needs of the industry. As well, the quality of the education of students in the advanced materials concentration could be sharpened to strengthen the skills of the emerging workforce.

12.3 Canadian Barriers[444, 445]

Some barriers which are unique to Canada are described below.

12.3.1 Shortage of Skilled and Managerial People

A June 1992 Prosperity Consultation on fabricated materials cited many issues that hinder growth in this arena. It addressed the need for more skilled and managerial people. This could be remedied by easing the immigration of skilled people. While barriers to personal mobility have been eliminated in Europe, they remain significant in North America. The study noted that the current point system for immigrants gives preference to applicants with skills that are in short supply. However, these lists are not really reflective of current shortages and could give greater preference to applicants with needed skills. And, when Canadian companies try to lure a person with a unique background or reputation to live and work in Canada, their efforts are thwarted because the family of the individual cannot get work permits or the Canadian taxation level is too high. Even professional mobility standards throughout the provinces have proven to be a barrier. In the long term, the education system should also be examined to address shortages in critical skills areas.

12.3.2 Need for Better Access to Technology Developments[444]

Canada is responsible for a very small share of patents worldwide - approximately two percent. The government's two major programs for accessing technology, IRAP and TIP, are unknown by most small businessmen. Better utilization of these programs is needed to enhance the flow of foreign technology into Canada.

12.3.3 Export Consideration[444]

Unlike the U.S., which gives some tax breaks to certain small business export sales compared to domestic sales, Canada lags in the encouragement of export sales. Canada's Export Development Corporation does not approve applications as quickly as other export credit agencies, which is causing Canada to lose production opportunities.

12.3.4 Canadian Content Policy

Canada has structured its procurement system to encourage development and maintain viability of domestic industry. Subject to Canada's international obligations under the GATT and the Canada-U.S. Free Trade Agreement, Canada maintains a preference for Canadian products and services where there exists sufficient competition. This preference for Canadian products and services as a sourcing tool has been in place for a number of years. However, significant changes to this approach were implemented in April 1992 to simplify the process. Suppliers will determine whether their bids fit into one of two groups based on the application of "rules of origin" contained in the FTA. Based on these rules, bids that meet the content requirement will be considered either Canadian or not. Where there is sufficient competition (usually three or more suppliers), only those suppliers offering qualified Canadian goods and services will be considered. This new approach is consistent with the U.S. Buy America regulation in that it is product based. However, unlike Buy America, Canada has removed the use of premiums for domestic content, giving U.S. firms an opportunity to bid in circumstances where they can achieve a Canadian product designation according to the rules of origin requirements, or where there is not sufficient competition in Canada to justify restricting tendering. It should be underscored that this policy is geared to Canadian government procurement of goods and services and does not apply or affect the procurement policies of individual Canadian companies. The impact of this policy is not very significant in regards to U.S./Canada trade matters since many Canadian companies are subsidiaries of U.S. parent companies and hence, not penalized by the Canadian Content Policy, since foreign owned domestically based companies are not precluded from participating in government procurements.

12.3.5 Canadian Industrial Regional Benefits (IRB) Policy[336]

Since the mid-1970's, Canada has sought to obtain maximum benefits for Canadian industry from major federal procurements. In 1986, Canada introduced a new procurement policy, which directs the Government's promotion of industrial and regional development through procurement. Emphasis is placed on long-term economic activity in large federal purchases, thus focusing less on seeking short-term benefits in the form of industrial offsets and a greater focus on long-term achievements in industrial development. This new policy replaces quantitative 100 percent offset targets (or dollar-to-dollar counter-trade) in favor of more selective industrial benefits, focusing on bilateral initiatives such as joint ventures, licensing arrangements, co-production agreements, and transfer of technology and investment. This program is geared to develop internationally competitive Canadian sources of supply. Some recognized IRB initiatives are technology transfer and development and promotion of exports in manufacturing and the advanced technology service sector.

12.3.6 Tariffs[348]

Canada has not waived tariffs on U.S. defense goods that enter Canada as part of the implementation of the Defense Production Sharing Arrangement (DPSA), although the U.S. has. It imposes tariff duties on goods imported under all prime contracts valued at less than $250,000, as well as on all subcontracts. However, these can be remitted upon request for those goods being returned to the U.S. rather than remaining in Canada for defense purposes.

13.0 Recommendations to Advance the MMC Sector

The North American MMC industry has achieved great technological strides, but has not established a viable and sustaining marketplace. In order for this vital technology to be available to the North American defense industrial base to meet future system performance requirements, government should encourage the use of MMCs in present and emerging applications and should assist the MMC industry in bridging the gap to commercialization. Both the U.S. and Canadian governments should be engaged in these activities to maximize the demand and the resources which can be applied to establishing this marketplace. As the marketplace becomes established and increased volume production reduces MMC cost and reinforces MMC demand, government participation can be reduced while advances in MMC technology continue based on the industry's return on investment from the marketplace.

This section presents the recommendations and roadmaps for making MMCs a viable market and for enhancing joint U.S./Canadian activities in achieving this viability. First, the goals to be achieved are presented. These goals represent the removal of present barriers which prevent the market viability of MMCs. The strategy to attain these goals is described in terms of two types of recommendations. General advancement recommendations provide a strategy for changing the current environment which affects the development and viability of virtually any technology. Follow-through on the recommendations will benefit not only MMCs but also any of the DOD critical technologies. Specific recommendations are keyed directly to the viability of the MMC marketplace. Follow-through on these recommendations will have significant impact on meeting the goals needed to achieve MMC viability. Both the general and specific recommendations are presented in roadmap format which distinguishes between near and far term actions to be pursued.

13.1 Goals

Based upon the substantial research performed for this study, as well as the numerous interviews with MMC proponents, the study group found four MMC industry advancement goals continually being discussed. These four goals are:

1) Lower the cost of producing and using MMCs;
2) Improve communications between government, industry, and academia;
3) Improve the commercial viability and increase the commercial demand for MMCs; and,
4) Strive to overcome the technical shortcomings of MMCs.

Cost is the principal constraint to the pervasive use of MMCs. In addition to the high cost of starting materials, processing, and fabrication, MMC development costs tend to be high due to the technical complexity of the material. If low cost goals are not met, the MMC industry products will not be commercially viable. Thus, lowering the cost of producing and using MMCs should be goal number one among all MMC proponents.

Removing barriers to communicating or sharing information concerning MMCs, such as non-proprietary technical data, should also be a priority. The industry forums that presently exist to focus and promote MMC technology have served a very useful purpose, but more promotion, education, and exchange of ideas is needed to ensure the advancement of MMC technology.

In order to further progress, the MMC industry, particularly the discontinuous MMC industry, must wean itself from DOD and other government funding and increase its commercial demand. MMC technology has developed in the U.S. with substantial support from U.S. defense agencies. A substantial number of MMC concepts have been explored and several have reached a reasonable level of maturity. A strategy must be implemented to direct MMCs into high volume commercial applications.

The government and industry MMC proponents believe that the technology shortcomings of MMCs, particularly continuous MMCs, also need to be addressed before the industry can advance. Future applications, particularly high performance aerospace applications, will demand that secondary processing issues such as repairability and recyclability be addressed. Other technology shortcomings also need to be addressed.

The sections that follow present recommendations designed to assist in fulfilling these goals. These recommendations are divided between general advancement recommendations and specific recommendations. The general advancement recommendations have more of a policy flavor whereas the specific recommendations have more of a technology slant.

13.2 General Advancement Recommendations

The following paragraphs organize general advancement recommendations into three strategies: improving the economic viability associated with advancing new technologies; improving communications between government, industry, and academia; and improving MMC awareness through improved education. Each of these strategies comprise multiple recommendations. Roadmaps for executing these three strategies are provided as Figure 13-1.

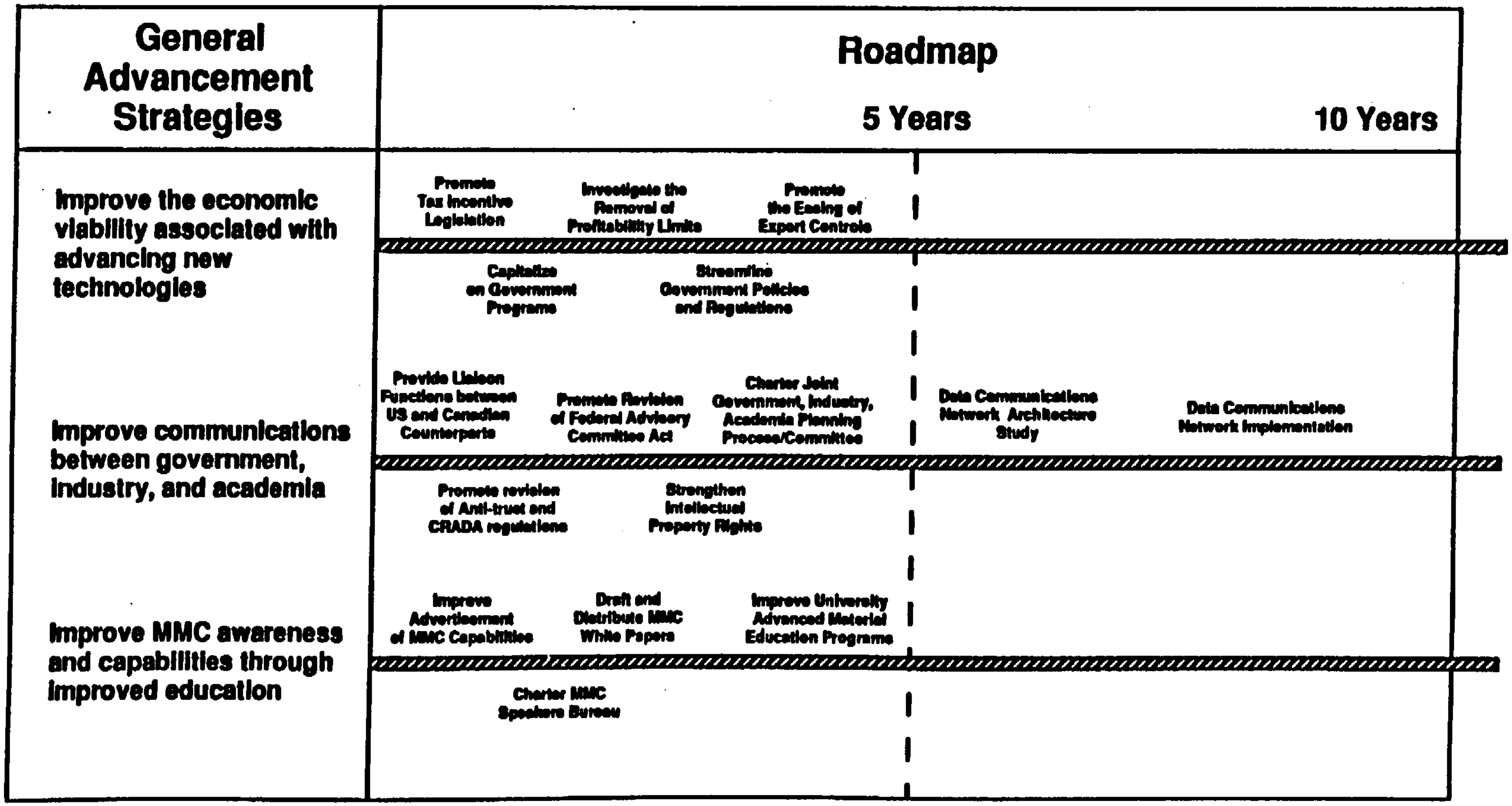

Figure 13-1. Roadmap of General Advancement Strategies

13.2.1 Improve the Economic Viability Associated With Advancing New Technologies[389, 444, 53, 19, 20]

MMC advancement is hindered by the development and potential plant recapitalization costs required to develop and adopt this technology. Companies in competitive global regions are not stopped by these obstacles due in part to government support. There are several avenues open to the U.S. and Canadian governments which could help propel the industry forward. These avenues include providing tax incentives, better utilization of existing and new government programs, removing artificial limits on profitability, overhauling government policies and regulations, and easing export controls. Many of these options have been proposed by the Suppliers of Advanced Composite Materials Association and the United States Advanced Ceramics Association for the advanced materials arena. Each of these recommendations is discussed in greater detail in the following paragraphs.

13.2.1.1 Provide Tax Incentives

Recognizing the capital-intensive nature of the MMC industry and the need to promote adoption of MMC technology, the U.S. tax incentives described in the following paragraphs could be effective in lowering the cost of producing and using MMCs and enhancing the commercial viability of this advanced material. There are a number of tax incentives that could be implemented immediately to further enhance the MMC industry:

1) Legislate a tax incentive to encourage the use of MMCs in existing and new applications, thereby aiding in market "pull through" and the commercialization of MMCs. End users of domestically produced advanced materials should be eligible for tax credits on purchases, developmental/qualification expenses, and new capital investments associated with commercial use of these materials. This would help offset the near-term cost and perceived risk of introducing MMCs into commercial applications.
2) Provide accelerated depreciation rates on capital invested in MMC technology.
3) Make the R&D tax credit permanent. This credit has received extensions in the past; however, companies do not know whether they should rely on this incentive for current and future R&D initiatives.

Canadian tax incentives that have been proposed by a Canadian private sector consultation group are very similar to the U.S. incentives. These include extending the Scientific Research and Experimental Development tax credit system to include the improvement of production processes and the initial commercialization of new products;

raising capital cost allowance rates to more realistic levels, taking into consideration inflation and obsolescence; creating a highly accelerated capital cost allowance rate similar to that provided applications software for productivity enhancing equipment; and establishing an investment tax credit for business to offset the higher cost of borrowing in Canada.[444]

Suggested Offices for These Actions: U.S. Congress/ Canadian Parliament

13.2.1.2 Better Utilization of Existing and New Government Programs

There are a number of programs in place that could be used more effectively to further the current state of MMC technology, to support a broad range of dual-use applications, and to help accelerate the commercialization of MMC technology. For instance, the ManTech Materials Processing and Fabrication Programs could prove effective for increasing producibility and for reducing costs of advanced materials for defense and non-defense applications. The DOC's Advanced Technology Program could be structured to relate its activities more closely to product commercialization (it currently supports development of laboratory prototypes and proof of technical feasibility but not commercial (pre-manufacturing) prototypes or proof of commercial feasibility). The DPA Title III program has just recently undergone some significant policy changes, including an emphasis on promoting dual-use products, fostering commercial-military integration of R&D and production, and according a strong preference to small businesses. It also now allows projects for technology insertion. These policy and program changes could prove beneficial in enhancing the economic viability of the MMC industry.

Many of the new programs outlined under ARPA's Technology Reinvestment Project focus on dual-use activities and the integration of the commercial and military industries. These programs are certainly appealing for aiding in the commercialization of MMCs, hence furthering the economic viability of MMCs.

Suggested Offices for These Actions: OSD ManTech Program Office, OSD DPA Title III Program Office, DOC Advanced Technology Program Office, ARPA's Technology Reinvestment Program Office, Technology Development Activity Area for Materials Structure Manufacturing - Insertion of Advanced Materials

The eligibility of Canadian firms to participate in the U.S.'s existing and new programs needs to be clarified. In the FY 93 Defense Authorization Act, it is explicitly stated that Canadian firms are to be considered part of the national technology and industrial base. Based on this legislation, it would appear that Canadian firms should be allowed to be involved in these programs. U.S. Government decisionmakers need to be made aware of the Canadian facet to the U.S. industrial base. In this same vein, Canadian government decisionmakers should be made more cognizant to the potential benefits of U.S. firms in their defense base.[40]

Suggested Office for This Action: Canadian Embassy, NADIBO

Relative to the Canadian programs, many companies involved in some aspect of MMC production and fabrication are not familiar with the Canadian programs that could potentially provide them with funding. For instance, Inco expressed interest in finding out more information about the DIPP program. Heightened awareness of the different programs in place on both sides of the border is needed.[444]

Suggested Offices for This Action: DND, EAITC, ISTC, NRC, Natural Sciences and Engineering Research Council

Both the U.S. and Canada need to track more actively or make more readily available the state of technology in other countries in order to keep abreast of events and to identify new materials trends. The Canadians have in place two programs for accessing technology, the Industrial Research and Assistance Program and the Technology Inflow Program. These programs would be better utilized if given a higher profile and made better known to small businessmen.

Suggested Offices for These Actions: U.S. and Canadian Embassies, U.S. State Department, Canadian Government, NRC Industrial Research and Assistance Program Office, Technology Inflow Program Office

13.2.1.3 Remove Artificial Limits on Profitability

The current level of profitability that is allowed on DoD contracts is solely based on low capital-intensive industries, but is applied equally to high capital-intensive industries. Profit is defined as a fixed percentage above costs, resulting in an averge after-tax profit margin of approximately five percent for defense contractors. In a competitive commercial business, these products would warrant a 12 percent or more return on investment to be appealing to industry. The government should allow a return that is more appropriate for the high economic risk than is currently permitted by traditional government procurement regulations, taking into consideration the high cost of capital, not just direct development and production costs. This would encourage MMC producers to become more involved in government programs and would help stabilize the balance sheets of the individual companies.

Suggested Office for This Action: Office of the Under Secretary of Defense (Acquisition and Technology)

13.2.1.4 Overhaul Government Policies and Regulations

As mentioned previously, the multitude of government policies and regulations discourages industrial participation in government programs and increases the cost and effort of those that do participate. Some of the fixes needed to better streamline the process include:

1) Overhaul defense procurement regulations to allow integration of civilian and defense industrial bases,
2) Reduce the amount of government paper work to lower costs to compete,
3) Simplify federal accounting standards to reduce overhead costs, and
4) Reduce auditing and oversight.

The Clinton Administration recognizes that current government policies and regulations are in need of revamping and that the use of less-costly, commercial-style procurement practices should be examined. The Administration is actively developing an acquisition reform program to replace the current acquisition policy. The Canadian Government also recognizes the necessity of streamlining its regulations.

Suggested Offices for These Actions: OSD, Office of the Deputy Undersecretary for Acquisition Reform/DND

In Canada, immigration controls have proved a barrier to obtaining people with critical skills needed in the MMC field. For example, with two-wage-earner families typical in the current social and economic environment, individuals may be reluctant to immigrate into Canada if their spouses are not permitted to work. The impact of this barrier could be lessened if the immediate families of these highly skilled immigrants were permitted to work upon entering the country. By bolstering the technical skill base, the technical shortcomings of MMCs could be surmounted.

Suggested Office for This Action: Canadian Parliament

Canadian companies would benefit from legislation put in place in Canada similar to the Foreign Sales Corporation legislation in the U.S. to help simplify exports. In addition, the Export Development Corporation's services should be made more competitive and less time consuming to further enhance export sales, thus making the MMC market in Canada more commercially viable.

Suggested Office for These Actions: Canadian Parliament

13.2.1.5 Ease Export Controls

Frequently, U.S. companies are placed at a disadvantage when marketing abroad an advanced material that is listed on the U.S. Munitions Control Lists. Foreign competitors that are not subject to these restrictions are able to sell the material freely in other countries. Easing export controls will assure that U.S. industry does not suffer from unilateral controls imposed by these munitions control lists. By accelerating the rate at which MMC products and technologies that have become commercially available are removed from the U.S. control lists and by basing restrictions on product performance levels critical to national security rather than generic chemical composition, international trade of MMCs could be enhanced, thus improving the commercial viability of the industry. The government could further facilitate trade by supporting export and re-export policies that allow goods and technologies licensed for export into one Coordinating Committee (CoCom) on Multilateral Export Controls country to be authorized for use in all CoCom Countries.

Suggested Offices for These Actions: U.S. Government, State Department, Department of Commerce, CoCom

13.2.2 Improve Communications Between MMC Proponents

Strengthening the communication links between government, industry, and academia is crucial to keeping the flow of information regarding MMCs current and up-to-date. Effective communication ties can serve to target and overcome technical shortcomings through the sharing of ideas and to address potential applications with decisionmakers. Recommendations that will improve communications include providing liaison functions between U.S. and Canadian counterparts, chartering a joint planning group, reducing the time and complexity involved in establishing Cooperative Research and Development Agreements (CRADAs), enhancing and protecting intellectual property agreements, and establishing a data communications network. Each of these recommendations is discussed in the following paragraphs.

13.2.2.1 Provide Liaison Functions Between U.S. and Canadian Counterparts

Currently, the Canadian and U.S. governments interact on advanced materials through the Technical Cooperation Program and other various international organizations. The two countries could better integrate planning on critical technologies by inviting representatives from the other country to sit in on planning meetings taking place in their respective country. Another possibility would be to establish a special working group through the DDSA program that deals specifically with advanced materials, including MMCs.

<u>Suggested Offices for These Actions</u>: Advanced Industrial Materials Directorate, DDSA Program Office, OSD, DND

13.2.2.2 Charter Joint Planning Group

At present, the Federal Advisory Committee Act constrains industry-government consultation by restricting industry from participating in advisory groups that help shape the future direction of government policies. These restrictions should be eased so that U.S. industry can participate in the planning processes of the advanced materials programs, such as the U.S. Advanced Materials and Processing Program, in a sustained, long-term and concurrent fashion. Formally chartering a joint government, industry and academia planning committee to help set the national material program policies and priorities would prove much more effective in formulating and implementing technology policy and government R&D programs than seeking industry's input through occasional ad hoc workshops. This would also help to allocate resources in a manner that avoids duplication of effort and would provide a useful and productive forum for exchanging information. Leadership of this group could be provided by a trade association familiar with the unique needs of the MMC industry. In fact, many MMC producers have been meeting recently to discuss the possibility of forming such an association, either independently or as a specific subcommittee of a larger association. Such an association could be the perfect vehicle for this type of interaction.

Suggested Office for This Action: OSD, DND

Both the U.S. and Canadian governments offer a multitude of different programs that industry could capitalize on. Unfortunately, many companies are not familiar with all the options available to them. The governments should try to provide their programs with a higher profile.

Suggested Offices for This Action: OSD/DND; Program Offices Responsible for Various Programs

13.2.2.3 Reduce Time and Complexity Involved in Establishing CRADAs

Some companies have stated that it has taken up to two years to cut through the paper work involved in establishing a CRADA. By that time, the R&D initiative would be overtaken by events. By reducing the time and complexity, MMC technical shortcomings could be pinpointed and addressed at an early stage, leading more rapidly to lower costs.

Suggested Offices for This Action: Offices of Research and Technology Applications at the Federal Laboratories, DOC/NIST

13.2.2.4 Enhance and Protect Intellectual Property Right Agreements

The MMC industry is actively concerned with protecting their unique MMC capabilities and processes. This concern has hampered the level of communication between industry and government and is a consideration with producers on the international front. To address contractor concerns about losing their intellectual property rights when becoming involved with the government, and thus enhance communication between the two parties, the government could exercise the following options:

1) Waive ownership to technology data rights for domestic MMC producers participating in federally funded technology programs on a cost-shared basis. This will help attract producers to apply their more innovative and commercially viable MMC technologies in federally sponsored programs.
2) Clarify the FAR regulations concerning "subject inventions" so that developments made by industry during a government contract that are made with

private or independent research and development funds do not fall under the auspices of subject inventions.

3) Apply a 'constructive-reduction-to-practice rule,' by modifying the subject invention definition to include reference to a constructive-reduction-to-practice. This would avoid having the invention deemed a subject invention when industry has developed a concept that has not been completely proven prior to entering into a government contract.

Suggested Office for This Action: U.S. Administration, OSD

With regard to protecting the intellectual property rights of companies abroad, the government could put forward proposals to reduce foreign tariffs, strengthen U.S. intellectual property rights, and rally against unfair trade practices in the Uruguay Round discussions (current discussions concerning the General Agreement on Tariffs and Trade agreement). Many industrialists have expressed concern that the current negotiations have placed too much emphasis on agricultural subsidies and not enough attention on technology issues. However, the recent talks that have taken place in Japan have centered more on these advanced materials issues and show great promise.

Suggested Office for This Action: Office of the United States Trade Representative (USTR), State Department, Department of Commerce

Another option to ensure that U.S. companies enjoy the same access to foreign markets that foreign companies enjoy in the U.S. is to enact a stronger, sharper international trade policy stance, similar to the Super 301. The Super 301, which expired in 1990, directed the USTR to identify those countries that deny adequate and effective protection for intellectual property rights or deny fair and equitable market access to persons that rely on intellectual property protection. These countries were then labeled "priority foreign countries" and were subject to investigation conducted in an accelerated time frame under section 301. If particular or recurring problems existed with respect to intellectual property rights or market access for persons relying on intellectual property, these countries were then placed on a "priority watch list" and "watch list" and were the focus of increased bilateral attention on the problem areas.

Suggested Office for This Action: USTR, State Department, Department of Commerce

13.2.2.5 Establish Data Communications Network

One significant program that could provide interested parties with hands-on up-to-date information on the state-of-the-art of MMC technology is to establish a data communications network that would facilitate the efficient transfer of non-proprietary technical ideas and data. This network would provide the community with an on-line capability to tap into the current efforts taking place in the MMC world. It is envisioned that a system using Internet could prove extremely effective. A network architecture study would need to be undertaken, followed by actual implementation.

Suggested Office for This Action: MMC Industry Association

13.2.3 Improve MMC Awareness and Capabilities Through Improved Education

Education is key to acquiring the scientists needed to study the specific problems of the MMC community and determine applications for MMCs. Two other major target audiences that could benefit from further education concerning composite materials, and MMCs in particular, are government decisionmakers and academia.

13.2.3.1 Heighten Awareness of Government Decisionmakers

Part of the problem with incorporating MMCs into applications is the lack of awareness of government decisionmakers concerning the benefits of MMCs. A public relations campaign aimed at these key decisionmakers could help to promote the adoption of MMCs into applications. The American Society of Metals (ASM) International Materials Coalition has scheduled luncheon forums between industry representatives and political officials to provide industry with the opportunity to discuss their needs with these political officials. More of these efforts specifically tailored to MMCs could be effective in further heightening the awareness of the unique capabilities of MMCs. In addition, having speakers present papers on MMCs at various conferences could prove to be a useful communication tool. The distribution to key policy officials of white papers on how to develop the MMC industry would also be valuable.

Suggested Offices for This Action: MMC Industry Association, Professional Societies

13.2.3.2 Improve Academic Programs

Recent surveys conducted by SACMA have shown that the number of university students enrolled in advanced composite processing and fabrication programs is not sufficient to provide the research, development and applications expertise the industry will need to compete effectively in the years ahead. Also, the current educational structure for the advanced materials area is in need of revamping. Hence, the issue of improved academic programs is twofold: increasing the pool of skilled workers that currently exist and enhancing the quality of science and technology programs relevant to materials processing, manufacturing and utilization relevant to commercial application. A national education program promoted by the government to strengthen the technical skill base required to support the future needs of the U.S. advanced composites industry is recommended. The Suppliers of Advanced Composite Materials Association (SACMA) and the United States Advanced Ceramics Association (USACA) have outlined four education and training initiatives: processing and fabrication, quality and reliability, design and application, and worker skills and resources. The latter is designed to provide incentives for defense related firms to retrain workers for non-defense related careers. This recommendation dovetails with Clinton's policy goal to strengthen the skills of America's workforce.

With regard to Canada, the suggestion was made that the provincial funding system be altered to provide more funding for sciences and mathematics. The four education initiatives outlined in the above paragraph would greatly enhance the knowledge base of Canada's future scientists as well.

<u>Suggested Offices for This Action</u>: MMC Industry Association, Department of Education, Professional Societies

Another possibility for attracting students to become involved in advanced composite processing and fabrication programs is for the individual companies to offer scholarships in that arena for students. This not only would help expand the skill base of the future workforce, but would also offer the companies with a list of potential candidates for positions in the field.

<u>Suggested Offices For This Action</u>: MMC Industry Association, Professional Societies

13.3 Specific Recommendations

As mentioned above, the specific recommendations described herein focus more directly on MMCs and primarily address technology issues. Figure 13-2 presents a programmatic roadmap that shows how these specific recommendations could be implemented over time. Specific recommendations include the following actions:

1) Create a low cost MMC insertion program for automotive applications,
2) Create military retrofit applications for MMCs,

3) Improve the secondary processing techniques for MMCs,
4) Improve production techniques for continuous MMCs, and,
5) Broaden the scope and improve existing MMC design, analysis, and test techniques.

These recommendations and the details of the roadmap are described further in the sections that follow.

13.3.1 Create a Low Cost MMC Insertion Program for Automotive Applications

The creation of a government directed MMC insertion program into an industry with a large potential commercial market could lower the cost of using MMCs and help to demonstrate their commercial viability. Then, if their demonstrated performance fulfills the expectations of their advertised performance, an increase in commercial demand should follow.

The tailorability of MMC materials should present an opportunity for automotive manufacturers to improve performance and to reduce costs. Potential benefits include improved fuel economy, improved packaging efficiency, reduced weight, reduced emmisions, reduced noise, reduced vibrations, and reduced maintenance. The introduction of stricter CAFE standards will further emphasize improved fuel economy. As discussed in Section 7 (see Figure 7-4), there are numerous actual and potential applications of MMCs in automobiles. The potential commercial market for MMCs is enormous.

A government directed insertion program into the automotive industry could utilize an existing effort such as the Department of Commerce/NIST Advanced Technology Program to provide focus and momentum. After appropriate demonstrations, a pilot insertion program could then be initiated in a set of automobiles such as the government fleet of vehicles. If the MMCs prove their worth, insertion into non-governmental vehicles could then begin with the ultimate goal being equal consideration of MMCs for all appropriate automobile parts.

Suggested Office for This Action: Department of Commerce/NIST

MMC Specific Recommendations	Roadmap: to 5 Years	Roadmap: 5 Years to 10 Years
Create a low cost MMC insertion program for automotive applications	NIST Advanced Technology Program Initiation; Pilot Insertion Program	Insertion Program Scale-up; Automotive MMC Full Scale Production
Develop a program to create military retrofit applications for MMCs	Identify Potential Retrofit Parts; Discontinuous MMC Retrofit Demonstration; Discontinuous MMC Retrofit Qualification	Discontinuous MMC Retrofit Insertion; Continuous MMC Retrofit Qualification; Continuous MMC Retrofit Insertion; Continuous MMC Retrofit Demonstration
Develop a program to improve secondary processing techniques for MMCs	Evaluate Repair Methods; Discontinuous MMC Fabrication Demonstration; Repair Method Development; Repair Process Qualification/ Demonstration; Evaluate Recyclability Methods; Recyclability Method Demonstration	Field Repair Development; Field Repair Qualification/ Demonstration; Continuous MMC Fabrication Demonstration
Improve production techniques for continuous MMCs	Small Diameter Fiber Development; Increased Strength and CTE Reinforcement Development; Fiber Pilot Plant; Plasma Spray Development; Alloy Pilot Plant	High Temperature Fiber Development; Fiber Production Plant; Foil Scale-Up; Powder Scale-Up; Alloy Production Plant
Broaden the scope and improve the existing MMC design, analysis, and test techniques	Database Development; Test Method Development; Standards Improvement/ Development; NDI/NDE Development; Material Specifications Development	Sub-element Testing; Document Design Methods; Field Testing; NDI/NDE of Large Structures

Figure 13-2. Roadmap of Specific Recommendations

13.3.2 Create Military Retrofit Applications for MMCs

The cost of MMCs could also be reduced through a non-commercial insertion program designed to create a market within the DOD for retrofit parts fabricated from MMC materials. This program would start with a tri-service study to identify potential candidate parts for retrofit using MMCs. Once a list was complete, a small set of systems would then be selected to demonstrate and test MMC retrofit parts. Since discontinuous MMCs are a more mature technology than continuous MMCs, these first demonstrations would focus on discontinuous MMC retrofitted parts.

If the discontinuous MMC demonstrations progressed satisfactorily, the retrofitted MMC parts would then proceed to a qualification process. The qualification process would be based upon necessary MMC standards and specifications development. The demand for these discontinuous MMC retrofit parts should increase once the parts are qualified. Further applications for discontinuous MMC retrofit parts should also ensue.

When continuous MMC technology matures, the same process can be employed to qualify continuous MMC retrofit parts. Since applications of continuous MMC retrofit parts will probably require higher performance and greater reliability than discontinuous retrofit parts, a longer demonstration phase may be required.

Suggested Office for This Action: OSD

13.3.3 Improve the Secondary Processing Techniques for MMCs

Secondary processing technologies for MMCs involve many steps and are labor intensive. Unless significant reductions in costs of secondary processing techniques are achieved, the widespread use of MMCs may never occur. Improved secondary processing techniques should help improve the commercial viability of MMCs in addition to helping reduce the cost of producing and using MMCs.

Of vital importance to the process of commercializing MMC technology is the ability to make and repair real components that can be formed and joined to one another and to non-composite structures. Thus, secondary fabrication processes such as joining, forming, drilling, machining, cleaning, repairing, and recycling of consolidated MMC components need to be improved.

A program to improve the secondary processing techniques of MMCs could begin with an evaluation of repair recycling methods in order to focus on those techniques that offer the greatest return on investment. Simultaneously, demonstrations of the existing discontinuous MMC fabrication methods could be scheduled that will provide the MMC material for the commercial MMC and military MMC pilot insertion programs.

Subsequently, demonstrations for the selected repair and recycling methods could be scheduled, followed by field repair qualification. Continuous MMC fabrication demonstrations should also be scheduled when the continuous MMC technology is more mature in order to provide material for the military continuous MMC pilot insertion program.

Suggested Office for This Action: OSD/ManTech Program Office

13.3.4 Improve Production Techniques for Continuous MMCs

Most of the technical shortcomings of MMCs are found in the production techniques of continuous MMCs. These production techniques represent the entire range of activities from synthesis of constituent materials to forming and joining complex shapes. Continuous MMC properties depend on the control of the structure and the composition of the elements and are a subject for basic research. Better understanding and control of the chemical processes that occur during consolidation and in-service are also required. Process modeling, advanced sensor development, and real-time, on-line process controls can improve process reliability.

On the other end of the spectrum, large-scale, precision rolling of metal foils, and new forming and assembly techniques are required for full scale parts. Methods for joining MMCs to other materials in complex assemblies have not been addressed to any degree and bonding and/or fasteners represent a difficult technical challenge.

Synthesis, processing science, and engineering advances are essential to improve quality and lower costs of MMCs and can lead to new compositions with better properties. The National Research Council in its report on maintaining competitiveness in the field of material sciences and engineering pointed out a weakness in the U.S. position on research in this field and recommended federal support for a national initiative in synthesis and processing.

Reinforcement of MMCs with continuous ceramic or carbon fibers provides the highest performance materials but at a high cost. The costs of the fiber and preform can account for 25 percent to 75 percent of the finished product and are a significant component of life-cycle-costs. Large reductions in fiber costs are needed, especially for applications where the use of this material would be pervasive, e.g., in conventional aircraft.

The performance-to-cost ratio can be improved by developing better fibers, ones that are fully compatible with the matrix. The fiber-interface-matrix system must be considered as a whole. In some cases, interface coating development alone may be sufficient to improve performance. Improved fiber-interface combinations are needed for the higher temperature metal and intermetallic materials. High specific strength and stiffness, chemical and thermal stability, minimum CTE mismatch, and high creep resistance are desired properties of the fibers.

Suggested Office for This Action: OSD/ManTech

13.3.5 Broaden the Scope and Improve Existing MMC Design, Analysis, and Test Techniques

Improved MMC material databases, standards, specifications, and test methods were universal recommendations among those interviewed for this study. Such improvements would improve communications among MMC proponents within government, industry, and academia, as well as assisting in improving MMC commercial viability and overcoming MMC technical shortcomings.

In order to consider a MMC for an application as in the retrofit insertion program recommended above, the MMC must be qualified for use in terms of standards, specifications, and a material property database. Two continuous fiber MMCs are currently manufactured to specifications and are flight qualified: boron/aluminum on the space shuttle and graphite/aluminum on the Hubble Space Telescope. Although characterization studies have been done on many other composite systems, the data are generally scattered and incomplete.

A standardized engineering database not only helps demonstrate the producibility of an MMC, but also requires the development of testing standards and data reporting formats. Development of the database therefore helps the industrial base present its own set of standards to the industrial community in the competition for global markets. Even before test standards exist, an engineering database that includes descriptions of the tests actually used to generate each data set becomes a prime tool for comparing different test variants and furthering the evolution towards standard tests. In addition, such a database leads to overall cost savings by facilitating the sharing of data between laboratories, thereby eliminating redundant testing.

Suggested Office for This Action: MMCIAC

Appendix A - Federal Science and Technology Infrastructure[357, 301, 431, 7, 45, 58, 70, 302, 304, 308, 306]

In both the U.S. and Canada, the federal government has a wide variety of departments and programs in place that deal with the science and technology base. Those directly affecting the MMC sector were briefly described in the report. This Appendix will provide much more detail on departments involved in the science and technology base and programs that enhance R&D and cooperative ventures. It will first address the U.S. science and technology base infrastructure, the U.S. programs in place that deal with science and technology issues, other U.S. departments/groups that are potential facilitators in the science and technology arena, and other U.S. programs that enhance the science and technology arena. Next, the Canadian federal government science and technology base infrastructure will be highlighted, and its programs, other departments/offices and other programs that enhance the S&T arena detailed. Other associations/societies concerned with research and development will then be described.

A.1 U.S. Federal Science And Technology Base Infrastructure

The federal government's role in the arena of science and technology affairs involves close coordination and interplay between several different organizations.

A.1.1 Department Of State

The Department of State has statutory responsibility for concluding and managing international agreements, thereby providing the formal legal framework for cooperation. The Department also participates in the negotiation of technology-related trade issues. It has a network of over two dozen full-time science and technology officers posted in over 20 missions around the world that provide important liaison, communication and information functions, all of which support the management and development of technical cooperation. In 1992, the Department of State established the Defense Trade Advisory Group , which is composed of 45 members from defense firms, academia and other organizations. Its mission is to help facilitate the reduction of impediments to legitimate defense exports and to improve interagency coordination of international defense trade issues.

The State Department's Bureau of Oceans and International Environmental and Scientific Affairs (OES) is the central U.S. Government coordinating point for international science and technology activities conducted by U.S. technical agencies. It assures that international science and technology interests receive appropriate emphasis in overall U.S. foreign policy deliberations and oversees numerous bilateral and multilateral science and technology agreements.

U.S. embassies and consulates abroad represent U.S. interests pertaining to science and technology issues. The Department of State assigns full-time Environment, Science and Technology (EST) Officers to advise ambassadors of science and technology issues and assist in the negotiation of cooperative agreements and programs.

The State Department, in conjunction with the Commerce Department's National Technical Information Service, manages the Science and Technology Reporting Information Distribution Enhancement (STRIDE) program. This program ensures that unclassified reports on foreign research and development activities are distributed to the private sector, academic institutions, and Federal laboratories.

A.1.2 Executive Offices

Most elements of the Executive Office of the President are involved in some aspect of international scientific and technology affairs. The Office of the U.S. Trade Representative is involved in technology-related trade issues. The Council of Economic Advisors and the Cabinet Councils and the Competitiveness Council have an overall responsibility for economic competitiveness, where technology is a key factor. The National Space Council addresses space policy , where the role of technology is a major consideration. The Office of Management and Budget oversees the budget aspects of the science and technology arena.

The National Academy of Sciences (NAS) provide the Federal government with science and engineering advice. Its National Research Council advice helps Federal agencies set Government priorities, policies, and planning. Advice on materials science and engineering is provided by NRC through its National Materials Advisory Board.

The National Critical Materials Council advises the President on national materials policy and establishes responsibilities and coordination among Federal materials policies, programs, and activities. A specific objective of this council is to develop a national Federal program plan for advanced materials research and development, including processing and manufacturing technologies. The council, in conjuction with White House Office of Science and Technology Policy (OSTP) and OMB, make recommendations to Congress regarding Federal advanced materials R&D.

The White House Office of Science and Technology Policy (OSTP) plays a strategic role in integrating science, technology and foreign policy issues. Established by statute in 1976, OSTP is charged with providing access to authoritative information and expert scientific, engineering and technological advice for the President, Federal officials, and Congress and with coordinating science and technology policy throughout the Federal Government. The OSTP has a Committee on Materials (COMAT). The Director of OSTP is also the Assistant to the President for Science and Technology; chairman of the Federal Coordinating Council on Science, Engineering and Technology; and chairman of the President's Council of Advisors on Science and Technology. He chairs the Operating Committee of the Critical Technologies Institute and serves as a member of the National Critical Materials Council.

OSTP works closely with the Federal agencies that support research and development, reviewing Federal science and technology programs to ensure that the R&D resources are used efficiently and serving as the U.S. focus for many bilateral and multilateral agreements in science and technology.

A.1.3 Federal Coordinating Council for Science, Engineering and Technology

The Federal Coordinating Council for Science, Engineering and Technology (FCCSET) was established in 1976 to address science and technology policy issues affecting multiple agencies. Chaired by the Director of OSTP, the Council coordinates Federal R&D programs and other multi-agency science and technology activities, providing a mechanism for focusing attention on science and technology policy issues within the Federal agencies.

Within the FCCSET Committee on Industry and Technology, there is a Subcommittee on Materials. This subcommittee spearheads the Advanced Materials and Processing Program (AMPP), which is a coordinated interagency program representing the efforts of ten Federal agencies, the Office of Management and Budget, and the Office of Science and Technology Policy. Prompted by the recognition of the need for a stronger overall Federal commitment of materials R&D and growing concern about foreign competition (which already has had a significant impact on manufacturing and national competitiveness), the goal of the AMPP is to address the needs and opportunities in materials to increase the effectiveness of the Federal R&D program in materials science and technology, taking advantage of opportunities for significant technical breakthroughs. This program represents the first coordinated Federal approach to materials science and technology. Activities range from fundamental research on material structures to major pilot-plant technology demonstration projects. The AMPP has four strategic objectives:

1) Establish and maintain the U.S. scientific and technological leadership position in advanced materials and processing, by achieving balance in materials R&D through the division of resources appropriately among projects and placing the emphasis on research results.

2) Bridge the gap between innovation and application of advanced materials technologies, fostering R&D ventures with the private sector to translate advances in materials and processing into advances in new products.

3) Support agencies' mission objectives to meet national needs with improvements in advanced materials and processing, optimizing interagency R&D planning, coordination and execution.

4) Encourage university and private sector R&D activities in materials technologies, their applications, and their implementation through highly leveraged Federal investments and other cost-sharing arrangements.

The AMPP focuses on nine broad classes of materials: biomaterials and biomolecular materials, ceramics, composites, electronic materials, magnetic materials, metals, optical/photonic materials, polymers, and superconducting materials.

A.1.4 Department of Commerce

The Department of Commerce (DOC) maintains a list of R&D consortia registered under the National Cooperative Research Act of 1984. This list is prepared by the Clearinghouse for State and Local Initiatives on Productivity, Technology and Innovation in the Office of Technology Commercialization, the Technology Administration at DOC.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

The Department of Commerce's National Institute of Standards and Technology (NIST) plays a major role in Federal efforts to improve the use of technology. Its mission is to (1) enhance the competitiveness of American industry while maintaining the function of lead national laboratory providing the measurements, calibrations, and quality assurance techniques, (2) assist private-sector initiatives to capitalize on advanced technology, (3) advance, through cooperative efforts with industry, universities, and Government laboratories, R&D projects that the private sector can optimize for commercial and industrial applications, and (4) promote shared risks, accelerated development and the pooling of skills. NIST is organized into ten operational units: eight laboratories, Technology Services, and an administrative support unit. Research in materials science and technology is carried out in seven of the eight laboratories. The majority of NIST materials R&D is carried out by the Materials Science and Engineering Laboratory, which is the central Federal resource for measurement-related materials research in support of industrial needs. Technology Services conducts and supports materials R&D in reference materials and data, calibration services, and new external technology efforts through the Manufacturing Technology Center Program and state technology outreach programs. NIST has established five Regional Manufacturing Technology Centers which provide small businesses with information and expertise on manufacturing technologies and practices, matching funds and client fees..

INTERNATIONAL TRADE ADMINISTRATION

The International Trade Administration (ITA) provides economic data and analysis on materials markets in the U.S., including production and demand statistics. The ITA has recently conducted a major competitive assessment of the domestic industry producing composites.

PATENT AND TRADEMARK OFFICE

The Patent and Trademark Office (PTO) issues patents and register trademarks. It issues three types of patents: plant patents, design patents and utility patents. Patents for new materials normally grant ownership rights for 17 years. The PTO patent file library is a good source of information on R&D for materials companies.

A.1.5 The Department of Defense

The scope of materials R&D in the Department of Defense (DOD) is broad and organized into the following budget categories:

- 6.1, Military science
- 6.2, Exploratory Development
- 6.3A, Advanced Technology Demonstrator Development.

Within DOD, materials R&D allocations are distributed to the Army, Navy, Air Force, and the Advanced Research Projects Agency (ARPA). The DOD spends almost 1/2 billion per year for materials and structures R&D. Of this funding 1/4 goes to universities, 1/2 to industry, and 1/4 is expended in-house. Approximately, 1/3 of this funding is spent on composites.

All of the Services participate in the DOD Project RELIANCE, which aims at restructuring the working relationships between the Services to promote greater efficiencies and effectiveness by increased Tri-Service interdependency. In March 1992, a formal Tri-Service Materials Focus was formed to provide new emphasis on joint planning, implementation, coordination, and oversight of Tri-Service Materials Science and Technology Programs. The Joint Laboratories (JDL) Technical Panel for Advanced Materials (TPAM) is assigned this mission.

The 6.1 effort, which entails basic research, is managed by the Office of Naval Research, the Air Force Office of Scientific Research, and the Army Research Office. ARPA has its own independent budget. Approximately 60 percent of 6.1 funding goes to universities, though a significant amount is contracted to in-house and industrial or non-profit laboratories.

The Services coordinate their Exploratory Development (6.2) efforts through joint tri-service planning. All plans and budgets are now initially proposed through the JDL/TPAM and then coordinated and approved through the individual Service management/command channels.

Advanced Technology Demonstrator Development (6.3A) concentrates on highly significant technology areas, making and testing major components or even entire systems to gain confidence and credibility before final application to a military weapons system.

OFFICE OF THE DIRECTOR DEFENSE RESEARCH
AND ENGINEERING (ODDR&E), MATERIALS AND STRUCTURES

This office serves as the principal advisor and assistant to the Under Secretary of Defense (Acquisition) for DOD scientific and technical matters on all research and technology associated with all laboratories and research, development and engineering centers operated by the Military Departments or other DOD components and federally funded R&D centers. This office directs the Secretaries of the Military Departments and heads of other components of the DOD, when necessary, with respect to all activities supported by funds that are for research (6.1), exploratory development (6.2), and advanced development prior to the development of specific systems (6.3a) within the DOD, as those terms are defined in the DOD Budget Guidance Manual. It oversees ARPA, the Defense Nuclear Agency and the technological aspects of the activities of the Strategic Defense Organization and the Defense Technology Security Administration. The director serves as the chairman of the Defense Technology Board and the Defense Planning and Resources Board.

A.1.6 Department of Energy

Most of the Department of Energy (DOE) funding is allocated among three program areas: basic materials research, defense needs, and nuclear energy. Its materials science program has three specific goals: 1) to provide information for solving materials problems, 2) to create new opportunities in materials development through research in energy conservation and use, and 3) to assist the materials community in planning, constructing, and operating unique materials-related facilities.

The Materials Sciences subprogram in the Office of Energy Research provides most of the development and operational support for the Department's work in materials. It conducts basic research on materials, their properties and behavior. The DOE also manages 15 collaborative research centers at DOE laboratories that are open to outside researchers in universities and industry.

The DOE's Office of Transportation Materials has recently developed a Lightweight Materials for Transportation Program Plan to realize the benefits of lighter weight vehicles. The program will support R&D activity at industrial sites through competitively bid subcontracts. It will enable companies to develop technology by using their capabilities and accessing supporting technology at national laboratories, universities, ongoing program activity at NASA, DOD, DOT, and NIST, leveraging industry resources through integrated team approaches.

A.1.7 National Science Foundation

The mission of NSF is to support research and education to improve the fundamental knowledge base in materials and to educate and train scientists and engineers in new technological challenges. NSF supports both experimental and theoretical research, with four primary objectives: to synthesize innovative functional materials; and to advance fundamental understanding of the behavior and properties of materials, their structure and composition, and their properties and performance at the atomic, molecular, microscopic, and macroscopic scales.

NSF supports research through grants to individuals and groups, support for centers, and support for National User Facilities. Although a significant portion of the funding goes to individuals and small groups, many research problems are so complex and instrument-intensive that collaborative efforts are warranted to make significant progress.

In addition, support for graduate fellowships and Minority Research Centers of Excellence is provided. The Division of International Programs, the Small Business Innovation Research (SBIR) Program, and the experimental Program to Stimulate Competitive Research also provide support for materials science and engineering.

Projects at NSF multi-user facilities foster communication among researchers and technology users. Development of links and technology transfer is strongly encouraged between its Materials Research Laboratories, Science and Technology Centers, Engineering Research Centers, Industry/University Cooperative Research Centers and other institutions and sectors. The Science and Technology Centers address problems that are so complex they require special facilities or collaborative relationships across disciplines that can best be provided by campus-based research centers. Engineering

Research Centers support a broad range of collaborative research efforts through the establishment of a three-way partnership involving academia, industry and the NSF, often with participation of state and other Federal agencies. Industry/Cooperative Research Centers encourage interaction between industry and universities by developing research programs defined by the industries supporting each center. NSF's National User Facilities are open to all qualified users from universities, industry and government laboratories.

NSF also supports research that helps to formulate national policies based on analysis of significant science and engineering issues.

A.1.8 National Aeronautics and Space Administration (NASA)

NASA develops a wide variety of aerospace technology through the conduct of R&D in support of its mission to promote aeronautics and the exploration of space. It has three research programs to develop and improve new materials: 1) Transatmospheric Research and Technology, 2) Materials Processing in Space, and 3) Materials and Structures Research and Technology. The majority of its R&D is supported by the Office of Advanced Concepts and Technology and the Office of Aeronautics. NASA has established Regional Technology Transfer Centers at its field centers in support of the Federal technology transfer mission. These centers assist clients in locating, assessing, acquiring and commercializing technologies from throughout NASA and the Federal R&D base. Another avenue for pursuing partnerships with NASA is through the American Technology Initiative in California.

A.1.9 Department of the Interior Bureau of Mines

The Bureau of Mines conducts new materials activities via two programs: 1) Information and Analysis, and 2) Minerals and Materials Science. Its new materials studies are directed towards obtaining information on new materials needed by the Federal Government and domestic industry, determining the role of new materials as substitutes for conventional minerals-based materials, and analyzing the effects of this substitution on the U.S. economy and national policies. The objective of the new materials science program in the Bureau is to help assure the availability of feed stocks necessary for the production of new materials. The Office of Advanced Materials Coordination coordinates the resources and needs of all Bureau of Mines offices conducting new materials studies.

NATIONAL STRATEGIC MATERIALS AND MINERALS
PROGRAM ADVISORY COMMITTEE

This committee fosters R&D, collects data to support policy decisions on strategic and critical minerals and materials, identifies U.S. technological capabilities for processing strategic and critical materials and makes recommendations to the Secretary of the Interior to improve these capabilities.

A.1.10 Legislative Branch

Congress has a major impact on Federal materials policies and activities through lawmaking and budget apropriation. It enacts laws that establish policies for new materials and sets annual funding limits on materials-related programs. Congress also has oversight authority to convene special hearings for examining executive branch program activities. Key permanent committees within which most budget or program review hearings are conducted for Federal materials science activities are the Senate Commerce Science and Transportation Committee; the Senate Energy and Natural Resources Committee; the Senate Armed Services Committee; the House Science, Space and Technology Committee; the House Energy and Commerce Committee; and the House Armed Services Committee.

The Office of Technology Assessment, the General Accounting Office, the Congressional Research Service, and the Congressional Budget Office provide information and advice to Congress for its oversight of science and engineering programs, including those for materials. These agencies have all been involved in analyses of specific new materials issues requested by Congress.

A.2 U.S. Science and Technology Programs

The U.S. federal government offers numerous programs to help facilitate and enhance efforts in the areas of research and development and technology transfer. The major U.S. science and technology programs are outlined below.

A.2.1 University Research Initiative

This program provides funding for R&D initiatives undertaken by universities.

A.2.2 The Manufacturing Technology Program

This DOD sponsored program is aimed at developing new and improved production processes and disseminating these results through the defense industrial base. Typically, ManTech funds the development of a new or improved process technology and private companies purchase the new equipment.

A.2.3 The Defense Production Act Title III Program

The purpose of the DPA Title III Program is to establish or expand domestic production capacity for materials that are critical to the DOD. This is accomplished by providing domestic industry with incentives in the form of purchases and purchase commitments for materials. Recently, the Title III Program has emphasized the development of capacity for advanced materials that will improve weapon systems performance and affordability. The Title III Program operates under the Deputy Assistant Secretary of Defense, Production Resources. Title III projects are authorized under Title III of the DPA of 1950. Section 303 of the act provides "for purchases of, or commitments to purchase, metals minerals, and other materials for Government use or resale.

Under 1984 amendments, each project must meet certain criteria:

- The mineral, metal or material is essential to the national defense;
- Without Title III, U.S. industry cannot reasonably be expected to provide the capability for the needed material, metal, or mineral in a timely manner;
- Title III is the most cost-effective, expedient, and practical alternative method for meeting the need; and
- The national defense demand for the mineral, metal or material is equal or greater than the output of domestic industrial capability.

In addition to these requirements of the DPA, DOD has these criteria:

- The project must be accomplished through a purchase or purchase commitment;
- The product of the Title III project must be identified in a specification agreed to by the U.S. Government; and
- Commercial viability after project completion must exist.

Legislation passed at the close of FY 92 gave new direction and flexibility to Title III, emphasizing use of Title III to expand capacity for critical technology items, modernize domestic production capabilities, and integrate military and commercial production.

Title III projects are normally performed in two phases. Phase one involves establishing domestic capability. In Phase II, capacity to meet DOD's demand for the material is achieved.

Currently, there are two MMC projects being conducted under the Title III program to expand existing production capability for high and moderate strength discontinuously reinforced aluminum (DRA) MMCs. These contracts were awarded in September 1989: one to DWA Composite Specialties, Inc. for moderate strength DRA and one to Advanced Composite Materials Corporation for high strength DRA.

A.2.4 Cooperative Research And Development Agreements

As part of the Stevenson-Wydler Technology Innovation Act (1980) and the Federal Technology Transfer Act (1986), legislation was enacted to enable federal laboratories to enter into cooperative research and development agreements (CRDAs, also known as CRADAs) with private businesses and other entities. Further support for this federal effort was provided by Executive Order 12591(1987), which instructed executive departments and agencies to encourage and facilitate collaboration among federal laboratories, state and local governments, universities, and the private sector, particularly small businesses, in order to assist in the transfer of technology to the marketplace. This order included provisions for establishing a technology-sharing program, an exchange of scientists and engineers between the private sector and federal laboratories, basic science and technology centers, and guidance with respect to international science and technology transfer. Since then, over 1000 CRADAs have been signed based on this authority. Through CRADAs, companies or groups of companies can work with one or more federal laboratories to pool resources and share risks in developing technologies, thereby leveraging R&D efforts to solve technological and industrial problems. The law sets the following conditions for a CRADA:

- Collaboration involves the expenditure of federal funds and the use of federal personnel, services, facilities, equipment, intellectual property or other resources. However, no federal funds may flow to the CRADA partner.

- Non-federal contributions include funds, personnel, services, facilities, equipment, intellectual property or other resources.

- Special consideration is given to small businesses and consortia involving small businesses.

- Preference is given to businesses that are located in the U.S. and undertake to manufacture substantially in the U.S. products that embody inventions developed under the CRADA or are produced using inventions developed under the CRADA.

- The U.S. Government always retains a non-exclusive or nontransferable, irrevocable, and paid-up license to practice any inventions developed under a CRADA for governmental purposes.

- The federal laboratory may in advance grant or agree to grant to a collaborating party exclusive patent licenses or assignments for all laboratory employee inventions made under the CRADA.

- Federal laboratories may protect from public access commercially valuable information produced under CRADAs by both federal and non-federal participants for up to five years as negotiated for each CRADA; trade secrets or commercially valuable information that is privileged or confidential information which is obtained in the conduct of research or as a result of activities under a CRADA from a non-federal participant will not be disclosed.

By law, each federal laboratory is required to establish an Office of Research and Technology Applications (ORTA) to actively identify and assess potential technologies and ideas from their own laboratories that may be transferred to state and local governments, industry, or universities and assist in domestic technology transfer efforts. The Army's Domestic Technology Transfer Program follows the guidelines documented in AR 70-57, Military-Civilian Technology Transfer. The Air Force program is covered by AFR 80-27, Air Force Domestic Technology Transfer. As part of a network of federal laboratories called the Federal Laboratory Consortium (FLC), each ORTA can provide assistance and make referrals to appropriate sources of technology among the federal laboratories. The FLC was formally chartered by the Federal Technology Transfer Act of 1986 to promote and strengthen technology transfer nationwide. The Consortium develops and tests transfer methods, addresses barriers to the process and emphasizes national initiatives where technology transfer has a role. An FLC Locator Network assists by matching potential collaborators with laboratory resources.

Since CRADAs are not a procurement contract (the government does not provide funding for services or products), complex military procurement can be avoided.

A.2.5 Space Act Agreements

NASA has separate, broad authority to encourage private sector use of NASA space research and technology, mandated by both the 1958 Space Act and the President's National Space Policy issued in 1989. Like CRADAs, Space Act agreements can be used to provide mutual leverage of government and industry resources in the cooperative pursuit of R&D efforts. Under this authority, NASA enters into a variety of non-reimbursable or reimbursable agreements involving the use or exchange of facilities, equipment, information, expertise, intellectual property rights, or other resources. In general, NASA acquires no rights to inventions made by the private participant and will afford the participant first option to obtain an exclusive, royalty-bearing commercial license to inventions made by NASA employees. Any commercially valuable information obtained from or produced by a participant will be disclosed and used only for the purposes of the agreement, and any such information generated by NASA will be protected from public access to the extent permitted by law.

IR&D funds may be used as a CRADA contribution in the case of DOD and NASA contractors, providing the costs would have been allowable as IR&D had there been no CRADA.

A.2.6 NIST's Advanced Technology Program

The NIST administers the Advanced Technology Program (ATP), which is a Federal Assistance Program that funds advanced technologies that have a significant potential for improving the competitiveness of U.S. businesses. While these technologies generally have broad-based impact, they are often characterized by high technical risks that inhibit an adequate level of private sector funding. The program is aimed at assisting businesses in developing pre-competitive generic technologies through joint ventures such as industry-academia cooperation. The ATP can fund projects in any field of technology, but are limited to funding projects that involve pre-competitive, generic technology development.

There are two categories of ATP applicants, single applicants and joint ventures. Single applicants can receive up to $2 million over a three-year period. Joint ventures can be funded up to a maximum of five years, with no dollar limit other than the available funds. Both types of applicants must cost share. Joint ventures must provide more than 50 percent of the funding for each year that the ATP funds the project.

ATP funding is available to eligible U.S. businesses and joint ventures. As described in Public Law 102-245. Sec. 201 (c) (6) (C), "a company shall be eligible to receive financial assistance only if:

(a) the Secretary finds that the company's participation in the program would be in the economic interest of the U.S., as evidenced by investments in the U.S. in research, development, and manufacturing (including, for example, the manufacture of major components or subassemblies in the U.S.); significant contributions to employment in the U.S.; and agreement with respect to any technology arising from assistance provided under this section to promote the manufacture within the U.S. of products resulting from that technology (taking into account the goals of promoting the competitiveness of U.S. industry), and to procure parts and materials from competitive suppliers; and

(b) either--

(i) the company is a U.S.-owned company; or

(ii) the Secretary finds that the company is incorporated in the U.S. and has a parent company which is incorporated in a country which affords to U.S.-owned companies opportunities, comparable to those afforded to any other company, to participate in any joint venture similar to those authorized under the Act;: affords to U.S.-owned companies local investment opportunities comparable to those afforded to any other company; and affords adequate and effective protection for the intellectual property rights of U.S.-owned companies."

Section 15 U.S.C. 278n(j)(2) of the ATP statute, as added by Public Law 102-245, defines the term "U.S.-owned company" as "a company that has a majority ownership or control by individuals who are citizens of the U.S." All applicants must provide a U.S.-Owned Company Assurance Statement. Those proposals that involve the participation of organizations that are not U.S.-owned must address in that statement the ownership requirements of P.L. 102-245.

Proposals for ATP funding must be industry led. Universities and federal laboratories are prohibited from receiving ATP funding directly, but may collaborate with single applicants or be members of a valid joint venture.

Public Law 102-245, The American Technology Preeminence Act of 1992, eliminated the requirement that the Federal Government receive a pro-rata share of royalty and licensing fees. It also slightly modified eligibility criteria. Non-profit independent research institutions are no longer eligible to apply as single applicants, but such an organization can participate in an industry-led joint venture.

A.2.7 DOC's Strategic Partnership Initiative

The Technology Administration of the DOC is spearheading an effort to provide catalytic strategic services on the subject of strategic partnerships. Initiated in 1991, this program was created to help technology pull-through from R&D to commercialization and to assist in the development of multi-industry teams that create and commercialize large-scale technologies. These vertically integrated teams are composed of non-competing firms representing manufacturers, suppliers and users of the technology to be developed. This approach is similar to the Japanese keiretsu system. The Technology Administration (TA) is furnishing information to increase public understanding, hosting workshops to explain the SPI concept and to disseminate information on specific technologies, and advising parties wishing to explore the formation of partnerships. The TA has no grant or loan authorities and does not promote any specific technology, partnership or company. The TA feels strongly that the federal government should get involved in strategic partnerships to compensate for important failures, partly caused by fears of government actions, in advanced technology markets. Past government antitrust litigation has created potentially unrealistic fears of joint actions. Some compelling reasons cited for this approach are that technological innovations generated by companies often do not lead to follow-on development/commercialization due to an inability to finance and that single companies may not be appropriate for exploiting multiple products developed from a single large-scale enabling technology. Advantages of strategic partnerships include:

- Efficiently create the critical mass to address a large-scale technology innovation challenge,
- Are vastly faster to market in major applications than other available multi-firm ventures,
- Are less costly and risky to participants than other available multi-firm ventures,
- Permits proprietary cooperation because there are no competitors among members of strategic partnership,
- Permits users to affect R&D agenda, fostering "market pull",
- Permits R&D cost sharing, and provides a guaranteed broad market,
- Enables risk reduction, economies of scale (and scope), and
- Enables rapid recoupment of investment costs.

In addressing the anti-trust concerns of such an alliance, the TA has pointed out the following:

- The joint R&D aspects of the team approach may be registered under the National Cooperative R&D Act of 1984, thereby securing antitrust protection.
- Long-term supplier-manufacturer relations among non-competitors that involve suppliers in the design of new products are not being challenged to date.
- Since strategic partnerships as envisioned do not include competing companies, they should be free of anti-trust concerns experienced by those multi-firm ventures not so structured.

Several companies have been meeting recently to explore the possibility of setting up a strategic partnership involving aluminum MMCs under this program.

A.3 Other Departments/Groups that are Potential Facilitators in the Science and Technology Arena

Other U.S. departments and groups play an important in R&D efforts, and help plan and coordinate work done in science and technology development. Some of the major departments and groups that serve in this capacity are outlined below.

A.3.1 President's Council of Advisors on Science and Technology (PCAST)

In January 1990, the President's Council of Advisors on Science and Technology (PCAST) was created. Composed of 12 individuals from the private sector, the Council is chaired by the Director of OSTP and reports directly to the President. The Council responds to the President upon request, focusing on the science and technology arena, policies impacting science and technology, and the structural and strategic management policies relating to science and technology.[418]

A.3.2 Trade Promotion Coordinating Committee

This committee coordinates the export promotion and export financing activities of the U.S., and coordinating the development of trade promotion policies and programs.

A.3.3 The DOD Manufacturing Technology Advisory Group Materials Processing and Fabrication Technical Committee

The charter of this technical committee is primarily focused on determining the long range objectives for the DOD to the development and application of composite materials, including MMCs, in a variety of DOD weapon systems, including aircraft, missiles, space systems, land vehicles, ships, submarines, and multiple subsystems.

A.3.4 The Metal Matrix Composites Information Analysis Center (MMCIAC)[14, 15]

The MMCIAC serves as the DOD's central source of engineering and technical data and R&D information on MMCs. The technical scope includes all scientific and technical information aspects of MMCs for support of DOD basic and applied research. Specifically, subject areas covered include MMC properties; key R&D concepts, results and trends; fabrication, processing and applications; processing equipment; measurement, testing and quality control; test equipment and evaluation methods; corrosion/deterioration detection, prevention and control, and other environmental effects on MMC and systems; sources, suppliers, and specifications for MMCs of concern to the DOD; operational serviceability and repair; MMC component design criteria; MMC industrial subsystem and system applications; theoretical performance computations; and assessment of international R&D technology to determine its impact on MMCs.

A.3.5 Defense Technical Information Center

DTIC provides scientific and technical information developed by DOD to help foster the dissemination of new technologies.

A.3.6 U.S. DLA/Defense Contract Administration Services Management Area

This office administers DOD contracts in Canada.

A.3.7 NASA's Research Institute For The Management Of Technology (RIMTECH)

RIMTECH is a technology transfer program established in 1986 to promote the development of commercial products from technologies generated at NASA's Jet Propulsion Laboratory.

A.3.8 Small Business Administration

The SBA aim is to strengthen the small business community. This is accomplished in part through its Small Business Development Center program, which provides business management and technical assistance to the nation's small businesses.

A.3.9 National Technology Transfer Center (NTTC)[378]

The NTTC is an independent organization initially funded by a five-year grant through NASA. The goal of the organization is to provide a user-friendly gateway to federal research and development resources in order to expedite the transfer of federally funded technology to American business and industry. A toll-free telephone number provides callers from business and industry with free person-to-person contacts, using the center's information resources and alliances to locate current and completed research, confirm pertinence of that information with the appropriate federal laboratory, and provide laboratory contacts that the caller can use to secure answers to technical questions, explore licensing opportunities, and pursue CRADAs. Approximately 39 percent of the client requests the NTTC has received have concerned materials.

An electronic bulletin board provides announcements of new federal technologies available for licensing and other technology transfer opportunities, a directory of persons and resources in the technology transfer community, and electronic mail capabilities.

The center also has instituted training courses and curriculum development, and offers seminars, forums and short courses fostering innovation and technology transfer awareness among executives and professionals in government, business and higher education.

Strategic Partnerships are initiated through a fund for strategic partnering, which provides funding for model programs teaming companies and federal laboratories with a combination of research universities, non-profit organizations and state and local economic development entities to stimulate economic growth and provide positive examples of technology transfer.

A.3.10 National Center for Advanced Technologies[342]

This center was established as a non-profit research and educational foundation by the Aerospace Industries Association in 1989 to coordinate activities that would keep the U.S. aerospace industry as a major international competitor.

A.3.11 National Center for Manufacturing Sciences

This center is a not-for-profit research consortium organized under the National Cooperative Research Act of 1984. Working with industry, academia, Government, and others, this center works on research projects to develop solutions to specific R&D challenges and implement them into the manufacturing operations of its member companies and their respective supplier base. The center is building a Manufacturing Information Resource Center for retrieving and circulating data.

A.4 Other U.S. Programs that Enhance the Science and Technology Arena

Other U.S. programs offered in the U.S. to enhance science and technology efforts are briefly highlighted in the following paragraphs.

A.4.1 NIST's State Technology Extension Program

This program, established by the Omnibus Trade and Competitiveness Act of 1988, provides technology assistance to state technology programs throughout the U.S. to help those programs improve the competitiveness of small and medium sized companies through the application of science and technology.

A.4.2 Federal Grants

The Federal government helps to sustain the pool of technically trained manpower through Federal grants, which support graduate students with fellowships, traineeships, or research assistance positions. To name just a few of the programs in place, the Air Force offers the USAF/National Research Council (NRC-RRA) Program, The University Research Program, the Summer Faculty Research Program, the Graduate Student Research Program, the Laboratory Graduate Fellowship Program, and the National Defense Science and Engineering Graduate Fellowship Program.

A.4.3 U.S. Foreign Comparative Test Program

Funded by the U.S. Government, this program is designed to investigate foreign hardware (non-developmental item) against a defined military requirement. Only about 20 percent of these projects ever reach production.

A.4.4 State Programs

There are numerous state programs in place geared to fostering technology transfer and R&D initiatives. These include the California State University, Fullerton Information Network; the Georgia Tech Manufacturing Research Center; the Indiana Business Modernization and Technology Corporation; the University of Maryland Engineering Research Center; Maryland Industrial Partnerships; Michigan Industrial Technology Institute, Ohio Technology Transfer Organization; Ohio Edison Materials Technology Center; Peninsula Advanced Technology Center; Pennsylvania Technology Development and Education Program; the Pennsylvania State University Research and Technology Transfer Program; the Pennsylvania Technical Assistance Program; the Ben Franklin Partnership Technology Centers; the South Carolina Research Authority; the Southern Technology Council; and the Austin Technology Incubator.

A.5 Canadian Federal Government Science and Technology Base Infrastructure

As in the U.S., there are many different departments involved in various aspects of the science and technology base, requiring close coordination and communication among the components.

A.5.1 Department Of National Defence

The R&D program of DND is geared toward applying advances in science and technology to improve the operational capabilities of the Canadian forces. There are six Defence Research Establishments of DND which provide in-house defence R&D. R&D activities are also carried out in companies and universities under R&D contracts and in other departments on a cost-recoverable basis. An important part of CRAD initiatives with industry is the DIR program.

The Chief of R&D Group (CRAD) reports directly to the Deputy Minister of DND, and is responsible for the overall R&D program. The CRAD group consists of three divisions: R&D Policy, R&D Operations, and R&D Services.

A.5.2 External Affairs And International Trade Canada

This department identifies export opportunities for defense and civilian products, advises Canadian industry about key markets, establishes and manages Canadian participation in bilateral and multilateral cooperative defense trading agreements, and negotiates removal of impediments to trade. EAITC manages agreements between Canada and other countries concerning international science and technology collaboration. These agreements provide a formal structure for researchers to determine cooperative ventures, identify partners and facilitate collaboration. They also oversee numerous specific sectoral science and technology arrangements in place between government agencies, both federal and provincial, and their counterparts abroad. These arrangements frequently take the form of Memoranda of Understanding or Exchanges of Letters. This department also is responsible for managing Canada's space agreements, all of which are undertaken in partnership with other countries, since Canada's space sector is dependent on foreign markets for 70 percent of sales.

EAITC administers the DDSP and acts as the focal point until detailed discussions are initiated.

AEROSPACE AND DEFENCE INDUSTRIES BRANCH

Working in close cooperation with the aerospace and defense industries, this organization develops and implements industrial policies and strategies. ADIB is responsible for the management of the DIPP.

DEFENCE PROGRAMS AND
ADVANCED TECHNOLOGY BUREAU

This bureau is responsible for promoting the export of Canadian defense and civilian high technology products. Two divisions of this bureau are the International Defence Programs, Aerospace and Marine Division and the Science and Technology Division, both of which focus on promoting their respective areas of emphasis.

A.5.3 Industry, Science And Technology Canada

ISTC promotes international competitiveness in Canadian industry, science and technology by facilitating cooperation among private and public sector partners; developing industry and science policies; encouraging innovation, R&D and diffusion of technologies; fostering entrepreneurship; and facilitating the collection and dissemination of information. ISTC represents the Canadian Government in the approval and implementation of shared development projects. It administers the DIP program. Industry Sector Branches recommend suitable Canadian companies for specific programs, prepare a project agreement, and monitor the project contract to completion. The ISTC maintains a business opportunities sourcing system - a computerized data base on Canadian companies, their products and markets in support of domestic and international marketing.

A.5.4 Government Services Canada (GSC)

The Science and Professional Services Directorate of GSC provides a centre for federal government R&D contracting. GSC, in cooperation with Industry and Science Canada, operates the Unsolicited Proposals Brokerage Service which receives and brokers R&D proposals to potential government sponsors. The service addresses both federal government R&D priorities as well as science and technology objectives of government departments.

A.6 Canada's Science And Technology Programs[353]

The major programs utilized by the Canadian government in assisting industry in R&D efforts are outlined below. These programs often entail numerous oversight and management functions, involving several different program offices.

A.6.1 Defence Industry Productivity Program (DIPP)

The objective of the DIPP is to develop and maintain strong defense-related industries across Canada, capable of competing over the long term in domestic and export markets. The industrial environment is characterized by relatively high commercial, technical and financial risk. The DIPP is the funding source for the Canadian share of a U.S.-Canada DDSP. Actual contracting is implemented by Supply and Services Canada on ISTC's behalf. Four types of assistance are available:

1) R&D - R&D of defense related products and for sustaining the associated technology base, including engineering R&D; materials and components; construction, test and evaluation of prototypes, and the equipment that may be required to conduct these activities.

2) Source Establishment - establish qualified Canadian suppliers of defense related products to include engineering, manufacturing and production studies, the application of new equipment, experimental production, evaluation, testing and associated laboratory work, prototypes, samples, drawings and software.

3) Capital Assistance - to acquire advanced production equipment to modernize/upgrade, to include advanced machine tools and other machine systems and test and quality assurance equipment.

4) Market Feasibility - studies to establish the specifications and characteristics of defense related products required to meet market demand or to determine market sector characteristics for those products when needs have been identified in Canadian or export markets.

Any corporation, institution, cooperative association, partnership or individual wanting to undertake a project in Canada, related to the development, manufacture or support of defense related products may apply for funding. The applicant must be established in Canada, must substantially undertake the project in Canada and must show that the project shall be substantially exploited from a Canadian base.

Two significant changes to the program have recently been enacted:

1) assistance is now available for projects oriented toward the domestic market, and

2) fast-track evaluation procedures have been introduced for dealing with small DIPP projects from small companies.

A.6.2 Strategic Technologies Program

The Strategic Technologies Program is an initiative of the Advanced Industrial Materials Directorate of Industry, Science and Technology Canada to help industry establish alliances with other Canadian firms, foreign firms, universities or research institutes on innovative projects. This program covers up to half of the eligible costs of R&D or technology application projects in leading-edge technologies undertaken by alliances to enhance industrial productivity and competitiveness. One of the three strategic technologies eligible for funding under this program is advanced industrial materials. Two types of alliances are supported :

1) R&D Alliances - a company sharing risks and working with one or more companies, universities or research institutes on leading-edge, pre-commercial R&D to develop the technology base needed for a range of new or improved products and processes

2) Technology Application Alliances - Two companies and one or more other organizations sharing risks and working jointly on pre-commercial technology development and related studies to determine the production, economic or market feasibility of new technological products or processes; to develop standards needed to permit applications; or to demonstrate to potential users in Canada the feasibility of leading-edge technology.

Projects must involve alliances among companies, universities or research institutes. These alliances may involve both foreign and domestic partners.

A.6.3 Technology Outreach Program

The TOP provides financial support for the creation and expansion of specialized technology centers to engage in national activities and services that accelerate the acquisition, development and diffusion of technology and critical management skills in industry. Applicants must be Canadian not-for-profit corporations.

<u>TECHNOLOGY OUTREACH PROGRAM -
ADVANCED MATERIALS NETWORKS</u>

This program is designed to support non-profit, private sector national networks of university scientists, engineers and industrialists in the exchange of information and the identification of emerging technologies. These networks are geared to facilitate joint planning between researchers and current or potential developers and users of advanced materials.

A.6.4 Defence Industrial Research Program (DIR)

The DIR program is intended to assist companies seeking support for defense research projects to improve the research and technological capabilities of the Canadian defense industry. This program is administered by the Chief of R&D (CRAD) of DND. There are currently over 50 active research projects initiated under this cost shared research program.

A.6.5 Industrial Research Assistance Program

This program, run by the National Research Council, is designed to help Canadian firms of all sizes to develop and apply technology for economic benefit by providing financial and technical support for industrial research projects. As part of this program, NRC maintains a National Technology Network of 72 specialized technology centers across Canada to facilitate technology diffusion and technology transfer. The NRC/IRAP Technology Network extends overseas so that Canadian embassies and consulates abroad may assist firms in identifying and obtaining access to useful foreign-based technology.

A.6.6 Technology Inflow Program

This program is a joint initiative of External Affairs, International Trade Canada, and the National Research Council of Canada's Industrial Research Assistance Program. Responsive to specific requests from Canadian industry involving foreign technology, the TIP facilitates the flow of foreign technology into Canada by offering information and advice on foreign sources and forms of technology. Some financial support is provided to primarily small- and medium-size incorporated (or registered) Canadian companies for certain activities related to the acquisition of this foreign technology. Among the services provided by the TIP is advice on cooperative agreements, technology licensing, and strategic partnerships. TIP also supports long term projects requiring foreign participation and complex technology exchanges or acquisitions.

A.7 Other Canadian Departments/Offices That Are Potential Facilitators In The Science And Technology Arena[353]

Other Canadian departments and offices that help facilitate science and technology strides are briefly described below.

A.7.1 National Advisory Board On Science And Technology

Created in 1986, this group comprises leaders of industry, university and labour who advise on domestic and international developments in science, technology and innovation and on how to coordinate the efforts of governments, universities, and the private sector.

A.7.2 Interdepartmental Committee on International Science and Technology Relations (ICISTR)

Chaired by EAITC, this committee coordinates the efforts of science based government departments and agencies in relation to various bilateral and multilateral dossiers. One subcommittee of this group focuses on advanced industrial materials.

A.7.3 Canadian Commercial Corporation

The CCC is owned and controlled by the Government of Canada. It performs the function of government-to-government contracting officer for the Canadian Government and interfaces between Canadian companies and U.S. government procurement agencies. Established in 1964, it simplifies export sales to foreign government and international agencies for Canadian suppliers by serving as prime contractor in government-to-government transactions. Most of the CCC's defense related sales are to the U.S. DOD under the DPSP/DDSP.

A.7.4 National Research Council Laboratories

This federal agency maintains research laboratories across Canada covering a wide spectrum of technologies. They seek cooperative relationships with industry through personnel exchanges, the sharing of laboratory facilities, and joint research programs. One center of particular note is the Industrial Materials Research Institute, which researches MMCs, among other things.

<u>NATIONAL RESEARCH COUNCIL CANADA -
INTELLECTUAL PROPERTY SERVICES OFFICE</u>

This office offers technology developed in the NRC laboratories for license.

A.7.5 Industrial Materials Research Institute

This institute conducts research in the development, behavior and durability of metals, polymers, ceramics and composites.

A.7.6 Canada Center for Mineral and Energy Technology

This center is a major technology research arm of the Federal Government Department of Energy, Mines and Resources Canada involved in, among other things, metallurgical research.

A.7.7 Canadian Advanced Industrial Materials Forum

This group provides information to companies on international technical developments, processes and applications of advanced industrial materials.

A.7.8 The Science and Technology Counsellors' Network

Science and Technology Counsellors are posted to Canadian missions abroad and provide the following services:

- Facilitate technology acquisition and technology transfer;
- Search out contacts, make introduction, and locate foreign firms interested in arrangements such as joint ventures and R&D collaborative projects;
- Gather information on specific science and technology areas and direct specialists to more detailed information; and
- Familiarize Canadian firms with the business practices and operations of science and technology organizations in host countries.

A.7.9 Technology Development Officers' Network

These officers are placed in Canadian missions abroad to assist Canadian small and medium sized firms in acquiring foreign technology. TDOs respond to requests and act as intermediaries between the supplier and recipient of a technology.

A.7.10 Canadian Defence Liaison Staff (Washington), Defence Research and Development

This office interacts with the U.S. in defense related science and technology activities normally accomplished through R&D by the U.S. military services and other DOD agencies. They are responsible for the acquisition and exchange of information in the defense-related science and technologies. This department fosters cooperative projects with the DOD, participating in negotiating and managing R&D bilateral and designated multilateral arrangements with the U.S. and allies.

A.7.11 Special Trade Relations Bureau - Export and Import Permits

This bureau informs exporters and importers about the requirements of the Export and Import Permits Act, relating to the control of exports from and imports into Canada for national security, foreign policy, or supply reasons.

A.7.12 Investment Canada

This agency works to encourage international and domestic investment in Canada, as well as to assist Canadian companies in locating potential investors, at home and abroad. They actively encourage joint ventures, strategic alliances, and technology transfers and identify Canadian partners for small and medium-sized companies with advanced technologies interested in serving North American or global markets from Canada.

A.8 Other Canadian Programs that Enhance the Science and Technology Arena[353]

Of definite benefit to the ongoing science and technology programs are a number of other Canadian programs that serve to enhance current research efforts. This section provides a brief description of some of these programs.

A.8.1 Research Partnerships Program

Sponsored by the Natural Sciences And Engineering Research Council, this program promotes cooperation among Canadian universities, companies and research-oriented federal government departments through a number of cost-sharing programs, including cooperative R&D projects, shared equipment and facilities, NSERC Visiting Fellowships, and Industrial Research Fellowships.

A.8.2 Advanced Manufacturing Technology Application Program

Available to any taxable company operating in Canada that is engaged in manufacturing or secondary processing, this program shares the cost of hiring outside consultants to assess the technical and economic feasibility of upgrading a firm's manufacturing operations.

A.8.3 Canadian Manufacturing Advanced Technology Exchange

Established by the Canadian Manufacturers' Association, the National Research Council, and Industry , Science and Technology Canada, CAN-MATE provides advice and information to manufacturers on advanced technology for production and processing. It helps Canadian manufacturers access information and expertise on advanced manufacturing technologies through database searches for state-of-the-art technological products and processes and patents.

A.8.4 Networks of Centres of Excellence

This Government initiative is designed to build university-industry-government alliances to strengthen Canada's competitiveness in strategic areas of R&D. The networks conduct pre-competitive research in nine major areas, including advanced industrial materials and processes.

A.8.5 Canadian Embassy's Technology Partnership Program

The Canadian Embassy Program seeks to link Canadian firms with U.S. firms in joint ventures. They arrange an exchange of corporate profiles between U.S. and Canadian firms with complementary technology and business directions so that they can explore the business possibilities.

A.8.6 Technology Networking System

This ISTC database contains information on Canadian and international technology centers, expertise and sources.

A.8.7 Distcovery

This service provides information on manufacturing licensing opportunities worldwide, creating industry awareness of transferable technology available through licensing and joint ventures.

A.8.8 Market Intelligence Service

This service provides import analysis and other market data on specific products for manufacturers planning for product development, market expansion or new investment in Canada.

A.8.9 Patent Information Exploitation Program

Worldwide searches of patents for companies are conducted free of charge through this program.

A.8.10 Program for Export Market Development (PEMD)

This program offers financial assistance to Canadian businesses to undertake or participate in export promotion activities. It shares the cost of activities Canadian companies would not or could not undertake alone and encourages existing Canadian exporters to enter new geographic and product markets.

A.8.11 World Information Network Exports

This computer-based information system helps Canada's trade development officers abroad to match foreign needs to Canadian capabilities. It contains information on more than 30,000 Canadian exporters.

A.8.12 New Exporters to Border States (Nebs)/New Exporters to U.S. South

These programs help businesses increase their exports to the U.S. by teaching participants about export pricing, selection of agents, legal considerations, etc. These programs are a cooperative activity involving numerous Government organizations, including External Affairs, International Trade Canada, ISTC, Canadian consulates, regional International Trade Centres, and provincial trade departments.

A.8.13 Centre for Industrial and Technological Cooperation

Formed in 1985 by the Japan External Trade Organization, it encourages investment of capital for technological and industrial development in Canada and Japan. It fosters industrial cooperation and technology exchange between the two countries and encourages joint ventures in the areas of technology and industry.

A.8.14 Management of Technology and Innovation Institute (MTI)

Jointly funded by industry, the Federal Government and McMaster University, MTI trains companies in the management of technological innovation.

A.8.15 Canada's Scholars in Technology Program

The aim of this program, administered by the Association of Canadian Community Colleges on behalf of ISTC, is to encourage students to pursue technology studies and careers as technicians and technologists. A minimum of 900 scholarships will be offered in 1993-1994. To participate, you must be a Canadian citizen or have permanent resident status in Canada.

A.9 Associations and Societies Concerned with Research and Development Activities

This section briefly addresses some of the associations and societies that are concerned with R&D activities, and their missions and functions.

A.9.1 Suppliers of Advanced Composite Materials Association (SACMA)

SACMA is an international trade association whose mission is to support growth of the U.S. advanced composite materials industry based on common interests.

A.9.2 Great Lakes Composites Consortium

This organization is dedicated to strengthening the production capabilities of U.S. industry in the area of advanced composites manufacturing. It promotes new industrial practices and processes resulting in composite product use and encourages new business development to enhance the U.S. industry's competitve position in composites manufacturing.

A.9.3 National Coalition for Advanced Manufacturing (NACFAM)

This coalition focuses on modernizing the nation's industrial infrastructure through the accelerated development and adoption of advanced manufacturing technologies and related business-management and education-training programs.

A.9.4 Technology Transfer Society

Founded in 1975, this non-profit organization provides training seminars.

A.9.5 University Composite Centers

Numerous universities have established composite centers (e.g., the Center of Excellence on Manufacturing Science of Composites at the University of Delaware).

Other associations concerned with the science and technology area include the Amercian Academy for the Advancement of Science, the Automotive Composites Consortium, Aerospace Industries Association, Integrated Dual Use Commercial Companies, American Society of Manufacturers, American Society of Testing and Materials, American Society of Metals, Federation of Materials Societies, American Society of Mechanical Engineers, Materials Research Society, Society of Aerospace and Manufacturing Process Engineers, and the National Association of Manufacturers.

Appendix B - U.S. Acquisition Regulations Parts with Application to Canadian Company Market Access[332]

Defense Supplement of the U.S. Federal Acquisition Regulations (DFARS)

DFAR	SUBJECT
205.203	Bid response time for Canadians can be 45 days
206.302-3/4	Access by Mobilization & International Agreements
208.4	Federal Supply Schedules/GSA
208.71	Authority for NASA Purchases
208.72	Industrial Preparedness Planning - Canada
209.1	Responsible Contractors - Canadian Commercial Corporation
209.3	First Article Testing
219.502-1	DDSA products cannot be set-aside (SBSA)
219.704	Sub Contracting Plans for Small Businesses
211.7005	Contract Clauses
225	Foreign Contracting (Including Canada)
225.1	Buy American Act
225.105	Evaluation of offers/Canadian accessibility
225.2	Buy American Act - Construction Restriction
225.6	Customs and Duties
225.7	Restrictions on Foreign Purchases
225.70	Berry, Byrnes Tollefson and other restrictions
225.7002	Waiver on Specialty Metals, NBC Clothing, etc.
225.7004	Canadian waivers on valves, tools, PAN, night vision, etc.
225.708	Restrictions on R+D (Bayh Amendment)
225.73	Foreign Military Sales
225.8	International Agreements
225.802-70	Defines Canada with U.S. and NOT as Foreign
225.870	Canadian Contracting (See following section)
225.872	Qualifying Countries - Solicitation procedures
225.872-2	Mobilization Base restrictions waived for Canada
225.872-8	Sub Contractors access
227	Patents, Data & Copyrights
233.2	Protests, Disputes & Appeals
235	R+D Contracting
236	Construction (NOT open to Canadians)
242	Contract Administration
242.102	Canadian Audits
246.406	Quality Assurance - NATO/Canadian Procedures
246.7	Warranties
249.700	Termination of Contracts - with CCC
252	Solicitation Procedures & Contract Clauses
252.225-7002	Sub Contracting
252.225-7009	Duty Free Entry
252.225-7025	Foreign Source Restrictions

PART	DESCRIPTION
225.870-1(a)	Canadian guarantees
225.870-1(b)	Canada considered part of Defense Industrial Base for Production Planning Purposes (Also 208.72).
225.870-1(c)	Contracting to be through CCC
225.870-1(d)	DOD receives same production rights, data and information from CCC as if from a U.S. company.
225.870-1(e)(1)	Cost & Pricing Industrial Security (Also 870-8 & 872-7) Customs documentation - Disputes
225.870-1(e)(2)	Audits by Audit Service Bureau (Also 870-5(b)(1))
225.870-1(e)(3)	Inspection (By DND)
225.870-2	Source Listing only through CCC
225.870-3	CCC is Prime Contractor
225.870-4	Contracting Procedures
225.870-4(b)	Direct communication authorized between Canadian Company and DOD agency
225.870-5	Contract Administration in Canada performed by U.S. Defense Contract Management Command (Also 249.7)
225.870-6	Termination Procedures (Also 249.7)
225.870-7	Quality Assurance and Acceptance by DND

FAR	SUBJECT
1.405	Deviations pertaining to treaties
3.104	Procurement Integrity/Improper Business Practices
6.302	Industrial Mobilization - Canada
9	Contractor qualifications
11	Commercial Products
15/16/17	Contracting Methods
19	Small Business/Set Asides
22.6	Walsh-Healy Public Contracts
25	Foreign Acquisition
27	Patents, Data & Copyrights
30/31	Cost Accounting/Principles
33	Protests, Disputes & Appeals
52	Contract Clauses
53	Forms

Appendix C - Point of Contact Database

POC	Point of Contact		Company	Company Address				Phone	Field of
ID #	Last Name	First Name	Name	Address	City	State/Prov.	Zip Code	Number	Expertise
1	Martin	Chauncey L.	3M Corporation						
2	Sorensen	Dr. James P.	3M Corporation						model factory
3	Case	Richard S.	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
4	Geiger	Alan	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
5	Hood	Paul	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
6	Huber	Frank K.	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
7	Jackson	Mike	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
8	Roth	Peter A.	Advanced Composites Materials Corporation	1525 South Buncombe Rd.	Greer	SC	29651-9208	(803) 877-0123	German-Army Tank Mirror, continuously reinforced, discontinuously reinforced
9	Blakely	Keith	Advanced Refractory Technologies, Inc.	699 Hertel Ave.	Buffalo	NY	14207	(716) 875-4091	SiC whiskers and whisker blends, preforms, and coated whiskers;
10	Martin	Steven	Advanced Refractory Technologies, Inc.	699 Hertel Ave.	Buffalo	NY	14207	(716) 875-4091	SiC whiskers and whisker blends, preforms, and coated whiskers;
11	Spohn	Mary	Advanced Refractory Technologies, Inc.	699 Hertel Ave.	Buffalo	NY	14207	(716) 875-4091	SiC whiskers and whisker blends, preforms, and coated whiskers;
12	Caplan	Dr. Ivan	Air Force Office of Scientific Research		Washington	DC			
13	Chong	Jim	Air Force Office of Scientific Research		Washington	DC			
14	Rosenstein	Al	Air Force Office of Scientific Research		Washington	DC			
15	Hansson	Dr. Inge	Alcan International Limited	Kingston R&D Center, P.O. Box 8400	Kingston	Ontario	K7L 5L9	(613) 541-2400	Alcan perspective, market for Duralcan production
16	Lewis	Dr. Trevor	Alcan International Limited	Kingston R&D Center, P.O. Box 8400	Kingston	Ontario	K7L 5L9	(613) 541-2400	Alcan perspective, market for Duralcan production
17	Lloyd	Dr. David J.	Alcan International Limited	Kingston R&D Center, P.O. Box 8400	Kingston	Ontario	K7L 5L9	(613) 541-2012	Alcan perspective, market for Duralcan production
18	Beabout	Dan	Alcoa Technical Center	100 Technical Dr.	Alcoa Center	PA	15069-0001		Advanced Composites area
19	Cook	Celeste R.	Alcoa Technical Center	100 Technical Dr.	Alcoa Center	PA	15069-0001		Does not deal with MMCs anymore; referred Dan Beabout
20	Hunt, Jr.	Dr. Warren	Alcoa Technical Center	100 Technical Dr.	Alcoa Center	PA	15069-0001	(412) 337-2440	Advanced Composites area
21	Sawtell, Ph.D.	Ralph	Alcoa Technical Center	100 Technical Dr.	Alcoa Center	PA	15069-0001	(412) 337-2397	Advanced Composites area
22	Schmidt	Dick	Alcoa Technical Center	100 Technical Dr.	Alcoa Center	PA	15069-0001		Advanced Composites area
23	Hall	Dr. James A.	Allied Signal Aerospace, Garrett Engine Division		Phoenix	AZ			components for marketplace
24	Bustamente	Bill	Amercom	8928 Fullbright	Chatsworth	CA	91311	(818) 882-4821	Boron Aluminum
25	Bird	Dr. Jim	Amercom	8928 Fullbright	Chatsworth	CA	91311	(818) 882-4821	Boron Aluminum
26	Klug	Bill	Amercom	8928 Fullbright	Chatsworth	CA	91311	(818) 882-4821	Boron Aluminum
27	Bacon	Dr. Roger	Amoco Performance Products, Inc.	4500 McGinnis Ferry Rd.	Alpharetta	GA	30202-3944	(404) 772-8312	source of carbon fiber in thermal mgmt system
28	McGuire	Clarke F.	Amoco Performance Products, Inc.	4500 McGinnis Ferry Rd.	Alpharetta	GA	30202-3944	(404) 772-8352	source of carbon fiber in thermal mgmt system
29	Palmer	Dennis	Amoco Performance Products, Inc.	4500 McGinnis Ferry Rd.	Alpharetta	GA	30202-3944		source of carbon fiber in thermal mgmt system
30	Brown	Dr. Squier	ASC-XR						NASP
31	Nicholas	Dr. Ted	ASC-XR						NASP
32	Weiss	Olin	Bell Helicopter		Fort Worth	TX			manufacturing development
33	Turney	Jane	Bell Northern Research		Ottawa	Ontario			
34	Rimbos	Peter G.	Boeing Commercial Airplane Co.		Seattle	WA			marketing perspective

Appendix C - Point of Contact Database

POC	Point of Contact		Company	Company Address				Phone	Field of
ID #	Last Name	First Name	Name	Address	City	State/Prov.	Zip Code	Number	Expertise
35	Hawboldt	Bruce	Brincombe Materials Processing Lab, University of British Columbia			British Columbia		(604) 822-3667	Microstructural engineering of MMCs
36	Hastings	Dr. R.R.	Canadian Research and Development (CRAD)	Constitution Bldg., 7th floor, 305 Rideau St.	Ottawa	Ontario	K1A OK2	(613) 996-2014	
37	Ross	Dr. John	Canadian Research and Development (CRAD)	Constitution Bldg., 7th Floor, 305 Rideau St.	Ottawa	Ontario	K1A OK2	(613) 992-5829	
38	Sturrock	Dr. William	Canadian Research and Development (CRAD)		FMO Victoria	BC	VOS 1BO	(604) 363-2925	
39	Kennerknecht	Dr. Steven	Cercast (part of Helmet Corp.)	3905 Industrial Blvd.	Montreal North, Que		H1H 2Z2	(514) 322-2371	shape casting (fabricating) composites for various aerospace and civilian applications
40	Sood	Dr. Raman	Cermics Kingston Ceramiques, Inc.	P.O. Box 655	Kingston	Ontario	K7L 4X1	(613) 548-7253	powder metallurgy for MMCs
41	Rack	Dr. Henry J.	Clemson University	319 Riggs Hall	Clemson	SC	29634-0921	(803) 565-5636	tribology of MMCs, precipitation of MMC systems
42	Harrigan	William	Composites Lanxide						discontinuous area
43	Niscanen	Paul	Composites Lanxide		Newark	DE			
44	Barker	William	ARPA/DSO, Materials Science						3M, University Research Initiative, commercial aerospace
45	Wilcox	Ben	ARPA/DSO, Materials Science						3M, University Research Initiative, commercial aerospace
46	White	Dr. Robert M.	Department of Commerce						export/import, thermal applications
47	Amay	Francois	Duralcan USA, Alcan Corporation	10505 Roselle St.	San Diego	CA	92121	(619) 587-1411	
48	Hoover	William	Duralcan USA, Alcan Corporation	10505 Roselle St.	San Diego	CA	92121	(619) 587-1411	
49	Lane	Charles	Duralcan USA, Alcan Corporation	10505 Roselle St.	San Diego	CA	92121	(619) 587-1411	
50	Schuster	David M.	Duralcan USA, Alcan Corporation	10505 Roselle St.	San Diego	CA	92121	(619) 587-1411	
51	Dolowy, Jr.	Joseph F.	DWA Composites Specialties, Inc.	21119 Superior St.	Chatsworth	CA	91311	(818) 998-1504	discontinuous, reinforced
52	van den Bergh	Mark	DWA Composites Specialties, Inc.	21119 Superior St.	Chatsworth	CA	91311	(818) 998-1504	discontinuous, reinforced
53	Masounave	Dr. J.	Ecole de Technologie Superieur University	4750 Henre Julean Street	Montreal	Quebec		(514) 289-8864	hybrid Al MMC composites
54	L'Esperance		Ecole Polytechnique					(514) 340-4532	
55	Richard	Daniel J.	FMC Corporate Technology Center		Santa Clara	CA			armor and tank service vehicles
56	Zweben	Carl	GE Astro Space Division		Philadelphia	PA			materials, aerospace apps, teaches course on
57	Barker	Dr. James F.	General Electric Aircraft Engines		Evendale	OH			high temperature, continuously reinforced
58	Williams	Jim	General Electric Aircraft Engines		Evendale	OH			
59	Beetz, Jr.	Dr. Charles T.	General Motors Research Laboratory		Warren	MI			
60	Kinna	Marlin	Global Associates		Alexandria	VA		(703) 351-5660	
61	Richard	Peter N.	Hardric Laboratories, Inc.	1490 Main St.	Waltham	MA	02154	(617) 894-4723	beryllium component manufacturing
62	Myers	Norbert C.	HITCO		Gardena	CA			testing
63	Hong	Bill	IDA		Alexandria	VA			looks at various ITAR regulations
64	Hove	John	IDA		Alexandria	VA		(703) 578-2869	looks at various ITAR regs
65	Rigdon	Mike	IDA		Alexandria	VA			
66	Van Atta	Richard	IDA		Alexandria	VA			integrating defense into the national technology and industrial base, dual use issues
67	Bell	Dr. James A. E.	Inco Ltd.	J. Roy Gordon Rsearch Lab, 2060 Flavelle Blvd.	Sheridan Park, Mississauga	Ontario	L5K 1Z9	(416) 822-3322	
68	Stephenson	Tom	Inco Ltd.	J. Roy Gordon Rsearch Lab, 2060 Flavelle Blvd.	Sheridan Park, Mississauga	Ontario	L5K 1Z9	(416) 822-3322	aluminum-based composites in wear resistant applications of light materials for automotive application; nickel-coated fibers
69	Leslie	Ian O.	Industry, Science and Technology Centre (ISTC), Fabricated Metals Department	235 Queen St., 8th Floor West Tower	Ottawa	Ontario	K1A 0H5	(613) 954-3134	
70	Martel	Allen	Industry, Science and Technology Centre (ISTC), Fabricated Metals Department	235 Queen St., 8th Floor West Tower	Ottawa	Ontario	K1A OH5	(613) 954-3526	

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POC ID #	Point of Contact Last Name	First Name	Company Name	Company Address: Address	City	State/Prov.	Zip Code	Phone Number	Field of Expertise
71	Stone	Tony	Industry, Science and Technology Centre (ISTC), Fabricated Metals Department	235 Queen St., 8th Floor West Tower	Ottawa	Ontario	K1A OH5	(613) 954-3084	
72	Thibodeau	Marcel	Industry, Science and Technology Centre (ISTC), Fabricated Metals Department	235 Queen St., 8th Floor West Tower	Ottawa	Ontario	K1A OH5	(613) 954-3118	
73	Johnson	Timothy L.	Lanxide Corporation		Newark	DE			market oriented, continuous, discontinuous
74	Schiroky	Dr. Gerhard	Lanxide Corporation		Newark	DE			
75	Angers	Roch	Lavel University, Quebec University						composites, powder metallurgy
76	Chellman	David J.	Lockheed Georgia Co.		Marietta	GA			AF programs
77	Min	B. K.	Lockheed Missiles and Space Co.		Sunnyvale	CA			continuously reinforced applications for spacecrafts
78	van Siclen	Robert R.	LTV Aerospace		Dallas	TX			in charge of 91A white papers, overall policy recs.
79	Fields	Richard	Martin Marietta		Orlando	FL			in charge of database, established new test standards for MMCs
80	Misra	Dr. Mohan	Martin Marietta Space Systems		Denver	CO			head of advanced materials, in-site reinforced materials missile shrouds, lightweight stiff materials
81	Reimann	Wally	Materials Directorate, Chief Metals and Ceramics Division						NASP
82	Newton	Dr. Crystal	Materials Sciences Corporation		Spring House	PA			polymer composites, ASTM-E-49
83	Rosen	Dr. B. Walter	Materials Sciences Corporation		Spring House	PA			polymer composites, ASTM-E-49
84	Chong	Dr. Diane	McDonnell Douglas		St. Louis	MI			database support, standardization, test techniques, 3M program planning, high aerospace apps
85	Harmon	Dr. Dave	McDonnell Douglas		St. Louis	MI			database support, standardization, test techniques, 3M program planning, high aerospace apps
86	Kirby	John	McDonnell Douglas Astronautics Co.	5301 Bolsa Ave.	Huntington Beach	CA	92647-2048	(714) 896-5169	advanced designs applications
87	Tracy	Dr. John J.	McDonnell Douglas Astronautics Co.	5301 Bolsa Ave.	Huntington Beach	CA	92647-2048	(714) 896-5169	advanced designs applications
88	Embury	Dr. J. David	McMaster University			Ontario		(416) 525-9140 ext 4295/4293	Studies of mixing, solidification and particle distribution. High temperature properties of composites. Basic studies of strengthening, fracture studies related to wear and machinability.
89	Irons	Dr. G.	McMaster University			Ontario			Studies of mixing, solidification and particle distribution. High temperature properties of composites. Basic studies of strengthening, fracture studies related to wear and machinability.
90	Sowerby	Dr. R.	McMaster University			Ontario			Studies of mixing, solidification and particle distribution. High temperature properties of composites. Basic studies of strengthening, fracture studies related to wear and machinability.
91	Weatherly	Dr. G.	McMaster University			Ontario			Fatigue of MMCs, electron microscopy of interfaces
92	Wilkinson	Dr. D.	McMaster University			Ontario			Studies of mixing, solidification and particle distribution. High temperature properties of composites. Basic studies of strengthening, fracture studies related to wear and machinability.
93	Lo	Jason	Metals Technology Lab of Canmet		Ottawa	Ontario	K1A 0G1	(613) 992-2669	
94	Tremblay	Dr. Real	Mining and Metallurgy Department, Laval University						
95	Cornie	Dr. James A.	MIT		Cambridge	MA			cast MMC
96	Moran	Steven	NASA Headquarters						standards, databases, military aircraft, NASP

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POC ID #	Point of Contact Last Name	First Name	Company Name	Company Address: Address	City	State/Prov.	Zip Code	Phone Number	Field of Expertise
97	Bigelow	Dr. Catherine	NASA Langley Research Center						high modulus fiber tech., NASP, process control, material models, databases, tech breakthrough requirements
98	Buckley	Dr. John	NASA Langley Research Center						high modulus fiber tech., NASP, process control, material models, databases
99	Dicus	Dr. Dennis L.	NASA Langley Research Center						high modulus fiber tech., NASP, process control, material models, databases
100	Johnson	Steve	NASA Langley Research Center						ASTM standards
101	Ligagore	Barry	NASA Langley Research Center						high modulus fiber tech., NASP, process control, material models, databases
102	DiCarlo	Dr. James A.	NASA Lewis						NASP, SST
103	Ellis	Dr. John R.	NASA Lewis						NASP, SST
104	Gray	Dr. Hugh	NASA Lewis						head of high temperature
105	McDanels	Dr. David L.	NASA Lewis						NASP, SST
106	Stephens	Dr. Joseph R.	NASA Lewis						high temperature commercial aviation
107	Vannucci	Ray	NASA Lewis						
108	Speaker	Steve	National Aerospace Plane Contract, General Dynamics		Fort Worth	TX			wrote some AIA papers, manufacturing aspects, policy recs.
109	Handworker	Carol	National Institute of Standards and Technology		Gaithersburg	MD			standards, export/import
110	Champagne	Dr. Blaise	National Research Council of Canada, Industrial Materials Institute	75 de Mortagne	Boucherville	Quebec	J4B 6Y4	(514) 641-2280	aluminum silicon carbide composites, foundry, powder metallurgy, shaping of material by casting, recasting
111	Turenne	Dr. Sylvain	National Research Council of Canada, Industrial Materials Institute	75 de Mortagne	Boucherville	Quebec	J4B 6Y4	(514) 641-2280	aluminum silicon carbide composites, foundry, powder metallurgy, shaping of material by casting, recasting
112	Widder	Dr. Joel	National Science Foundation						
113	Deluccia	Dr. John J.	Naval Air Development Center		Warminster	PA			thermal management
114	London	Dr. Gilbert J.	Naval Air Development Center		Warminster	PA			thermal management
115	Crowe	Dr. Charles R.	Naval Research Laboratories						continually reinforced materials
116	Everett	Richard	Naval Research Laboratories						continually reinforced materials
117	Bertram	Dr. Albert L.	Naval Surface Warfare Center		Silver Spring	MD			
118	Hahn	Dr. Michael T.	Northrop Corporation		Hawthorne	CA		(310) 322-6146	all upcoming aircraft programs (military)
119	Kendall	George	Northrop Corporation		Hawthorne	CA		(310) 322-6146	all upcoming aircraft programs (military)
120	Lamarca	Dr. Marlo	NSERC						
121	Fishman	Dr. Steven G.	Office of Naval Research						discontinuous, Canadian Cooperation
122	Sloter	Dr. Lewis E.	Office of Naval Technology						current funding info
123	Bromley	Dr. D. Allen	Office of Science and Technology Policy, Executive Office of the President		Washington	DC			
124	Persh	Jerome	Office of the Director of Defense Research and Engineering (R&AT)						
125	Traceski	Frank T.	Office of the Secretary of Defense						standards, barrier to use
126	McGear	Dr. Peter	Ontario Center for Materials Research, Queen's University			Ontario			
127	Simpson	Dr. C. J. (Craig)	Ontario Hydro	800 Kipling Ave., KR208	Toronto	Ontario	M8Z 5S4	(416) 231-4111 x6344	
128	Cook	Arnold	P-Cast Equipment Corporation		Pittsburgh	PA			
129	Durham	Dr. S.	Pratt & Whitney						
130	Ho	Dr. C. Y.	Purdue University			IN			MMC IAC
131	Boyd	Douglas	Queen's University		Kingston	Ontario		(613) 545-2746	Electrochemical routes for production of composites. Control of interface reactions in MMCs.

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POC ID #	Point of Contact Last Name	First Name	Company Name	Company Address: Address	City	State/Prov.	Zip Code	Phone Number	Field of Expertise
132	Erb	Dr. U.	Queen's University		Kingston	Ontario		(613) 545-2750	Electrochemical routes for production of composites. Control of interface reactions in MMCs.
133	Dvorak	Dr. George	Rensselear Polytechnic Institute		Troy	NY			Concurrent Engineering, process controls
134	McCreight	Lou	Research Opportunities, Inc. (ROI)	2200 Amapola Ct., Ste. 101	Torrance	CA	90501	(310) 533-5149	thermal structural applications
135	Riley	Bill	Research Opportunities, Inc. (ROI)	2200 Amapola Ct., Ste. 101	Torrance	CA	90501	(310) 533-5149	thermal mgmt, MMC markets, technology
136	Rubin	Lou	Research Opportunities, Inc. (ROI)	2200 Amapola Ct., Ste. 101	Torrance	CA	90501	(310) 533-5149	
137	Doherty	Jim	Rocketdyne		Chatsworth	CA			NASP consortium
138	Cox	Brian	Rockwell International		Downey	CA			
139	Zadorozny	Dr. Edward A.	Rockwell International		Downey	CA			
140	Bampton	Cliff	Rockwell Science Center (RSC)	1049 Camino des Rios, PO Box 1085		CA	91358	(805) 373-4453	Long range research
141	Thakker	Dr. Ash B.	Rolls Royce, Inc.	2849 Paces Ferry Rd.	Atlanta	GA	30339-3769	(404) 436-7900	continuous and reinforced areas, engine work
142	Apte	Dr. P.	Sherritt Gordon						
143	Causey	Sam	Southern Research Associates		Birmingham	AL			testing org, test techniques
144	Starrett	Stu	Southern Research Associates		Birmingham	AL			head of testing, testing org, test techniques
145	Glatz	John	SPARTA						
146	Durako	Bill	Sunstrand Corporation		Rockford	IL			motor pump housings, international market
147	Rinehart	Ted	Systems Support Division, Watervliet Directorate						NASP
148	Henshaw	Dr. James	Textron		Lowell	MA			continuously reinforced titanium, silicon fiber-6, reinforcements in aluminum and titanium material
149	Purgert	Robert	Thompson Aluminum Casting Co., Inc.	4850 Chaincraft Rd.	Cleveland	OH	44125	(216) 581-9200	making test bars to generate a database
150	Josephs	Brian	Touchstone Research Labs		Wheeling	WV			NASA certified testing lab, primarily tests for 3M MMC program
151	Nardone	Vince	United Technologies Research Center		Hartford	CT			head of advanced composites developments, turbine blades
152	Strife	Dr. James R.	United Technologies Research Center		East Hartford	CT			turbine blades
153	Henein	Dr.	University of Alberta						composite preparation by spray deposition on a porous base
154	Brimacombe	Dr. K.	University of British Columbia			British Columbia		(604) 822-3667	Microstructural engineering of MMCs
155	Samarasekera	Dr. I.	University of British Columbia			British Columbia			Microstructural engineering of MMCs
156	Evans	Dr. Anthony	University of California, Santa Barbara		Santa Barbara	CA		(805) 893-4634	design tech., training engineers on continuing reinforced, NASP aircraft, 3-M design, development of design tools, material selection
157	Leckie	Dr.	University of California, Santa Barbara		Santa Barbara	CA		(805) 893-4634	design tech., training engineers on continuing reinforced, NASP aircraft, 3-M design, development of design tools, material selection
158	Levi	Dr. Carlos	University of California, Santa Barbara		Santa Barbara	CA		(805) 893-4634	
159	Zok	Dr. Frank	University of California, Santa Barbara		Santa Barbara	CA		(805) 893-4634	design tech., training engineers on continuing reinforced, NASP aircraft, 3-M design, development of design tools, material selection
160	Froes	Dr. F.H. (Sam)	University of Idaho		Moscow	ID			discontinuous and continuous
161	Toguri	Dr. J.	University of Toronto		Toronto	Ontario		(416) 978-5003	wetting of NI-coated carbon by Al
162	Wang	Dr. Z.	University of Toronto		Toronto	Ontario		(416) 978-4412	Fatigue of MMCs, electron microscopy of interfaces
163	Wadley	Dr. Hayden	University of Virginia			VA			
164	Varin	Dr. R. A.	University of Waterloo					(519) 679-2111 ext 8307	

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165	Dryden	Dr. J. R.	University of Western Ontario			Ontario			Modelling of internal stresses in composites
166	Alpas	Dr. Ahmet T.	University of Windsor					(519) 252-4232 ext 2602	wear of MMCs (high temperature)
167	Sutton	Dr. Clifford	US Air Force, Robins AFB	WR-ALC/TIEM, Suite 122, 255 Second St.	Robins AFB	GA	31098	(912) 926-4521	support aircraft maintenance
168	Tenenbaum	Dr. David	US Army Tank and Automotive Command		Warren	MI			TACOM induction program
169	Stinchcomb	Dr. Wayne W.	Virginia Polytech Institute		Blacksburg	VA			heads up ASTM D-30, high modulus fibers and their reinforcements, US/Japan advanced composites
170	Eid	Eric	West Aim Technology, University of Alberta			Alberta			
171	Roach	Ingrid	West Aim Technology, University of Alberta			Alberta			
172	Wood	Dr. Ralph	West Virginia University		Morgantown	WV			3M Model Factory
173	Burke	Dr. Michael	Westinghouse Research Laboratory	1310 Beulah Rd.	Pittsburgh	PA	15235	(412) 256-1788	nondestructive testing of MMCs
174	Gungor	Dr. Mehmet	Westinghouse Research Laboratory	1310 Beulah Rd.	Pittsburgh	PA	15235	(412) 256-1211	nondestructive testing of MMCs
175	Liaw	Peter	Westinghouse Research Laboratory	1310 Beulah Rd.	Pittsburgh	PA	15235		nondestructive testing of MMCs
176	Moon	David	Westinghouse Research Laboratory	1310 Beulah Rd.	Pittsburgh	PA	15235	(412) 256-2817	nondestructive testing of MMCs
177	Gilbride	John	Wright Patterson AFB		WPAFB	OH	45433-6503	(513) 255-9665 ext 221	
178	Pohlenz	Eric Lee	Wright Patterson AFB		WPAFB	OH	45433-6533	(513) 255-9665 ext 224	
179	Geyer	Norm	Wright Patterson Research and Development Center, Wright Patterson AFB		Dayton	OH			NASP
180	Gunderson	Allen W.	Wright Patterson Research and Development Center, Wright Patterson AFB		Dayton	OH			NASP

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ID #	Document Title	Author	pg #	Document Date	Source of Document	Topic *
1	1991 Industrial Base Strategic Plan	D. Punatar, Wright Laboratory (Manufacturing Technology Directorate)		Dec-1991		Policy
2	1993 Bluebook	Advanced Composites		1993		Product
3	8 Tips to Understanding Aluminum Metal Matrix Composites (pamphlet)	The Aluminum Association, Inc.				Products
4	A Detailed Technology Roadmap for: Composite Materials	Aerospace Industries Association of America, Inc.		May-1989		Policy
5	A Taxing Situation...Solution	Linn H. Matthews, Suppliers of Advanced Composite Materials Association (SACMA)				Policy
6	A Technology Czar Wouldn't Hurt	Aviation Week and Space Technology	9	20-Jan-1992		General
7	Advanced Materials and Processing: The Fiscal Year 1993 Program	FCCSET Committee on Industry and Technology		1993	BDM	Products
8	Aerospace Industries Association (pamphlet)	Aerospace Industries Association (AIA)			David O. Schillerstrom	Program
9	Aluminum Association Nomenclature System for Aluminum Metal Matrix Composite Materials	The Aluminum Association, Inc.				Products
10	American National Standard Alloy and Temper Designation Systems for Aluminum	The Aluminum Association, Inc.				Products
11	Annex D: Canadian/US Facilitators					US/Canada
12	Arc Welding Guidelines	Duralcan Composites			Dr. David J. Lloyd	Products
13	Army Industrial Based Sector Surveys (briefing)	Army Materiel Command				Policy
14	Assessment of Metal Matrix Composite Technology	Metal Matrix Composites Information Analysis Center (MMCIAC)		Mar-1990		Product
15	Assessment of Metal Matrix Composite Technology	William McNamara, Metal Matrix Composites Information Analysis Center (MMCIAC)		Apr-1990		Product
16	Authorization Act – Title XLII - Defense Technology and Industrial Base, Reinvestment, and Conversion					Policy
17	Barriers to Domestic Technology Transfer - Hearing	102D Congress		25-Jul-1991		Policy
18	Bidirectional Metal Matrix Composites Torque Tube/Study	ManTech Project Book 1992			John Klempay	Product
19	Bridging the Gap: A National Imperative for Advanced Materials	J. Michael Bowman, Suppliers of Advanced Composite Materials Association (SACMA)				General
20	Bridging the Gap: An Advanced Ceramics Development and Commercialization Program	United States Advanced Ceramics Association		Oct-1990	J. Caitlin Storhaug	Program
21	Canada-US Free-Trade Agreement, A Canadian Science and Technology Viewpoint, The	Guy Steed, Technology in Society		1989		US/Canada
22	Canadian Industry and the United States Defence Market	Department of External Affairs-Canada		1988		Policy (US/Canada)
23	Cocom Becomes Agency to Promote Technology Transfers	Stuart Auerbach & John Mintz, Washington Post				Policy
24	Composites Diversification on the Fast Track	Richard Dauksys, Suppliers of Advanced Composite Materials Association (SACMA)				General

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25	Composites in Manufacturing 1993	Society of Manufacturing Engineers (SME)		1993	BDM	Program
26	Concepts, Materials, and Efficiencies of Piston Compounded Adiabatic Engines	James A.E. Bell, INCO Limited			Dr. James A.E. Bell	Products
27	Control of Unclassified Technology Data with Military of Space Applications	DoD US-Canada Joint Certification Program		Mar-1991		Policy
28	Cooperative Planning on U.S./Canadian Munitions - Phase I & II Report	North American Defense Industrial Base Organization (NADIBO)		Aug-1989	Cynthia	Policy (US/Canada)
29	Critical Technologies Plan	DoD Secretary of Defense		15-Mar-1990		Products/Policy
30	Critical Technologies Plan	DoD Secretary of Defense		01-May-1991		Products/Policy
31	Critical Technology Assessment: Advanced Composites	US Department of Commerce, Bureau of Export Administration				Products
32	Critical Technology Assessments					General
33	Defence Export Shipper's Guide	Department of External Affairs-Canada				Policy (US/Canada)
34	Defence Industry Productivity Program (DIPP)	Industry, Science and Technology (Canada)		04-Feb-1992		Research/Funding
35	Defense Critical Technologies Plan (briefing)	Office of Deputy Director of Defense, Research and Engineering (presented by Dr. Leo Young)			Cynthia	Program
36	Defense Industrial Base (Hearings Before the Structure of US Defense Industrial Base Panel of the Committee on Armed Services House of Representatives)	102d Congress		1992		Policy
37	Defense Industrial Base Report (briefing)	Dan Cundiff, Planning and Assessment Division, Production Base Directorate, Deputy Assistant Secretary of Defense (Production Resources)				Policy
38	Defense Science and Technology Strategy	Director of Defense Research and Engineering		Jul-1992		Policy
39	Defense Technology Base: Risks of Foreign Dependencies for Military Unique Critical Technologies	General Accounting Office (GAO)		Jun-1992		Policy
40	Department of Defense Appropriations Act, 1993 (Public Law 102-396)	102d Congress		06-Oct-1992		Policy
41	Department of Defense Appropriations Bill, 1992	102D Congress		04-Jun-1991		Policy
42	Department of Defense Appropriations Bill, 1993	102d Congress (Senate)				Policy
43	Department of Defense Appropriations Bill, 1993 (Report of the Committee on Appropriations)	102d Congress (House of Representatives)		1992		Policy
44	Diffusing Innovations: Implementing the Technology Transfer Act of 1986	General Accounting Office (GAO)		May-1991	Dr. David J. Lloyd	Policy
45	Discontinuously Reinforced Aluminum-Moderate Strength	ManTech Project Book 1992			John Klempay	Product
46	DND Research and Development Program, The			Dec-1990		Research

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47	DoD Key Technologies Plan	Director of Defense Research and Engineering		Jul-1992		Products/Policy
48	DoD Science and Technology Programs Composite Materials					Funding
49	Does America Need a Technology Policy?	Harvard Business Review	24	Mar-Apr 1992		Policy
50	DPA Title III Program Accelerates Critical and Strategic Materials Development	Information Analysis Center Current Highlights		Dec-1989	Bill McNamara	Program
51	Dual Use Technologies...A Chorus of Voices	James N. Burns, Suppliers of Advanced Composite Materials Association (SACMA)				Program
52	Emerging Technologies: A Survey of Technical & Economic Opportunities	Technology Administration - U.S. Department of Commerce		Spring 1990		General
53	Evolving European Defence Sector: Implications for Europe and North America, The	Centre for International and Strategic Studies				Policy
54	Factors Influencing the Properties of Particulate Reinforced Composites Produced by Molten Metal Mixing	D.J. Lloyd, Alcan International, Inc.			Dr. David J. Lloyd	Products
55	First Steps Toward Competitiveness	Aviation Week and Space Technology	9	16-Sep-1991		Policy
56	Flight Vehicles of the Future	Vicki P. McConnell, Advanced Composites	28	Jan/Feb 1992		Products
57	Foreign Take-Overs and Utilization of US Developed Metal-Matrix Composites Technology (memo)	Jerome Persh, Office of Director of Defense Research and Engineering		02-Jan-1992	Jerome Persh	Funding
58	High Modulus Pitch-based Graphite Fibers	ManTech Project Book 1992			John Klempay	Product
59	High Technology Competitiveness: Trends in U.S. and Foreign Performance	General Accounting Office (GAO)		Sep-1992		Policy
60	Impact of Conventional Arms Reductions on Defence Procurement: The Advanced Technology Base	North Atlantic Council		30-Aug-1990		Policy
61	Industrial Base Surveys (Executive Summary)					General
62	Industry Collaboration Grows for Technology Development	Aviation Week and Space Technology	20	16-Sep-1991		Policy
63	Innovative Manufacturing of Titanium Aluminide and Titanium Alloy Foil	ManTech Project Book 1992			John Klempay	Product
64	Insertion: A Path & Bridge to Product Commercialization	Jeff Hendrix, Suppliers of Advanced Composite Materials Association (SACMA)				General
65	Japanese Composites Revisited	Advanced Composites		Jan-Feb 92		Product
66	Machining Guidelines	Duralcan Composites			Dr. David J. Lloyd	Products
67	Making Appropriations for the Department of Defense for the Fiscal Year Ending September 30, 1993, and for Other Purposes	102d Congress				Policy
68	Making New Technology Work for Manufacturing Competitiveness: A Management Perspective	Bitthal Gujrati, Proceedings of Manufacturing International 1992				Program
69	ManTech Database (fax)	MTIAC		10-Dec-1992	Joel Pacheco	Program
70	Manufacturing Science for Titanium Aluminide Composite Engine Structures	ManTech Project Book 1992			John Klempay	Product

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71	Materials Head Master List	Washington Technology Newspaper		21-Mar-1991		General
72	Memorandum for the Record: Briefing Charts from Metal Matrix Composites Steering Committee Meeting, Institute for Defense Analysis	John E. Hove and John P. Henderson, Institute for Defense Analysis		12-14 March 1991		Products
73	Metal and Ceramic Matrix Composites Activities in Europe	ESN Information Bulletin			Marlin Kinna	Program
74	Metal Matrix Composite Vendor/Supplier Fabrication Evaluation	ManTech Project Book 1992			John Klempay	Products
75	Metal Matrix Composites/Industry Association Meeting			Jan-1993		Policy/Products
76	NADIBO Critical Technologies Rationalization Workshop	North American Defense Industrial Base Organization (NADIBO)		Mar-1991		Products
77	NASP Spins Off Materials Technology Applications	Advanced Composites	16	Mar-Apr 92		Products
78	National Defense Authorization Act for Fiscal Year 1993 (Conference Report)	102d Congress		1992		Policy
79	National Defense Authorization Act for Fiscal Year 1993 (Public Law 102-484)	102d Congress		23-Oct-1992		Policy
80	National Defense Authorization Act for Fiscal Year 1993 (Report of the Committee on Armed Services House of Representatives)	102d Congress		1992		Policy
81	National Defense Authorization Act for Fiscal Year 1993 (Report)	102d Congress		1992		Policy
82	National Defense Authorization Act for Fiscal Year 1993 Report	102D Congress		19-May-1992		Policy
83	National Security Assessment of the US Gear Industry	US Department of Commerce		Jan-1991		Products
84	National Strategies for Technology Trade	Victor G. Bradley, Technology in Society		1989		Policy
85	National Technology Strategies Under Free Trade	Christopher T. Hill, Technology in Society		1989		Policy
86	New Thinking and American Defense Technology	Carnegie Commission on Science, Technology and Government		Aug-1990		Policy
87	Nickel Coated Fibres for Aerospace Applications	J.A.E. Bell and G. Hansen, INCO Limited			Dr. James A.E. Bell	Products
88	Nickel-Coated Carbon Fibre Paper: A Low Cost Alternative to Particulate Reinforced Metal Matrix Composites	T.F. Stephenson and J.A.E. Bell, INCO Limited			Dr. James A.E. Bell	Products
89	Nickel-Coated Carbon Fibre Preforms for Metal Matrix Composites	T.F. Stephenson and J.A.E. Bell, INCO Limited			Dr. James A.E. Bell	Products
90	Objectives -- Table 3: Barriers				Cynthia S. (?)	Policy
91	Particulate Reinforced Composites Produced by Molten Metal Mixing	D.J. Lloyd, Alcan International, Inc.			Dr. David J. Lloyd	Products
92	Proceedings, Fourteenth Annual Discontinuously Reinforced MMC Working Group Meeting	DoD Metal Matrix Composites Information Analysis Center (MMCIAC)		Nov-1992		Products

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93	Properties of Nickel Coated Carbon and Kevlar Fibres Produced by Decomposition of Nickel Carbonyl	J.A.E. Bell and G. Hansen, INCO Limited			Dr. James A.E. Bell	Products
94	Publication and Audiovisual Guide	The Aluminum Association, Inc.		1992		Policy
95	Rationalization Effort (briefing) and Rationalization Project (briefing)	North American Defense Industrial Base Organization (NADIBO)		Jun-1991	Cynthia Gonsalves	Policy
96	Report to Congress on the Defense Industrial Base	DoD Assistant Secretary of Defense (Prod & Logistics)		Oct-1990		Products
97	Report to Congress on the Defense Industrial Base	DoD Undersecretary of Defense (Acquisition)		Nov-1991		Policy
98	Report to Congress on the Defense Industrial Base: Critical Industries Planning	DoD Office of Industrial Base Assessment		Oct-1990		Products
99	Research, Development and Acquisition with Canada	Partners		11-Jun-1991		Policy (US/Canada)
100	S.1507 - A Bill	102D Congress		19-Jul-1991		Policy
101	Sector #4: Medium and Large Caliber Weapons	BG Robert W. Pointer, Jr. and Fred J. Clas, HQ US Army Materiel Command		03-May-1992		Products
102	Sector Analysis of Composites Manufacture (Final)	BDM		Dec-1989	BDM	Products
103	Sector Analysis of Forged Products (Final)	BDM		Nov-1989	BDM	Products
104	Securities and Future Markets: Cross-Border Information Sharing Is Improving, but Obstacles Remain	General Accounting Office (GAO)		Jul-1992		Policy (US/Canada)
105	Solidification Processing of Metal Matrix Composites	A. Mortensen and I. Jin, International Materials Review		1992	Dr. David J. Lloyd	Products
106	Special Materials (briefing)	Textron		23-Nov-1989		Products
107	SRI Study Executive Summary	SRI			Rod Waite	General
108	Technical Cooperation Program (TTCP) Handbook, The	Subcommittee on Non-Atomic Military Research and Development	4			Products/Policy
109	Technology Assessments and Forecasts				IEA	General
110	Technology Development and Canada-US Free Trade	Thomas Wudwud, Technology in Society		1989		US/Canada
111	Technology Focus Survey and Annex	Centre for International and Strategic Studies		23-May-1991		Policy (US/Canada)
112	Technology Partnership Program	Canadian Embassy				Policy
113	Technology Transfer Success - for Competitors	Washington Technology		21-Feb-1991		Policy
114	Technology Transfer: Barriers Limit Royalty Sharing's Effectiveness	General Accounting Office (GAO)		Dec-1992		Policy
115	Test Standards and Engineering Databases for Advanced Composites	Aerospace Industries Association (AIA)		Jul-1992		Products/Research
116	Testimony of the Honorable Richard A. Gephardt Before the House Energy and Commerce Subcommittee on Commerce, Consumer Protection and Competitiveness			26-Feb-1990		Funding/ Congressional

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117	Time for a National Advanced Materials Action Agenda	Dr. Robert A. Cooper, Suppliers of Advanced Composite Materials Association (SACMA)				Policy
118	Titanium Matrix Composite Initiative	ManTech Project Book 1992			John Klempay	Product
119	Topics for Presentations/Discussions during the October Meeting of the DoD Metal Matrix Composite Technology Committee (memo)	B.B. Rath, Materials Science and Component Technology Directorate, Naval Research Lab		12-Aug-1989	Marlin Kinna	Program
120	United States Advanced Ceramics Association (USACA) (pamphlet)	United States Advanced Ceramics Association (USACA)				Program
121	US Department of Commerce... Publications Listing					General
122	US Industrial Outlook '92: Business Forecasts for 350 Industries	US Department of Commerce		1992		General
123	US Needs Leadership and Vision to Develop a New Industrial Policy	Aviation Week and Space Technology	59	20-Jan-1992		Policy
124	Use of National Defense Stockpile R&D Funds (memo)	John Todaro, Office of Assistant Secretary of Defense			Ken Foster	Research, Funding
125	Boron Fiber: The Strength to Compete	Michael Buck, Materials Engineering		Jul-1992		Products
126	Metal & Ceramic Composites Come Down to Earth	Margaret Hunt, Materials Engineering		Jul-1992		Products
127	Epic Proportions in Metal Matrix Composites	Margaret Hunt, Materials Engineering		Jul-1992		Products
128	Machining metal matrix composites	GA Chadwick & PJ Heath, Metals & Materials		Feb-1990		Products
129	Metal matrix composites—ready for take-off?	D Charles, Metals & Materials		Feb-1990		Products
130	Canadian Trip Report	Dave Fox, BDM		03-Mar-1993	BDM	General
131	Investment in Castings	Steve Kennerknecht, Materials Edge		Jan-1992		Products
132	Metal-Matrix Composites for Electronic Packaging	Carl Zweben, JOM		Jul-1992		Products
133	Advances in Cast MMCs	Pradeep Rohatgi, Advanced Materials & Processes		Feb-1990	BDM	Products
134	Herculean Proportions	Al Fleming		05-Sep-1991	Pete Pollack	Products
135	Metals on the Aerospace Frontier	Michelle Dibble, Machine Design		06-Jun-1991		Products
136	What's Being Done to Weld Metal Matrix Composites?	Bob Irving, Welding Journal		Jun-1991	BDM	Products
137	Revolutionary "Ceramic Wood" Drive Adds Strength to Langert Gold Club Line (press release)	Langer Gold Co., Inc.		05-Nov-1991	The Aluminum Assoc.	Products
138	After the Cold War - Living with Lower Defense Spending	Office of Technology Assessment				Funding
139	Memorandum: Feb 9 Meeting with Chauncy Martin	Michael Brown, BDM			BDM	General
140	Processing Titanium Aluminide Foils	C. Bassi, J.A. Peters, J. Wittenaeur, JOM		Sep-1989		Products
141	The Aging Response and Creep of DRA Composites	M. House, K. Meinert, R Bhagat, JOM		Aug-1991		Products
142	Intermetallic Compounds: Structure and Properties	D.M. Shah, D.L. Anton, JOM		Feb-1992		Products
143	Metal Matrix Composite and Graphite/Epoxy Optical Gimbal	P. Juneau, C. Zweben, J. Altpater, A. Ikeda, B. Rodini, GE Company		Apr-1986	GE Company	Products
144	Advanced Composites - A Revolution for the Designer	Carl Zweben, GE Astro Space Division			AIAA	Products

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145	Metal Matrix Composite and Graphite/Epoxy Driver Shaft	N. Buschman, M. DiNardo, C. Zweben, GE Company				Products
146	Metal-Matrix Composites: Materials in Transition - Part I	Vicki P. McConnell, Advanced Composites		May/June 1990		Products
147	Metal-Matrix Composites: Materials in Transition - Part II	Vicki P. McConnell, Advanced Composites		July/Aug 1990		Products
148	Metal Matrix Composites	Carl Zweben		Jan-1987		Products
149	Strength of Ceramic Metal-Matrix Fibre Composites	V.I. Kazmin, S.T. Mileiko, V.V. Tvardovsky, Composites Science & Technology		1990		Products
150	High-Temperature Discontinuously Reinforced Aluminum	M.S. Zedalis, J.D. Bryant, P.S.Gilman, S.K. Dos, JOM		Aug-1991		Products
151	Synthesis of Particulate Reinforced Metal Matrix Composites Using Spray Atomization & Co-Deposition	Enrique Lavernia, Sampe Quarterly		Jan-1991	GSFC Library	Products
152	Low Expansion Metal Matrix Composites Boost Avionics	A. Geiger, M. Jackson, Advanced Materials and Processes		Jul-1989	MML Library	Products
153	Characterization of Metal-Matrix Composites Fabricated by Vacuum Infiltration of a Liquid Metal Under an Inert Gas Pressure	Jeng-Maw Chiou, D.D.L Chung, Journal of Materials Science		05-May-1991	NIST/RIC	Products
154	Review of Corrosion Studies on Aluminum Metal Matrix Composites	A. Turnball, British Corossion Journal		1992	NIST/RIC	Products
155	Strengthening Mechanisms in Particulate MMC: Remarks on a Paper by Miller & Humphreys	RJ Arsenault, Scripta Mettalurgica et Materialia		1991	MML Library	Products
156	Metal-Matrix Composites	Dr. Henry Rack, Advanced Materials and Processes		Jan-1990	NSX Library	Products
157	Spray Atomization and Codeposited 6061 Al/SiC Composites	Yue Wu, Enrique Lavernia, JOM		Aug-1991		Products
158	Friction and Wear of Fiber-Reinforced MMCs	N.Saka, N. Szeto, T. Erturk, Wear		1992	GSFC Library	Products
159	Discontinuously Reinforced Aluminum: Ready for the 1990s	Paul Gilman, JOM		Aug-1991		Products
160	Notes on Composite Material Behavior: #1	Martin Marietta Intracompany Memo		04-Nov-1991		Products
161	Rapid-solidification processing improves MMC properties	Advanced Materials and Processes		Nov-1990	MML Library	Products
162	Trimming the Cost of MMCs	S. Abkowitz, P. Weihrauch, Advanced Materials and Processes		Jul-1989	MML Library	Products
163	Advanced Materials: The Newsletter of High Performance			26-Aug-1991		Products
164	Metal Matrix Composites Overview	Carl Zweben		Feb-1985	MMCIAC	Products
165	Lightweight MMC/Steel Hybrid Geer	M. DiNardo, C. Zweben, GE Company			GE Company	Products
166	Honda Prelude Brochure	Honda		1992	C. Zweben	Products
167	Particulate Reinforced MMC - A Review	I.A. Ibrahim, F.A. Mohamed, E.J. Lavernia, Journal of Materials Science		01-Mar-1991	NIST/RIC	Products
168	FY91 Materials Technology Area Plan	HQ Air Force Systems Command				Products
169	Developments in Metallic Materials for Aerospace Applications	J. Wadsworth, F.H. Froes, JOM		May-1989		Products

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170	Selecting High-Temperature Structural Intermetallics	D.L. Anton, D.M. Shah, D.N. Duhl, A.F. Giamei, JOM		Sep-1989		Products
171	Chemical Synthesis of Micrometer-Sized Nickel Aluminum Power	J.C. Withers, H. -C. Shiao, R.O. Loutfy, Ping Wang, JOM		Aug-1991		Products
172	Progress in Understanding of Gamma Titanium Aluminides	Young-Won Kim, Dennis Dimiduk, JOM		Aug-1991		Products
173	Scaling Up Particulate Reinforced Aluminum Composites for Commercial Production	William Harrigan, Jr., JOM		Aug-1991		Products
174	Technical and Commercial Implications of Solidification Processing and Pressure Infiltration Casting Technology for Fiber Reinforced Metal Composites	J. Cornie, A. Mortensen, F. Field, S. Stokes, ATA Materials		1989		Products
175	Cast Aluminum MMCs Have Arrived	John Vaccari, American Machinist		Jun-1991	C. Zweben	Products
176	The Processing and Properties of Discontinuous Reinforced Aluminum Composites	Alan Geinger, J. Andrew Walker, JOM		Aug-1991		Products
177	Aluminum Composites Come in For a Landing	Paul McGuire, Machine Design		23-Apr-1992		Products
178	Cast Aluminum-Matrix Composites for Automotive Applications	Pradeep Rohatgi, JOM		Apr-1991		Products
179	MMCs and IPM: A Modeling Perspective	Dan Backman, JOM		Jul-1990	GSFC Library	Products
180	Improving Performance & Quality Using Advanced Composite Materials in Mechanical Systems (brochure)	National Technology University				Products
181	Title III brochures	DoD			Pete Pollak	Program
182	MMC Sector Study, Canadian Site Trip Itinerary	Dave Fox, BDM			BDM	General
183	Free Trade Treaty in Trouble, White House Warned	Peter Behr, The Washington Post		12-Mar-1993	Washington Post	Policy
184	Metal Matrix Composites (chart)	Canmet			Jason Lo	Products
185	Stages in MMC Product Development (chart)	Canmet			Jason Lo	Products
186	Stages in Product Development with Commercial MMCs	Canmet			Jason Lo	Products
187	Mechanical Test Methods for Metal-Matrix Composites: A Status Report for the U.S.	Leonard Mordfin, NIST			Dr. Leonard Mordfin	Products
188	Discontinuously Reinforced Metal- and Ceramic-Matrix Composites	Leonard Mordfin, NIST		08-Mar-1991	Dr. Leonard Mordfin	Products
189	Metal Matrix Composites	R. Fields, T. Shives, C. Handwerker, L. Mordfin		Jun-1909	Dr. Leonard Mordfin	Products
190	Canadian Trip Notes: Meeting with Jason Lo and Ian Leslie	Dave Fox, BDM			BDM	General
191	Canadian Trip Notes: Meeting with John Ross, R.R. Hastings, and William Sturrack	Dave Fox, BDM			BDM	General
192	Canadian Trip Notes: Meeting with Sylvain Turenne and Blaise Champagne	Dave Fox, BDM			BDM	General
193	IMI: Partnership with Industry (brochure)	Industrial Materials Institute				Program

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194	Advancing Automotive Efficiency - Aluminum: It's Time to Take Us Off the Shelf	The Aluminum Association		07-Nov-1991	The Aluminum Association	Products
195	The Future of Metals	T.W. Eager, Welding Journal		Jun-1991		Products
196	New Processes for Welding Needed	American Metal Market		03-Jun-1991	The Aluminum Association	Products
197	A Prospectus on Deformation Processing of Aluminum Matrix Composites	Battelle		Mar-1991	The Aluminum Association	Products
198	MMC Base - A Database Management System for Metal Matrix Composites	MMCIAC				Products
199	Current Highlights	DoD MMCIAC		Dec-1990		Products
200	Canadian MMC consortium publications	Ontario Centre for Materials Research			Peter McGeer	Products
201	Typical Physical Property Data for Aluminum Metal Matrix Composites (various documents)				The Aluminum Association	Products
202	High Temperature Discontinuously Reinforced Aluminum (HTDRA)	Allied Signal			The Aluminum Association	Products
203	12th Annual Discontinuously Reinforced MMC Working Group Meeting			06-Feb-1990		Policy
204	Aluminum Metal Matrix Composites	The Aluminum Association		Feb-1985		Products
205	Duralcan Composites for Wrought Products	Alcan				Products
206	MMC Materials & Their Reclamation Issues (abstract)	Dr. David Schuster, Duralcan			The Aluminum Association	Policy
207	Composites Group Eyes Shipment Dip					Products
208	Final Part Fabrication (briefing)	Duralcan			The Aluminum Association	Products
209	SAMPE makes waves in Congress	Robert Wilson, Cermic Industry		Oct-1991	Alcan	Policy
210	Reinforcing the Best of Aluminum (briefing)	Paul Gilman, Allied-Signal, Inc.		21-Nov-1991	Allied-Signal	Products
211	Trends in Aluminum Matrix Composites (briefing)	William Hover, Duralcan		07-Nov-1991		Products
212	Mission Statement: Task Group for the Development of Aluminum Metal Matrix Composites			15-Jul-1991		Program
213	Composite Market Reports, Inc. listings	Composite Market Reports, Inc.				General
214	Suggestions for Joint AATGMMC-MMCIAC Programs	Dave Higa, DoD MMCIAC		21-Aug-1991		Program
215	MMC Programs Aim At Automotive Markets	Advanced Materials				Program
216	Ceramics Kingston Ceramiques Inc. (brochure)				Ceramics Kingston Ceramiques Inc.	Products
217	Background/Barriers/Foreign Competition					Policy
218	Advanced Nickel Electrode Structures and Battery Research @ INCO	V.A. Ettel, INCO Limited			Dr. J.A.E. Bell	Products

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219	INCO Annua Report 1991	INCO Limited		1991	Dr. J.A.E. Bell	Products
220	Research Pro; ress: Liquid Processing of MMCs	G.A. Irons, G.S. Hanumanth & K. Owasu-Boahen, McMaster University			Dr. J. David Embury	Research
221	Canadian Tri Notes: Ontario Hydro, INCO Limited	Dave Fox, BDM		26-Feb-1993	BDM	General
222	Southeast Tri Notes: Dr. Thakker, Clifford Sutton, Henry Rack, Clarke McGu re, Richard Case	Don Higgins, BDM		30-Mar-1993	BDM	General
223	Melting & Ca ting Processes for High-Temperature Intermetallics	S. Sen & D.M. Stefanescu, JOM		May-1991		Products
224	Recycling & I eclamation, as Part of the Commercialization of Metal-Matrix Composites	Dr. David Schuster, Duralcan		20-Nov-1991	Duralcan	Products
225	Holding the I dge: Maintaining the Defense Technology Base	U.S. Office of Technology Assessment		Jan-1990	NTIS	Policy
226	Electronic Ma terials Handbook, Volume 1, Packaging	ASM International Handbook Committee				Products
227	Aeronautical Technologies for the Twenty-First Century - Executive Su mary	National Research Council		1992		Research
228	Structural Int ermetallics	F.H. Froes, JOM		Sep-1989		Products
229	Selecting Hig 1-Temperature Structural Intermetallic Compounds: The Materials Science Approach	R. Fleischer & A. Taub, JOM		Sep-1989		Products
230	Southern Cal fornia Trip Notes: Bill Riley, J. Dirby, B. Bustamente, C. Bampton, Dr. Leckie, G. Kendall	Dave Fox, BDM		8-12 Mar 93	BDM	General
231	The World Won't Beat A Path To Your Door	D.M. Schuster, Duralcan		1993	Duralcan	Products
232	Foundry Practice for the First Castable Aluminum/Ceramic Composite Material	D. Hammond, Modern Casting		Aug-1989		Products
233	Casting Aluminum/Ceramic Composites at Progress Castings	P. Bralower, Modern Casting		Aug-1989		Products
234	Southern Cal fornia Trip Notes: D.M. Schuster	Dave Fox, BDM			BDM	General
235	Canadian Trip Notes: Dr. Masonnave	Dave Fox, BDM			BDM	General
236	Canadian Trip Notes: S. Kennerknecht	Dave Fox, BDM		22-Feb-1993	BDM	General
237	TechLink - Metal Matrix Composites	SRI International		May-1991	S. Kennerknecht	Products
238	Castable Composites Target New Applications	D. Hammond, Modern Casting		Sep-1990	S. Kennerknecht	Products
239	Advanced Materials and Processes	ASM International		Jun-1991	S. Kennerknecht	Products
240	Scaling Up Metal-Matrix Composite Fabrication	D. Ginburg, Composites in Manufacturing		1991	S. Kennerknecht	Products
241	Investment in Castings	Materials Edge		Jan-1992	S. Kennerknecht	Products
242	Investment Cast Metal Matrix Composites for High Temperature Applications: An Assessment of Duralcan F3K.20S	X. Dumant and S. Kennerknecht, Cercast Group			S. Kennerknecht	Products
243	Silicon Carbide Reinforced Aluminum Investment Castings	Cercast Group		Apr-1990	S. Kennerknecht	Products
244	Investment Cast Metal Matrix Composites	X. Dumant, S. Kennerknecht, R. Tombari		1990	S. Kennerknecht	Products
245	MMC Studies Via the Investment Casting Process	S. Kennerknecht, Cercast Group		Sep-1990	S. Kennerknecht	Products

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246	Investment Cast Metal Matrix Composites for Microelectronic Packaging	X. Dumant, Cercast Group		03-May-1991	S. Kennerknecht	Products
247	High Quality Aluminum Casting Technical Survey Investment Casting Process	Cercast Group			S. Kennerknecht	Products
248	Cercast Group brochure	Cercast Group			S. Kennerknecht	Products
249	Federal Technology Transfer Act of 1986	99th Congress		21-Apr-1986		Policy
250	Federal Technology Transfer Act of 1985	99th Congress		05-Dec-1985		Policy
251	Federal Technology Transfer Act of 1986	99th Congress		02-Oct-1986		Policy
252	Public Law 99-502	99th Congress		20-Oct-1986		Policy
253	H.R. 5229—Fundamental Competitiveness Act of 1992 and H.R. 5230—American Technology and Competitiveness Act of 1992	U.S. House of Representatives		05-Aug-1992		Policy
254	Fiscal Year 1993 Technology Administration Authorization	U.S. House of Representatives		25-Feb-1992		Policy
255	The National Science Foundation	U.S. House of Representatives		25 Feb; 3 Mar 1992		Policy
256	Federal Aviation Administration's Research and Development Program	U.S. House of Representatives		Sep-1992		Policy
257	Manufacturing Research and Education	U.S. House of Representatives		12-May-1992		Policy
258	New Opportunities in High Technology Industry for Southern California	U.S. House of Representatives		11-Feb-1992		Policy
259	Policy Options for Promoting Economic Growth	U.S. House of Representatives		05-May-1992		Policy
260	American Technology Preeminence Act of 1991	102d Congress		26-Jun-1991		Policy
261	H.R. 5231—The National Competitiveness Act of 1992	U.S. House of Representatives		June 3, 4, 1992		Policy
262	New Directions for the DOE Multiprogram Laboratories—Implications for the Federal Laboratory System	U.S. House of Representatives		24-Sep-1992		Policy
263	Transfer of Technology from Federal Laboratories	U.S. House of Representatives		30-May-1991		Policy
264	The Future of the Department of Energy Laboratories	U.S. House of Representatives		09-Oct-1991		Policy
265	H.R. 4549—The Magnetic Levitation Transportation and Competitiveness Act of 1990	U.S. House of Representatives		07-Jun-1990		Policy
266	H.R. 5521—National Aeronautical Research and Competitiveness Act of 1992	U.S. House of Representatives		15-Sep-1992		Policy
267	H.R. 5343—Technical Amendments to the American Technology Preeminence Act	U.S. House of Representatives		10-Jun-1992		Policy
268	The Role of Basic Research in Economic Competitiveness	U.S. House of Representatives		20-Jun-1991		Policy
269	H.R. 4726—The Opportunities in Science and Technology Act of 1992	U.S. House of Representatives		23-Jun-1992		Policy
270	Setting Priorities in Science	U.S. House of Representatives		April 7, 8, 1992		Policy

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271	The Role of Science in Adjudicating Trade Disputes Under the North American Free Trade Agreement	U.S. House of Representatives		30-Sep-1992		Policy
272	Transfer of Technology From the Federal Laboratories	U.S. House of Representatives		03-May-1990		Policy
273	National Competitiveness Act of 1992	102d Congress		22-Jul-1992		Policy
274	Foreign Relations Authorization Act, Fiscal Years 1992 and 1993	102d Congress		03-Oct-1991		Policy
275	Omnibus Export Amendments Act of 1991	102d Congress		23-Oct-1991		Policy
276	Technology Transfer Improvements Act of 1991	102d Congress		06-Dec-1991		Policy
277	Small Business Innovation Development Amendment Act of 1992	102d Congress		09-Jun-1992		Policy
278	Small Business Innovation Development Amendment Act of 1992	102d Congress		02-Jul-1992		Policy
279	Small Business Innovation Development Amendment Act of 1992	102d Congress		07-Jul-1992		Policy
280	Trade Expansion Act of 1992	102d Congress		23-Jun-1992		Policy
281	Defense Production Act Amendments of 1991	102d Congress		25-Sep-1991		Policy
282	Defense Production Act Amendments of 1991	102d Congress		18-Sep-1991		Policy
283	International Cooperation Act of 1991	102d Congress		04-Jun-1991		Policy
284	Airbus Industrie: An Economic and Trade Perspective	U.S. House of Representatives		Mar-92		Policy
285	American Technology Preeminence Act H.R. 1989	U.S. House of Representatives		Feb 26, 27, 1991		Policy
286	The Reauthorization of the Export Administration Act	U.S. House of Representatives		Sep 24, Oct 1, 10, 17, 1991		Policy
287	Public Law 102-588	102d Congress		04-Nov-1992		Policy
288	Defense Production Act Amendments of 1992	102d Congress		05-Oct-1992		Policy
289	H.R. 1208	103d Congress		03-Mar-1993		Policy
290	H.R. 344	103d Congress		05-Jan-1993		Policy
291	H.R. 523	103d Congress		21-Jan-1993		Policy
292	H.R. 1300	103d Congress		10-Mar-1993		Policy
293	H.R. 856	103d Congress		04-Feb-1993		Policy
294	S. 450	103d Congress		25-Feb-1993		Policy
295	S. 473	103d Congress		02-Mar-1993		Policy
296	S. 4	103d Congress		21-Jan-1993		Policy
297	The DoD Drawdown: Planned Spending and Employment Cuts (Appendix A)	Logistics Management Institute		Feb-1993		Policy
298	Defense and Economy (Appendix C)	Institute for Defense Analysis		Feb-1993		Policy
299	Registration: The First Step in Defense Trade	United States Department of State		Jul-1992		Policy
300	Understanding Strategic Partnerships	Dr. Robert Aten, Technology Adminstration		17-Feb-1993	Bob Aten	Policy

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301	Science and Technology	Office of Science and Technology Policy		Feb-1993		Policy
302	Report of the Defense Production Act Title III Program (Fiscal Year 1992)	Department of Defense		Apr-1993		Policy
303	Title III Program	Department of Defense				Policy
304	Cooperative Research and Development Agreements (CRDA)	Office of Research and Technology Applications				Policy
305	What is the Federal Laboratory Consortium for Technology Transfer?					Policy
306	News Link	Federal Laboratory Consortium for Technology Transfer		Mar-1993		Policy
307	A Technology Support System for Industry and Smaller Businesses	Federal Laboratory Consortium for Technology Transfer				Policy
308	Opportunities for Cooperative R&D	Army Domestic Technology Transfer Program, U.S. Army Research Lab		31-Mar-1993		Policy
309	Air Force Domestic Technology Transfer	Air Force		Nov-1992		Policy
310	Military-Civilian Technology Transfer	HQ, Department of the Army		25-Jul-1991		Policy
311	Federal Laboratory Consortium for Technology Transfer	Federal Laboratory Consortium for Technology				Program
312	News Link	Federal Laboratory Consortium for Technology Transfer		Jan-1993		Research
313	Science Culture Canada	Industry, Science and Technology Canada				Program
314	"How To" Explore Science and Technology	Industry, Science and Technology Canada				Program
315	Strategic Technologies	Industry, Science and Technology Canada				Program
316	Industry, Science and Technology Canada—A Preliminary Study of the Competitiveness of Distribution Channels	Ernst & Young		Mar-1991		US/Canada
317	Small Business Innovation Research (SBIR)—Program Solicitation	National Science Foundation		14-Jun-1993	BDM	Program
318	Foreign Acquisition of Critical U.S. Industries: Where Should the United States Draw the Line?	Theodore H. Moran The Washington Quarterly		Spring 1993		Policy
319	Title III Reauthorization Emphasizes Dual-Use	John F. Morton, National Defense		Apr-1993		Policy
320	Thoughts on the Future of DoD Materials R&D	John E. Hove, Michael A. Rigdon, Institute for Defense Analysis		11-Jan-1993		Policy
321	Going Global—Program for Co-operation in Science and Technology with Western Europe	External Affairs and International Trade Canada		Fiscal Year 92/93		Policy
322	National Technology Initiative Summary Proceedings	U.S. Dept. of Agriculture, U.S. Dept. of Commerce, U.S. Dept. of Engery, NASA, U.S. Dept. of Transportation		Oct-1992	Len Ingber	Policy
323	The Defense Production Act of 1950			Nov-1992		Policy
324	Advanced Technology Program	National Institute of Standards and Technology				Program

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325	Capital Metals and Materials Forum			25-Feb		Policy
326	Strategic Technologies Program			Apr-1989		Program
327	The NRC/IRAP Technology Network	NRC/CNRC		Jun-1992		Program
328	Technology Inflow Program					Program
329	NRC/IRAP National Technology Network	NRC/CNRC		Jun-1992		Program
330	Technology Networking Guide International (TNGI)	Technology Liason Directorate Industry, Science and Technology Canada				Program
331	Extending the Network	External Affairs and International Trade Canada		1990		US/Canada
332	Accessing the United States Defence Market	External Affairs and International Trade Canada		1992		US/Canada
333	Strategic Technologies—An Overview	Industry, Science and Technology Canada				Program
334	Defence Research and Development Strategic Plan 1992			1992		Policy
335	Canada Scholars in Technology	Industry, Science and Technology Canada		1993		Program
336	Industrial and Regional Benefits for the Canadian Economy	Industry, Science and Technology Canada				Policy
337	Investment Canada: Helping Investment Happen	Investment Canada				Program
338	Suppliers' Guide—Doing Business with Supply and Services Canada	Supply and Services Canada		1992		Policy
339	Canada's Aerospace Industry—A Capability Guide	Aviation & Aerospace Magazine		1991		Program
340	International Traffic in Arms Regulation (ITAR) (22 CFR 120-130)	United States Department of State				Policy
341	Competing Under Free Trade	The Canadian Manufacturers' Association				Policy
342	Description of NCAT Cooperative Activities for Presentation to the Capital Metals & Materials Forum on "U.S. Advanced Technology Partnerships"	National Center for Advanced Technologies		25-Feb-1993		Program
343	Canadian Defence Policy	National Defence		Apr-1992		Policy
344	The Industrial Cooperative Program	Canadian International Development Agency				Program
345	Advanced Manufacturing Technologies	Industry, Science and Technology Canada				Program
346	Exporting the Competitiveness—Ten Steps for Small Business	Industry, Science and Technology Canada		Nov-1992		Program
347	Adjusting to the Drawdown	DoD		31-Dec-1992		Policy
348	Annex 3—The NADIB and Industry	NADIBO				US/Canada
349	Analysis of Defense Conversion Legislation (Appendix I)	Thomas Alison, Peter Almquist		Feb-1993		Policy
350	The Department of Defense Materials and Structures Science and Technology Programs (briefing)	Jerome Persh		Jan-1993		Funding/ Congressional
351	Program Information Package for Defense Technology Conversion, Reinvestment, and Transition Assistance	ARPA		10-Mar-1993		Policy
352	Annex 2—The NADIB and Industry	NADIBO				US/Canada
353	Technology Networking Guide Canada (TNGI)	Technology Liason Directorate Industry, Science and Technology Canada				Program

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ID #	Document Title	Author	pg #	Document Date	Source of Document	Topic *
354	Commentary	C.D. Howe Institute		Oct-1992		Policy
355	North American Free Grade Agreement	Canada		Aug-1992		Policy
356	The NAFTA Manual	Canada		Aug-1992		Policy
357	Science and Technology	Office of Science and Technology Policy		17-Mar-1992		Policy
358	The Impact of Reduced Defense Spending on US Defense Contractors (Appendix D0	Thomas Zoretich, David Rolley, Gregory Farrell, George Gerliczy		Feb-1993		Policy
359	Defense Drawdown: Financial Overview and Strategies for the Top 25 Prime Contractors (Appendix E)	David Pratt		Feb-1993		Policy
360	Impacts of Defense Spending Cuts on Industry Sectors, Occupational Groups, and Localities (Appendix F)	Earl Wingrove III, Donna Peterson, Scott Dahne		Feb-1993		Policy
361	A Method for Estimating Local Impacts of Cuts in Defense Spending (Appendix H)	Thomas Muller, Robert Hutchinson, Debra Goldstone, William Moore		Jan-1993		Policy
362	Military Personnel: End Strength, Separations, Transition Programs and Downsizing Strategy (Appendix J)	Albert Schroetel		Feb-1993		Policy
363	Civilian Personnel: End Strength, Separations, Transition Programs and Downsizing Strategy (Appendix K)	Sherry Holliman		Feb-1993		Policy
364	Summary of Regional Hearings (Appendix M)	Andrew Gilmour, Kristen Sheehan		Feb-1993		Policy
365	Defense Conversion Bibliography (Appendix N)	Andrew Gilmour, Kristen Sheehan		Feb-1993		Policy
366	The Service Industries Studies Program	Industry, Science and Technology Canada				Program
367	Compendium of Programs to Assist the Transition (Appendix G)	R. Hutchinson, L Schwartz, J. Cable, R. Hansen, R. Cook, P. Kostuik, G. Kelley		Feb-1993		Policy
368	Under-Funding the Future: Canada's Cost of Capital Problem	National Advisory Board on Science and Technology		17-Feb-1992		Funding
369	Corporate Plan 1991 - 1992	Industry, Science and Technology Canada		14-Jun-1991		Policy
370	Importing Goods into Canada? Documentation Simplified	Revenue Canada Customs and Excise		Jan-1993		Policy
371	Annual Report 1990-1991	Industry, Science and Technology Canada				Policy
372	NEBS (New Exporters to Border States)	External Affairs and International Trade Canada				Program
373	NEXUS (New Exporters to US South)	External Affairs and International Trade Canada				Program
374	Exploring the Joint Venture Option in Canada	Investment Canada		Jun-1909		Program
375	Statement on Competitiveness	Report of the National Advisory Board on Science and Technology		Mar-1991		Policy
376	Canadian Attitudes Toward Competitiveness and Entrepreneurship	Industry, Science and Technology Canada		Apr-1992		Policy
377	Canada's Business Culture	Industry, Science and Technology Canada				Policy
378	National Technology Transfer Center (information)	National Technology Transfer Center			Diane Hedinger	Program
379	From War to Peace: A History of Past Conversions (Appendix B)	William Stewart II		Jan-1993		Policy

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ID #	Document Title	Author	pg #	Document Date	Source of Document	Topic *
380	ISTC Programs and Services	Industry, Science and Technology Canada		Spring 1992		Program
381	Research Interests of the Air Force Office of Scientific Research	Bolling Air Force Base		01-Oct-1992		Research
382	Program for Export Market Development—PEMD Handbook	External Affairs and International Trade Canada		Jun-1992		Program
383	Overview—The North American Free Trade Agreement					Program
384	United States Department of Commerce News	Department of Commerce		12-Aug-1992		Policy
385	Capital Metals and Materials Forum					Program
386	Bridging the Maze	National Technology Transfer Center			Katherine Pavlock	Program
387	GreatLakes Composites Consortium (information)	GreatLakes Composites Consortium			BDM	Program
388	Textron Specialty Materials (information)	Textron Specialty Materials			BDM	Program
389	Advanced Materials Agenda for the Clinton Administration and the 103rd Congress	SACMA		Mar-1993		Policy
390	Suppliers of Advanced Composite Materials Association (information)	SACMA				Program
391	Code of Federal Regulations	National Archives and Records Administration		Apr-1991		Policy
392	Continuous Fiber-Reinforced Titanium Aluminide Composites	R.A. MacKay, P.K. Brindley, F.H. Froes, JOM		May-1991		Products
393	US Market Study for Continuous Fiber Metal Matrix Composites	Peter Schwarzkopf, 3M			Chauncey Martin	General
394	AIA Report	AIA				General
395	ManTech Project Book 1992	ManTech		1992		Program
396	Materials Division—Program Summary FY 1992	Office of Naval Research		Aug-1992		Program
397	Composite Materials Handbook	Mel Schwartz		2nd edition	BDM	General
398	Advanced Materials Processing: The Federal Program in Materials Science and Technology	FCCSET Committee on Industry and Technology		1993		Program
399	Critical Technologies	U.S. House of Representatives		21-Feb-1992		Policy
400	Country Reports on Economic Policy and Trade Practices	U.S. House of Representatives		Mar-1992		Policy
401	Congressional Workshop on Advanced Materials Research and Development	U.S. House of Representatives		Jun-1985		Policy
402	Science, Technology, and American Diplomacy 1992	Committee on Science, Space and Technology		May-1992		Policy
403	The Defense Industrial Research Program	National Defence				Program
404	Renewing US Science Policy: Private Sector Views	U.S. House of Representatives		24-Sep-1992		Policy
405	Investment Incentives and Capital Costs	U.S. House of Representatives		03-Mar-1993		Policy
406	Administration and Enforcement of US Export Control Programs	U.S. House of Representatives		April 19 and May 1, 1991		Policy
407	US Needs to Effectively Compete in High-Technology Markets	U.S. House of Representatives		28-Aug-1992		Policy
408	Is Science for Sale?: Transferring Technology from Universities to Foreign Corporations	Committee on Government Operations		1992		Policy

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409	Omnibus Export Amendments Act of 1992	U.S. House of Representatives		Oct-1992		Policy
410	Non-Ferrous Semi-Fabricated Metal Products	Industry, Science and Technology Canada				Products
411	NDHQ Policy Directive P 7/85	DND		18-Dec-1985		Policy
412	Navy Offices of Research and Technology Applications (ORTA)	Navy IR&D Office				Policy
413	Technology Partnership Program Canadian Company Profiles	Canadian Embassy				Policy
414	The NRC/IRAP Technology Network	National Research Council Canada		Jun-1992		Program
415	US Advanced Technology Partnership	Mr. William G. Morin, Capital Metals and Materials Forum		25-Feb-1993		Policy
416	Towards Competitiveness: Initiatives and Progress	Industry, Science and Technology Canada		Aug-1992		Program
417	Description of NCAT Cooperative Activities for Presentation to the Capital Metals & Materials Forum on "US Advanced Technology Partnership"	National Center for Advanced Technologies		25-Feb-1993		Program
418	Defense Trade Advisory Group	Defense Trade News		Oct-1992		Program
419	Partnership of Concerns	Defense Trade News		Oct-1992		Program
420	Munitions Control Newsletter	Department of State		Sep-1979		Policy
421	US Exports: Strategic Technology Controls	The DISAM Journal		Fall 1991		Policy
422	Antitrust—A Secret Trade Weapon?	National Journal		08-Feb-1992		Policy
423	Prosperity Through Innovation	Task Force on Challenges in Science, Technology and Related Skils				Program
424	Committee on Technology Acquisition and Diffusion	National Advisory Board on Science and Technology		Sep-1992		Policy
425	Science an Technology, Innovation and National Prosperity: The Need for Canada to Change Course	National Advisory Board on Science and Technology		Apr-1991		Policy
426	Government Committee	National Advisory Board on Science and		Feb-1988		Policy
427	Prosperity Through Competitiveness	Government of Canada		Jun-1991		Program
428	Integrating Defense into the National Technology and Industrial Base	Richard Van Atta		31-Mar-1993		Policy/Program/ Research
429	The Government's Role in Fostering Technology Development	Richard Van Atta		07-Apr-1992		Policy/Program/ Research
430	Utah Trip Report/Notes: G. Levy, Dr. Schuster, Dr. Harrigan, B. Norris, C.A. Anderson	Dave Fox, BDM		2-4 Feb 1993	BDM	General
431	The New Materials Society—Challenges and Opportunities Vol I	US Department of the Interior•Bureau of Mines		1990	William J. McDonough	Policy
432	The New Materials Society—Challenges and Opportunities Vol II	US Department of the Interior•Bureau of Mines		1990	William J. McDonough	Product
433	The New Materials Society—Challenges and Opportunities Vol III	US Department of the Interior•Bureau of Mines		1990	William J. McDonough	Product

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434	Advanced Materials	US Department of the Interior•Bureau of Mines		May-1993	William J. McDonough	Product
435	National Industrial Base Challenges	National Defense		Feb-1993		Policy
436	3M Meeting Notes	Mike Brown			BDM	General
437	MMC Update: East Asia & Western Europe	Bill Duggleby				General
438	California Trip Report	Dave Fox			BDM	General
439	Northeast Trip Report	Don Higgins			BDM	General
440	ASME Trip Report	Dave Fox			BDM	General
441	Lanxide Notes and Material	Dave Fox			BDM	General
442	Textron Notes	Dave Fox			BDM	General
443	Metal Matrix Composites in Japan	A. Mortensen, M. Koczk, S. Fishman		1993	Michael Rigdon, IDA	General
444	Prosperity Consultations Fabricated Materials: Gateway to the New Economy			Jun-1992		Policy
445	Prosperity Consultations Minerals and Metals Sector			May-1992		Policy

* 1. Products (including processes and manufacturing)
2. Policy
3. US/Canada
4. Research
5. Funding/Congressional
6. Program
7. General

Appendix E - Site Visit Selection Criteria

Site visit selection criteria is geared towards covering a broad spectrum of the MMC industry. Representatives from academia, industry, and government will need to be interviewed to provide a thorough overview of current activity within Canada and the U.S.

<u>Criteria for Academia</u>

Area of Research and Development
Involvement with University Research Initiative
Level of Funding
Length of Time Involved in Study of MMC Area
Joint Activity with Government
Joint Activity with Industry

<u>Criteria for Government</u>

Level of Interest in MMC Market (R&D, Applications, Critical Technologies Oversight, Project Reliance, etc.)
Policy/Regulatory Office
Research Facility
Program Site
Involvement with Military/NASA/Government Programs
Involvement With Standards
Involvement with Testing
Research and Development Funds Available
Joint Activity With Industry
Joint Activity With Academia

<u>Criteria for Industry</u>

Canadian Company
U.S. Company
Joint Activity with Government
Joint Activity with Academia
Joint Activity with Industry
Joint International Activity
Involvement with Commercial Sector
Involvement with Military Sector
Market Niche
Production Capabilities
Level of Activity
Stage of Process Development
Stage of Product Development
Unique Capability
Number of Applications
Dual Use Applications
Demand/Volume
Future Potential of Evolving Applications
Potential New Markets
Potential Demand
Expertise
Size

Experience with MMC technology
Funds Available for MMC Research and Development
Experience With Standards
Experience With Testing
Encounters With Barriers, Obstacles, and Facilitators
Involvement With Standards
Involvement With Policy Formulation/Recommendations
Involvement with Small Business Innovative Research Initiative

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	Institution	Program / Areas of Research
East Asia		
Japan	Art Metal Manufacturing Co.	• Manufacture of automative components
Japan	Chiba University Manufacturing Co.	• Wear of SiC whisker reinforced Al
Japan	Daido Institute of Technology	• SiC whisker reinforced Al
Japan	Daido Steel	• Plasma deposition of Ni-based functionally graded materials
Japan	Fuji Heavy Industries	• Solid state processing, including roll diffusion bonding
Japan	GIRI Kyushu	• Pressure infiltration of reinforced metals (in collaboration with Kyushu University) • Pressure casting, microstructure, and strength of carbon fiber reinforced aluminum, including hybrid composites (in collaboration with Nagasaki University for Honda Prelude™ model) • Powder metallurgy Al alloy/alumina-zirconia-silica particle retainer ring (temporarily mass produced) • Pressure cast stainless steel filament reinforced aluminum connecting rod (temporarily mass produced) • Various MMC prototypes: Al-MMC piston pin, Mg-MMC piston • Squeeze cast carbon fiber reinforced Mg
Japan	GIRI Nagoya	• Pressure infiltration and powder metallurgical processing of whisker and fiber reinforced Al • Superplasticity and deformation of reinforced metals (including collaboration with Daido Institute of Technology and Toyo Aluminum) • Superplasticity in P/M particle reinforced Al (in collaboration with Osaka University) • Compocasting of Al matrix composites (in collaboration with Matsushita and Nagoya University) • TiAl matrix SiC reinforced composites • Niobium matrix/NbSi2 and NbAl3, as well as Al matrix/Al2O3 composites
Japan	GIRI Osaka	• Fiber coating by VD • Interface and strength of coated carbon fiber reinforced Al wires • MoSi2 TiAl composites
Japan	GIRI Tohoku Manufacturing Co.	• Functionally graded TiB2-Ou by self propagating high temperature synthesis • SiC/AlN reinforced Mo
Japan	Hiroshima University	• Pressure infiltration and microstructural evolution of reinforced metals • Mechancal behavior of fiber reinforced metals • Intermetallic matrix composites by reactive infiltration • In-site eutectic composites
Japan	Hiroshima West Prefectoral Industrial Research Institute	• Postassium titanate whisker reinforced Al (in collaboration with Hiroshima University)
Japan	Hitachi Ltd.	• Copper-carbon composites for electrical applications
Japan	Hokkaido University	• Cyclic deformation of fiber reinforced metals • Functionally graded Ni or Al matrix composites for joining produced by pressureless sintering (in collaboration with Nisshin Steel)

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	Institution	Program / Areas of Research
Japan	Honda	• Pressure cast aluminum engine block featuring alumina+carbon short fiber reinforced cylinder linears (mass produced for Honda Prelude™ model) • Powder metallurgy Al alloy/alumina-zirconia-silica particle retainer ring (temporarily mass produced) • Pressure cast stainless steel filament reinforced aluminum connecting rod (temorarily mass produced) • Various MMC prototypes: Al-MMC piston pin, Mg-MMC piston. • Squeeze cast carbon fiber reinforced Mg
Japan	Industrial Products Research Institute	• Fabrication of C/Al composites by chemical vapor deposition
Japan	Industrial Research Institute of the Kanagawa Prefecture	• Squeeze cast C and SiC fiber or whisker reinforced Al composites
Japan	Ishikawajima-Harima Heavy Industries	• Manufacturing methods and forming/metal working techniques for fiber reinforced metals (W-fiber reinforced superalloy turbine blades by hot isostatic pressing, Ti-matrix composites), continuous B/Al matrix composites • Niobium matrix/Nb-Si2 and NbAl3, as well as Al matrix/Al2O3 composites
Japan	Kawasaki Heavy Industries	• Alumina fiber reinforced aluminum turbo-jet engine impeller • TiAl matrix SiC and MoSi2 reinforced composites
Japan	Kobe Steel	• SiC whisker reinforced aluminum by powder forging, HIP or pressure casting, deformation processing of these, including parts for automotive engines, bicycle frame and optical telescope support. • SiC filament reinforced Ti by P/M • Spray deposition of SiC/Al
Japan	Kyoto University	• Fracture and strength of fiber reinforced metals, in particular as influenced by interfacial coatings and internal flaws
Japan	Kyushu Institute of Technology	• Wetting of ceramics by metals (in collaboration with Kyushu University)
Japan	Kyushu University	• Micromechanics of MMCs • In-situ eutectic composites • Wetting of ceramics by metals
Japan	Mechanical Engineering Lab., Agency of Industrial Science and Technology	• Compocasting of carbide reinforced Cu (in collaboration with Sumitomo Metal Mining Co.) • Fatigue of fiber reinforced Al
Japan	Mitsubishi Aluminum Manufacturing Co.	• Pressure infiltrated and extruded SiC whisker/Al • Paritcle reinforced aluminum rear shock absorber cylinder for a Yamaha motorcycle • Reinforced aluminum alloy for internal combustion engine part • NiCr matrix ZrO2 reinforced composites
Japan	Mitsubishi Chemical Industries	• Infiltration of fiber reinforced aluminum

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
Japan	Mitsubishi Heavy Industries	• Pressure-infiltrated and extruded SiC whisker/Al alloys • Consolidation of C/Al and Nicalon/Al preform wires manufactured by Toray and Nippon Carbon, respectively • Ti matrix composites by HIPing • SiC fiber reinforced Ti TiAl • Alumina and thoria coatings for SiC monofilaments
Japan	Mitsubishi Kasei	• Produces graphite/aluminum (Gr/Al) composites
Japan	Mitsubishi Materials	• War, cutting tool applications and aluminum P/M composites
Japan	Mitsui Mining Company, Ltd.	• Alumina fiber reinforced aluminum parts for various applications
Japan	Miyagi National College of Technology	• Ceramic reinforced stainless steel by mechanically coating the metal with ceramic and sintering
Japan	Nagoya Municipal Industrial Research Institute	• Wet corrosion of alumina fiber reinforced Al-Si
Japan	Nagoya University of Technology	• Squeeze casting of C/Mg composites
Japan	National Defense Academy	• Squeeze cast whisker reinforced Al • Microstructure and properties of reinforced Al and Ni3Al
Japan	National Space Development Agency of Japan (NASDA)	• Processing of particle and hybrid fiber reinforced metals
Japan	Nihon University, Narashino	• Superplastic infiltrated whisker reinforced Zn-22Al • Hot extrusion of SiC whisker reinforced Mg
Japan	Niihama National College of Technology and Tokushima University Manufacturing Co.	• X-ray analysis of MMCs
Japan	Nikkiso	• Graphite whisker reinforced Al alloys by vapor deposition and hot-pressing as well as squeeze casting
Japan	Nippon Carbon	• Infiltrated SiC fiber reinforced aluminum tows • Face insert for golf clubs (commercial production)
Japan	Nippon Light Metals	• Agglomerated fiber reinforced aluminum
Japan	Nippon Steel	• Squeeze casting of fiber reinforced aluminum • Compocasting of particle reinforced aluminum • Functionally graded NiCr/ZrO2 composites by low pressure plasma spraying
Japan	Nippondenso	• Whisker-reinforced Cu • Tribological materials: SiC/WS2/Al
Japan	Nissan	• SiC/Al connecting rods • Directed metal oxidation • Magnesuim matrix alumina reinforced and aluminum matrix SiC whisker reinforced composites

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
Japan	Nkk	• Cast whisker and short fiber reinforced Al • Partially stabilized ZrO2/Ni and TiB2/Cu functionally graded structures • Ni/TiC composites by self-propagating high temperature synthesis
Japan	NRIM Tokyo	• Space processing of MMCs • Spray casting of MMCs • Non destructive evaluation, fatigue and fracture mechanisms of metal matrix composites • Wear of reinforced metals • Metal-metal composites • Ni and superalloy matrix composites • SiC fiber reinforced Al and Ti alloys • Wetting of ceramics by metals • Ni base alloy/ZrO2 functionally graded materials by plasma spraying • Functionally graded materials of Cr, Ti and Si and their respective carbides and nitrides produced by physical vapor deposition
Japan	NRIM Tsukuba	• Titanium and Ti3Al reinforced with submicron dispersion of oxides and carbides by powder metallurgy • Particle reinforced Ti alloys by reactive powder blending and powder metallurgy (in collaboration with Nippon Steel)
Japan	Okayama University of Science	• Mechanical behavior of whisker reinforced Al
Japan	Osaka University	• Wetting of ceramics by metal (in collaboration with other institutions, including Kanazawa Institute of Technology, Toyama College of Technology, Kinki University) • Functionally graded TiC-Ni by self propagating high temperature synthesis • Database compilation for high temperature composites for severe environments (Industiral Products Research Institute of the Unviersity of Osaka)
Japan	Rheo-Technology, Ltd.	• Compocasting
Japan	Science University of Tokyo	• Interface reactions • Physical properties of MMCs
Japan	Shikoku Chemicals Corporation	• Al-B-O whisker reinforced Alruded SiC whisker A/I
Japan	Showa Aluminum	• Mechanically alloyed SiC/Al and alumina/Al with particle sizes <1 µm
Japan	Showa Denko Company, Ltd.	• Alumina, graphite or silicon nitride particle reinforced Al alloys by pressing and sintering, including hypereutectic Al-Si
Japan	Sumitomo Chemical Co., Ltd.	• Alumina-silica fiber reinforced aluminum: squeeze casting, heat treatment and interface tailoring by chemical means (discontinued) • Fiber reinforced Zn-Al and Zn-Mg matrix composites
Japan	Sumitomo Metals Industries, Ltd.	• SiC whicker reinforced 2014 by squeeze casting or powder metallurgy • Ti-based MMC coatings • Ceramic particle reinforced superalloys

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
Japan	Suzuki Motor Co. (in collaboration with Agency of Industrial Science and Technology of Tokyo)	• Stir-casting process for production of hypereutectic Al-Si alloy matrix composites
Japan	Toho Beslon	• Ion-plated C/Al tape (possibly discontinued) structures
Japan	Tohoku University	• Characterization of Si-Ti-C-O fiber/Al • Elastic constants of MMCs • Zro2/stainless steel functionally graded composite structures by powder metallurgy
Japan	Tokai Carbon Co	• P/M and squeeze cast SiC whisker/Al
Japan	Tokai University	• Squeeze casting of SiC whisker/Al composites
Japan	Tokyo Institute of Technology	• Micromechanics, physical metallurgy and processing of reinforced metals • Eutectic in-situ MMCs • Wetting and bonding of metals to fibers interfacial reactivity
	Tokyo Medical and Dental University	• In-situ composites for dental applications
Japan	Tokyo Metropolitan Industrial Technical Institute	• Wettability of SiC and other reinforcement materials by the sessile drop method and dipping experiments
Japan	Tokyo Metropolitan University	• Solid state fabrication of SiC/Al by superplastic deformation of the matrix
Japan	Tokyo University	• Micromechanics and fracture of reinforced metals • Processing of metal matrix composites • Interfacial reactivity and strength of fiber reinforced metals, including C/Al, B/Al, SiC/Ti. • Processing of PCS-SiC/Al composites and properites, including radiation damage in SiC/Al (in collaboration with Nippon Carbon Co.) • Compocasting, thixoforming and related processes • Fatigue of MMCs • Monograph on metal matrix composites
Japan Japan	Tokyo University of Agriculture and Technology	• In-situ eutectic composites • Aluminum/ceramic particle composites by mechanical alloying (in collaboration with Yokohama National University)
Japan	Toray	• C fiber-reinforced Al by squeeze casting • C/Al preform wires by the TiB process • C fiber-reinforced Cu and Sn • Casting of MMCs
Japan	Toshiba	• Fiber and whisker reinforced 6061 • Fabrication of a whisker reinforced aluminum bolt • W fiber reinforced FeCrAlY
Japan	Toshiba Machine Co., Ltd.	• Stir-casting composite materials using an electromagnetic stirring apparatus
Japan	Toyo Aluminum Company, Ltd.	• Whisker reinforced Al by ball milling and powder metallurgy

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	Institution	Program / Areas of Research
Japan	Toyoda Loom Company	• Oriented fiber preform processing • Pressure cast oriented short fiber and whisker reinforced aluminum
Japan	Toyohashi University of Technology	• Pressure-cast SiC whisker/aluminum • Fracture of particle reinforced Al
Japan	Toyota Central R&D Laboratories	• Squeeze cast fiber reinforced aluminum • Invention and development of hybird fiber reinforced metals • NDE of MMCs
Japan	Toyota Motor Corporation	• Squeeze cast short fiber reinforced aluminum and Al-Al3Ni pistons (mass produced) • Plasma sprayed aluminum matrix composite on brake disk and drums surfaces • Duralcan™ brake rotors
Japan	Toyota Technological Institute	• Centrifugal infiltration of fiber preforms with aluminum • Spray casting of whisker reinforced aluminum • Extrusion of reinforced alumimum • Steel fiber reinforced Al
Japan	TYK Corporation	• "Metacs™" SiC particle reinforced Al by powder extrusion and zirconia reinforced Mo
Japan	Ube Industries	• Squeeze cast Tyranno™ Si-Ti-C-O fiber/Al and silicon nitride whisker/Al • R&D on hybrid fiber composites in collaboration with Toyota Central R&D Lab. • Plasma sprayed Al/Tyranno™ Si-Ti-C-O fiber tape • Fiber reinforced An-Al and Zn-Mg matrix composites
Japan	Waseda University	• Pressure infiltration of reinforced metals • Wetting of ceramics by metals
Japan	Yamagata University and Yokohama National University	• High-temperature behavior of fiber reinforced metals
South Korea	Dong Suh Industrial Co.	• Potassium Titanate Whisker Reinforced Aluminum (in collaboration with Inha University and Inchon)
South Korea	Hanyang University	• Wettability of Alumina/Aluminum Composites After Silicon Dioxide Treatment
South Korea	Inchon	• Potassium Titanate Whisker Reinforced Aluminum (in collaboration with Inha University and Dong Suh Industrial Co.)
South Korea	Inha University	• Potassium Titanate Whisker Reinforced Aluminum (in collaboration with Inchon and Dong Suh Industrial Co.)
South Korea	Yonsei University	• Studying Stell Fiber Reinforced Aluminum, Interfacial Reactions, Beta Silicon Carbide, and Testing of Carbon Fiber Reinforcements
Europe		
Belgium	Universite Catholique De Louvain La Neuve	• Ceramic/Metal Bonding by HIP
Federal Republic of Germany	Deutsche Forschung Und Versuchsanstalt Fur Luft Und Raumfahrt	• Development of Advanced Carbon-Magnesium Metal Matrix Compsoites by Applying the Semi-Liquid Phase Infiltration

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
Federal Republic of Germany	Deutsche Forschungsanstalt	• Prepregs and Composite Materials Made of Aluminum Alloys Reinforced With Continuous Fibres
Federal Republic of Germany	Didier Werke AG	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
Federal Republic of Germany	DLR	• Control of Fibre/Matrix Interactions in SiC/Ti Metal Matrix Composites
Federal Republic of Germany	Fraunhofer Gesellschaft	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
Federal Republic of Germany	Kolbenschmidt AG	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
Federal Republic of Germany	Bundesanstalt Fur Materialforschung Und	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Temperatures with Improved Creep Resistance, Chemical Stability, and Reliability
Federal Republic of Germany	Hamburger Institut Fuer Technologiefoerderung	• Fabrication and Joining of Graded Cermets by a Technique of Metal Infiltration
Federal Republic of Germany	Institut Fur Chemische Technik Karlsruhe Universitat	• Ceramic-Ceramic Composite Materials-A Modelling of the CVI Process
Federal Republic of Germany	Mahle GMBH	• Industrial Production Process for Silicon-Carbide Whiskers for Composite Materials Reinforcement
Federal Republic of Germany	MAN	• Reliability, Thermomechanical and Fatigue Behavior of High-Temperature Structural Fibrous
Federal Republic of Germany	Max-Planck-Institut, Stuttgart	• Organometallic Precursors for the Preparation of High-Performance Non-Oxide Ceramics and Ceramic-Matrix Composites
Federal Republic of Germany	Messerschmitt-Bolkow-Blohm GMBH	• Low-Cost MMC Made by Spray Deposition
Federal Republic of Germany	Otto Fuchs Metallwerke	• Low-Cost MMC Made by Spray Deposition
Federal Republic of Germany	Sintec Kermik GMBH	• Development Technology to Produce 2-and 3-D Carbon Reinforced Graphite Structures High-Strength and High-Temperature Application
Federal Republic of Germany	United Nationls Economic Commission for Europe (IKE), Stuttgart	• Ceramic Composites
Federal Republic of Germany	Kolbenschmidt Aktiengesellschaft	• Making Saffil Reinforced Aluminum Pistons for Diesel Trucks by Squeeze Casting
France	Aerospatiale, Les Mureaux	• Low-Cost MMC Made by Spray Deposition • Development of Advanced Carbon-Magnesium Metal Matrix Composites by Applying the Semi-Liquid Phase Infiltration • Prepregs and Composite Materials Made of Aluminum Alloys Reinforced With Continuous Fibres
France	Airbus Industrie	• Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
France	Armines/Ecole Des Mines De Paris	• Ceramic/Metal Bonding by HIP
France	ATOCHEM	• Organometallic Precursors for the Preparation of High-Performance Non-Oxide Ceramics and Ceramic-Matrix Composites
France	BROCHIER SA	• Organometallic Precursors for the Preparation of High-Performance Non-Oxide Ceramics and Ceramic-Matrix Composites
France	CEA/CEN Saclay, Gif-Sur-Yvette	• Ceramic/Metal Bonding by HIP
France	Ceramiques Techniques Desmarquest	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
France	Chimie Du Solide Du CNRS	• Prepregs and Composite Materials Made of Aluminum Alloys Reinforced With Continuous Fibres
France	Ecole Central de Paris	• Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
France	I Caen	• Ceramic Composites
France	I.N.P.G. Gernoble	• Industrial Production Process for Silicon-Carbide Whiskers for Composite Materials Reinforcement
France	Insa	• Low-Cost MMC Made by Spray Deposition
France	Institut National Des Sciences Appliquees	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
France	Institut National Polytechnique De Grenoble	• Assessment of Semi-Solid State Forming of Aluminium Metal Matrix Composites
France	Institut Nationale des Sciences Appliques-Lyon	• Reliability, Thermomechanical and Fatigue Behavior of High-Temperature Structural Fibrous
France	ONERA	• Control of Fibre/Matrix Interactions in SiC/Ti Metal Matrix Composites • Development of Advanced Carbon-Magnesium Metal Matrix Composites by Applying the Semi-Liquid Phase Infiltration
France	Pechiney Electrometallurgic	• Industrial Production Process for Silicon-Carbide Whiskers for Composite Materials Reinforcement • Low-Cost MMC Made by Spray Deposition
France	Renault	• Optimization of Ceramic Fibre Reinforced Aluminum Alloys
France	Saint Gobain Recherche, Aubervilliers	• Comparison of Short Fibre & Particulate Method for Reinforcement of Glass-Ceramic Materials
France	Societe Europeanne De Propulsion	• Reliability, Thermomechanical and Fatigue Behavior of High-Temperature Structural Fibrous
France	Pechiney	• Cast Light Alloy Matrix Composites-Assessment of the Rheocasting Route
France	Universite De Bordeaux	• Ceramic-Ceramic Composite Materials-A Modelling of the CVI Process • Prepregs and Composite Materials Made of Aluminum Alloys Reinforced With Continuous Fibres
France	Vertrotex International	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
Ireland	University of Dublin	• Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance
Ireland	University of Limerick	• Improved High-Temperature Corrosion-Resistant Silicon Nitride, Silicon Carbide Composites
Italy	Agusta S.P.A	• Development of Fibre Reinforced Aluminium Metal Matrix Composites for Applications in Aerospace Primary Components Using Powder Metallurgy Techniques • Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
Italy	Aluminia Spa Novara	• Development of Fibre Reinforced Aluminium Metal Matrix Composites for Applications in Aerospace Primary Components Using Powder Metallurgy Techniques
Netherlands	Delft University of Technology	• Assessment of Semi-Solid State Forming of Aluminium Metal Matrix Composites
Netherlands	National Aerospace Lab NLR	• Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
Netherlands	Technische Universiteit Delft	• Development of Fibre Reinforced Aluminium Metal Matrix Composites for Applications in Aerospace Primary Components Using Powder Metallurgy Techniques
Norway	Hydro Aluminium	• Optimization of Ceramic Fibre Reinforced Aluminum Alloys
Norway	Raufoss A/S	• Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
Norway	Senter for Industriforskning	• Optimization of Ceramic Fibre Reinforced Aluminum Alloys

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
Portugal	Laboratorio Nacional De Engenharia E Tecnologia Industrial (LNETI)	• Improved Aluminium Alloy Matrix Composites Through Microstructural Control of the Processing and Fabrication Routes • Low-Cost MMC Made by Spray Deposition
Portugal	Universidade De Porto	• Industrial Production Process for Silicon-Carbide Whiskers for Composite Materials Reinforcement • Optimization of Ceramic Fibre Reinforced Aluminum Alloys
Spain	Ceramicas Tenacess SA	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
Spain	Instituto Ceramica Y Vidrio	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
Spain	Instituto Nacional De Tecnica Centre De Aerospacial, Madrid E	• Cast Light Alloy Matrix Composites-Assessment of the Rheocasting Route
Spain	Jose A. Lombia Camina SA	• Development of Ceramic and Ceramic-Composite Materials for Structural Applications at High-Termperatures with Improved Creep Resistance, Chemical Stability and Reliability
Spain	Politecnico Universidad Madrid	• Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance
Spain	Streesceit	• Novel Metal Matrix Composites Based on HyperEutectic Aluminum/Silicon Alloys
United Kingdom	AEA-Harwell	• Control of Fibre/Matrix Interactions in SiC/Ti Metal Matrix Composites
United Kingdom	Birmingham University	• Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance
United Kingdom	BP Advanced Composites, Ltd.	• Control of Fibre/Matrix Interactions in SiC/Ti Metal Matrix Composites
United Kingdom	British Aerospace	• Low-Cost MMC Made by Spray Deposition
United Kingdom	British Alcan	• Low-Cost MMC Made by Spray Deposition
United Kingdom	British Ceramic Research Ltd.	• Fabrication and Joining of Graded Cermets by a Technique of Metal Infiltration
United Kingdom	Carborundum, Sale	• Development of Fibre Reinforced Aluminium Metal Matrix Composites for Applications in Aerospace Primary Components Using Powder Metallurgy Techniques
United Kingdom	Fairey Tecramics, Ltd.	• Organometallic Precursors for the Preparation of High-Performance Non-Oxide Ceramics and Ceramic-Matrix Composites
United Kingdom	GEC Alsthom Ltd.	• Comparison of Short Fibre & Particulate Method for Reinforcement of Glass-Ceramic Materials
United Kingdom	Hi-Tech Metals R&D., Ltd.	• Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
United Kingdom	ICI Advanced Materials	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
United Kingdom	Imperial College	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
United Kingdom	Johnson Matthey Techn. Centre	• Metal Reinforced Ceramics
United Kingdom	Lucas Automotive, Ltd.	• Novel Metal Matrix Composites Based on HyperEutectic Aluminum/Silicon Alloys
United Kingdom	New Metals & Chemicals, Ltd.	• Development Technology to Produce 2-and 3-D Carbon Reinforced Graphite Structures High-Strength and High-Temperature Application
United Kingdom	Newcastle-Upon-Tyne Polytechnic	• Improved High-Temperature Corrosion-Resistant Silicon Nitride, Silicon Carbide Composites
United Kingdom	Non-Ferrous Technology	• Joining and Precision Casting of MMCs
United Kingdom	Osprey Metals, Ltd.	• Novel Metal Matrix Composites Based on HyperEutectic Aluminum/Silicon Alloys

Appendix F - Domestic and Foreign MMC Marketplace

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
United Kingdom	Oxford University	• Innovative Manufacturing Design & Assessment of Aluminium Matrix Composites for High-Temperature Performance
United Kingdom	Pera Consulting Firm	• High Speed Machine Tools
United Kingdom	Ricardo Consulting Eng., Ltd.	• Development of Novel Automotive Piston/Rod Components & Aerospace Gearboxes from Long Fibre/Metal Matrix Composites
United Kingdom	University of Loughborough	• Development Technology to Produce 2-and 3-D Carbon Reinforced Graphite Structures High-Strength and High-Temperature Application
United Kingdom	University of Manchester Insititute of Science and Technology	• Ceramic Composites
United Kingdom	University of Sheffield	• Novel Metal Matrix Composites Based on HyperEutectic Aluminum/Silicon Alloys
United Kingdom	University of Southampton	• Squeeze Casting of Light Alloys and Metal Matrix Composites-Mechanical Property Evaluation
United Kingdom	University of Strathclyde	• Improved Aluminium Alloy Matrix Composites Through Microstructural Control of the Processing and Fabrication Routes
United Kingdom	University of Surrey	• Optimization of Ceramic Fibre Reinforced Aluminum Alloys
United Kingdom	Welding Institute	• Joining and Precision Casting of MMCs
North America		
Canada	Alcan International, Ltd.	• Supporting Development of Al/Li MMCs at its British Research Lab • Low-Cost MMC Made by Spray Deposition • Produce Aluminum Based MMC with 20% Silicon Carbide Reinforcement
Canada	Ceramics Kingston Ceramiques, Inc.	• Powder Metallurgy for MMCs • Only SiC Whisker Producer in North America
Canada	Cercast	• Shape Casting (Fabricating) Composites for Various Aerospace and Civilian Applications • Investment Casting of Composites
Canada	Ecole de Technologie Superieur University	• Processing Capability that will Enable a Higher Concentration of SiC Reinforcement in Aluminum • Gravity Casting and Forging and Semi-Liquid State
Canada	Inco, Ltd.	• Aluminum Based Composites in Wear Resistant Applications of Light Materials for Automotive Applications
Canada	National Research Council of Canada	• Powder Injection Molding; High Temperature Semiconductor Cables and Coatings
Canada	Ontario Hydro	• Determining the feasibility of using MMCs as cables for power lines
United States	3M	• Ti/alpha alumina; CVD Fiber/Hot Press
United States	Advanced Composites Materials Corp.	• Producer of Whisker Reinforced MMCs
United States	Advanced Refractory Technology, Inc.	• Produce SiC Whiskers and Whisker Blends, Preforms, and Coated Whiskers • Perform R&D to Develop Additional Reinforcements for MMC Applications, Including TiNw and SiC Fiber.
United States	Alcoa	• INNOMETAL X2080/SiC particulate.
United States	Allied Signal, Inc.	• Particulate reinforced SiC/Al
United States	Amercom	• Boron Aluminum (Original Developer and Only Qualified Producer of)

Domestic and Foreign Metal Matrix Composite Marketplace		
Region/Country	**Institution**	**Program / Areas of Research**
United States	Amoco Performance Products, Inc.	• Manufacturer/Supplier of Continuous Carbon Pitch Fiber
United States	California Consolidated Technology Inc.	• Discontinuously reinforced aluminum based MMCs
United States	Clemson University	• Research on Tribology of MMCs and Studies on Precipitation of MMC Systems
United States	DuPont Co.	• Limited supplier of fiber reinforced aluminum, magnesium, and lead MMC.
United States	Duralcan	• Manufacture Ceramic (SiC or Al2O3) Particle Reinforced Alumium Alloy Ingot, Billet and Rolling Slab • Cast Aluminum and Magnesium MMCs with Aluminum Oxide (Alumina) or Silicon Carbide (SiC) Particulate Reinforcement
United States	DWA Composites Specialties, Inc.	• Develop a Moderate Strength Discontinuously Reinforced MMC with an Aluminum Matrix and SiC Reinforcement • Continuous Fiber Reinforced Aluminum, Graphite Reinforced Metals, and Discontinuous MMCs
United States	Fiber Materials, Inc. (FMI)	• Continuous carbon boron and SiC fiber reinforced aluminum, magnesium and copper.
United States	General Electric Laboratories	• Develop a Rapid-Solidification Low-Pressure Plasma-Deposition Process to Manufacture Titanium Alumide Fiber-Reinforced with Silicon Carbide, Titanium Diboride, and Titanium Carbide.
United States	Lanxide Corp.	• Electronic Packaging Materials
United States	Martin Marietta Research Laboratories	• Using its "XD" Process to Make Titanium Aluminide Dispersion-Strengthened with Titanium Diboride.
United States	Northrop Corp.	• Discontiuously Reinforced Aluminum and Continuous SCS-6 Fiber Reinforced Titanium (Alpha Beta and Beta) MMCs
United States	P-Cast Equipment Corp.	• Sells Laboratory Experimental Casting Equipment for Composite Material Research
United States	Pratt & Whitney	• Rapidly-Solidified Powders of Titanium Aluminide for the Aurora
United States	Research Opportunities Inc. (ROI)	• Tests MMC Materials for Thermal Management Applications
United States	Rockwell Science Center	• High Temperature Intermetallics; Titanium Aluminide for High Temperature and Low Density Materials for the NASP Program
United States	Rolls Royce	• Titanium Continuously Reinforced with Silicon Carbide and Discontiuously Reinforced Aluminum
United States	Textron Specialty Materials	• Develop a Rapid-Solidification Low-Pressure Plasma-Deposition Process to Manufacture Titanium Alumide Fiber-Reinforced with Silicon Carbide, Titanium Diboride, and Titanium Carbide. • Silicon Carbide-Reinforced Titanium Skin Panels and Other NASP Airframe Componenets, Capable of Operating at Temperatures Above 850°C
United States	University of California at Santa Barbara	• MMC Applications in Jet Engines (Contiuous Fiber Reinforced Titanium (Titanium Aluminides))
Australia		
Australia	Comalco	• Extruded COMRAL™-85 composite

NORTH AMERICAN DEFENSE INDUSTRIAL BASE ORGANIZATION (NADIBO)

TECHNOLOGY BASE ENHANCEMENT PROJECT

AUG '91

TECHNOLOGY BASE PROJECT BACKGROUND

- Working group established—April '90
- Initial proposal submitted to Steering Committee—November 90
- Workshop held at DSMC—February '91
  - Reviewed critical technologies lists for project candidates
  - Selected four potential technologies
  - Defined down-selection process
  - Agreed on need for feasibility study

TECHNOLOGY BASE PROJECT SELECTION CRITERIA

- **Joint Capability**
  - The Existance of both a development and manufacturing capability in the US *and* Canada
- **Size of Business Base**
  - Capable of Adequately assessing a majority of the companies in the chosen technology area with available resources
- **Industry Interest**
  - As represented by the survey responses
- **Window of Opportunity**
  - The ability to leverage significant changes within the industry given limited resources

TECHNOLOGY BASE PROJECT TECHNOLOGY CANDIDATES

- Advanced Materials
  - Polymer Matrix
  - Ceramic Matrix
  - Metal Matrix
  - Carbon-Carbon
  - Super Alloys

- Flexible Manufacturing
  - Systems Integration
  - No Machines/Controllers
  - System Software
  - Robotics

- Passive Sensors
  - Acoustic
  - Diagnostic
  - Infrared/Electro-optic
  - Micro/Millimeter Wave
  - Multispectral

- NBC Protection
  - Protective Materials
  - Biotechnology
  - CW Therapy
  - Immunology
  - Solid Sorbent Technology

TECHNOLOGY BASE PROJECT "EXPERT" SURVEY

- Survey was used to rank subtechnologies
  - Potential for military and commercial application
  - Level of investment warranted
- Solicited "Expert" opinion from industry, government, and academe
- Approximately 200 surveys mailed (45% rate of return)
- Two subtechnologies selected for potential evaluation: MMCs and IR/EO sensors
- Subsequent sanity check with industry led to selection of MMC Technology as best candidate for feasibility study

TECHNOLOGY BASE PROJECT SELECTED SUBTECHNOLOGY

- Metal Matrix Composite (MMC) Technology
  - Emerging technology with promising military and commercial applications
  - Industrial capabilities being developed in both U.S. and Canada
  - Business base is definable and manageable
  - Window of opportunity is ideal, growth potential in both countries
  - Well rated in survey

TECHNOLOGY BASE PROJECT FEASIBILITY STUDY GOALS

- **Use a focused approach to investigate joint (U.S./Canada) development of industrial base capabilities**
- **Utilize DOD and DND critical defense technologies plans as a basis for investigating the potential for joint activity in the MMC area**
- **Develop a roadmap outlining industry and government activities which would enhance the ability of the MMC industry to support defense requirements**

TECHNOLOGY BASE PROJECT FEASIBILITY STUDY

- U.S./Canadian analyst team
- Six month effort
- Industry involvement planned
- Strategy
  1. Baseline current technology, market relationships, policies/regulations
  2. Compare U.S. and Canadian activities for complementary capabilities, duplication of effort or barriers to cooperation
  3. Develop roadmap to lay out recommended actions to enhance joint activity
- Estimated funding required: $200,000

TECHNOLOGY BASE PROJECT SPECIFIC AREAS OF ANALYSIS

- Policy/regulation evaluation
  - Trade agreements
  - Data issues (proprietary/classified)
  - Joint management structures
  - Contractual processes
- Joint issues/options
  - Canada/U.S. industrial collaboration (existing/planned)
  - Identifiable barriers to joint effort
  - Industry view of cost/benefit associated with enhanced collaboration

6–7 OCT. '92 TBEP MEETING

On 6&7 Oct. '92 a TBEP meeting was held at Wright-Patterson AFB

- Immediate initiation of the TBEP subject to final approval from the appropriate authorities
- The establishment of a TBEP Working Group including representatives from the USAF, U.S. Army, and DND
- An agreement that the U.S. Army would act as the OPI for the feasibility study

IN ADDITION, SEVERAL KEY MILESTONES WERE IDENTIFIED

- 14 Oct. '92—draft statement of work for feasibility study completed
- 1 Dec. '92—award the contract for the feasibility study
- 31 Mar. '93—submit draft of feasibility study for review by the Working Group
- 15 Apr. '93—Working Group meeting to discuss draft
- 21 May '93—submit final version of the study