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Chinese Developments in Advanced Composite Materials: The Strategic Implications

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A Research Paper

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Chinese Developments in Advanced Composite Materials: The Strategic Implications [redacted] 25X1

A Research Paper

This report was prepared by [redacted] Office of East Asian Analysis. Comments and queries are welcome and may be directed to the Chief, China Division, OEA, [redacted] 25X1

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Chinese Developments in Advanced Composite Materials: The Strategic Implications

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Overview

Information available as of 21 June 1985 was used in this report.

China has been engaged since at least 1979 in a major effort to establish an advanced composite materials industry—a capability that could significantly enhance its design and development of sophisticated weaponry. Specifically, advanced composites can provide China:
- Performance advantages for its intermediate-range and intercontinental ballistic missiles.
- Improved targeting accuracy of weapon reentry vehicles.
- Broad application in space-related structures.
- Higher performance and load-carrying capacities for fighter aircraft and helicopters.
- More advanced centrifuges for processing weapons-grade uranium.
- New dimensions in the design of deep submersibles for antisubmarine warfare.

The application of advanced composites to the development of these and other weapon systems in China has been the primary motivation for China's seeking rapid development of this technology. We believe that Beijing's top priority for using advanced composites, however, is to improve the targeting accuracy of its weapon reentry vehicles and to apply these high-strength, lightweight materials to fabrication of solid-propellant rocket motor casings in order to increase the range, throw weight, and performance characteristics of a new series of land-based and sea-based intermediate-range and intercontinental ballistic missiles.

For the past five years, the Chinese have been systematically studying advanced composite systems—fibers and binders—with the intent of achieving in their laboratories what world industry leaders are introducing into production. At the same time, China's military materials research facilities have been engaged in an unprecedented effort to acquire, replicate, and apply foreign-made composite materials, structural materials, and techniques to the fabrication of weapon system components. China has approached and, in some instances, met these objectives and is now prepared to import the necessary manufacturing technology to achieve volume production.

Carbon-carbon composite material, which is used for the fabrication of highly accurate weapon reentry vehicles, has been given greater emphasis in China's research effort than any other area of composite technology. We believe that China is capable of developing a carbon-carbon composite that is comparable to material used in weapon reentry vehicle nosetips being fabricated in the United States.

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China's rapid progress in carbon-carbon research can be attributed to information that has been made available to Chinese scientists who have attended international symposiums on this subject. At the same time, China's carbon-carbon specialists have shown persistence in their efforts to acquire—both legally and illegally—various composite materials manufacturing machinery and US-made materials in particular that they have openly acknowledged would be duplicated. China also has benefited from the Sino-US student exchange program, which from 1980-82 included one of the country's top experts on carbon-carbon research and an individual who was clearly involved in the development of composite materials for China's ballistic missile and space programs.

We believe that similar high-priority attention is being given to the acquisition of technology and equipment to support the development and serial manufacture of rocket motor casings for China's land-based variant of the CSS-NX-3 submarine-launched ballistic missile. [redacted] 25X1 25X1

[redacted] 25X1

When China can achieve the capability to develop and apply lightweight composite materials depends on how rapidly and extensively advanced composite materials technology, fabrication equipment, and manufacturing processes are introduced and absorbed. If Bejing is successful in obtaining one or more of the composite fiber and resin material production lines now being negotiated with firms in COCOM and non-COCOM member countries, startup production could begin within two years after procurement. If China is forced to continue its covert acquisition of composite materials and the manufacturing technology, we believe it will be three to four years before full production is reached. The delay arises from the complexities of arranging covert purchases and the fact that support from the supplying firms—company technicians assisting in installation, pilot production, and training the Chinese work force—is not normally as thorough in covert transactions as in normal commercial deals.

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In our view, the priority China clearly is giving to obtaining foreign assistance for its composite materials expansion effort suggests that it is unlikely to rely solely on domestic resources. Should China choose to forgo either overt or covert attempts to obtain foreign expertise, we believe that it would take five to eight years to meet its domestic requirements. In any event, China will have to maintain strict quality control standards both in materials production and in application methods—an area that has plagued the Chinese manufacturing industry in general.

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Scope Note

This paper provides a comprehensive and technical review of China's development of advanced composite materials over the past five years. (This term *advanced composite* generally implies the use of high-strength reinforcements of carbon, graphite, or an aramid in combination with a matrix material.) It compares China's achievements in the laboratory with Western state-of-the-art processes. The paper discusses China's current negotiations for advanced composite materials manufacturing equipment and technology and evaluates the strategic implications of China's entry into the advanced composite materials field—these materials are used for weapon reentry vehicles, solid-propellant rocket motor casings, space system structures, advanced aircraft, and helicopter components. Finally, it identifies the major Chinese research institutes in this field and describes their missions and work.

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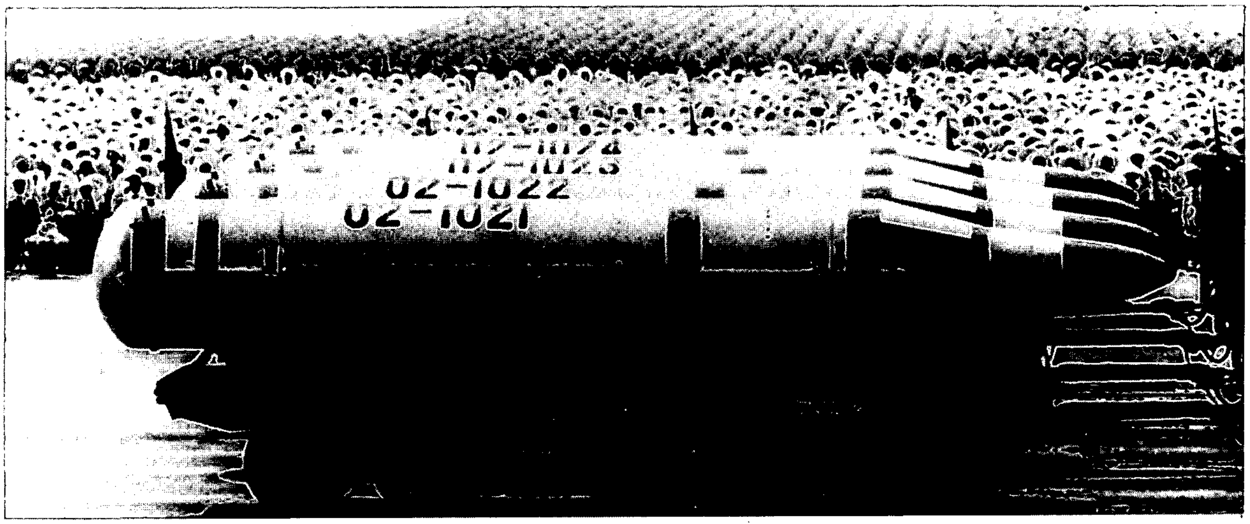

Figure 1. CSS-NX-3 at China's national day parade [redacted] 25X1

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Chinese Developments in Advanced Composite Materials: The Strategic Implications [redacted]

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Priorities and National Plans

A priority goal in China's science and technology planning is to gain a foothold in new or emerging technologies. No other field, with the exception of electronics, is more important to China's space age objectives than material sciences. Key within this high-technology field are advanced composites—materials that are used to form lightweight, high-strength components and structures for weapon reentry vehicles, solid-propellant rocket motor casings, satellite platforms, high-speed and high-performance aircraft, helicopter parts, and various other items having aerospace, land-based, or undersea applications. [redacted]

Because of their widespread application in advanced weapon system design and manufacture, the technologies and equipment to produce modern composite materials are tightly controlled by COCOM regulations. China, nevertheless, has been promoting a systematic study of various advanced composite systems—fibers and binders—over the past five years, with the intent of achieving in the laboratory what advanced countries were introducing into production. At the same time, China's military materials research facilities have been engaged in an unprecedented effort to acquire, duplicate, and implement foreign design, development, and manufacturing techniques needed to fabricate weapon system structures using advanced composite materials.[1] China has approached and, in some instances, met these research objectives and is now prepared to import the necessary manufacturing technology to achieve volume production. [redacted]

Advanced composites development has been frequently cited by the Beijing leadership as one of China's key science and technology (S&T) objectives along with microelectronics, computers, fiber optics, biotechnology, robotics, nuclear energy, and ocean sciences. In fact, the modernization of composite materials was designated a national goal by the Chinese Government in 1980, several years before China's overall S&T objectives were officially announced. Leading Chinese composite specialists also have voiced the belief that, during the remainder of this century, composite materials would be in the forefront of international materials science developments.[2] [redacted] 25X1

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The urgency of the Chinese program is reflected in the recent establishment of several major specialty organizations to deal specifically in the research, development, and manufacture of advanced composite materials. In October 1984, the Dalian New Materials Development Corporation was established to develop advanced composite materials through cooperation with foreign firms by utilizing foreign investment and importing advanced technologies. Materials to be developed by the corporation include metal-based and organic-based composites, glass epoxies, and carbon, graphite, borons, and Kevlar aramid fibers.[3] [redacted] 25X1

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The Chinese press announced plans in November 1984 to construct a chemical materials experimental base in Shanghai. Upon completion, the base will train professionals in applying laboratory research to industrial production. It will also function as a clearinghouse for imported technology and equipment used in manufacturing advanced composite materials and ceramics. Also in late 1984, the Beijing Aviation 25X1

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[1] See appendix A for a list of Chinese institutes engaged in composite materials R&D and their specific research functions. [redacted]

[3] Kevlar is a trade name for an aramid fiber produced by the du Pont Company. [redacted] 25X1

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College began publication of a Journal of Composite Materials to exchange the newest theoretical findings and experiments relating to composite materials research and to promote the development and application of composite materials in China. [redacted]

Chinese composite materials specialists reportedly hope that manufacturing equipment purchased abroad will enable Chinese plants to manufacture fiber composite products for export to generate foreign exchange for these facilities. At the same time, the Chinese are likely to use interest in such commercial production as a guise for acquiring composite technology that might otherwise be restricted. To stimulate any commercial application of advanced composites, however, China must first determine the cost advantages in design capabilities and reduction in weight of this material so that they can become competitive with metallic material alternatives. [redacted]

Defense Priorities

Despite potential civilian applications, military considerations will remain the driving force in China's efforts to move into this new technology. [redacted] China in 1979 gave the military sector top priority in the acquisition of composite materials in support of ongoing programs, and the research and development program was subordinated to the powerful National Defense Science, Technology, and Industry Commission (NDSTIC). [redacted] China's requirement for advanced composite materials and related manufacturing technologies covers a broad spectrum of military applications, particularly in the aerospace field—an area that one Chinese defense engineer recently acknowledged had no civilian application.

[redacted]

Solid-Propellant Ballistic Missiles

China's land-based variant of the CSS-NX-3 submarine-launched ballistic missile (SLBM) is a strong candidate for extensive application of high-strength, lightweight reinforcing fibers such as a Kevlar-equivalent aramid fiber. Kevlar, along with carbon fibers and glass fibers, is used in the US production of solid-propellant rocket motor casings (see figure 2). There is no convincing evidence that the Chinese are using advanced composites to produce the CSS-NX-3 or its land-based equivalent. [redacted]

[redacted] It is possible that both Lantian and the NDSTIC's Changsha Institute of Technology (CIT) can produce fiberglass-filament-wound rocket motor casings and may already be fabricating these types of structures for materials testing and evaluation. Liu Deshen, the current director of the SNMTI, reportedly was a professor at CIT specializing in filament winding of rocket motor casings when China was cooperating

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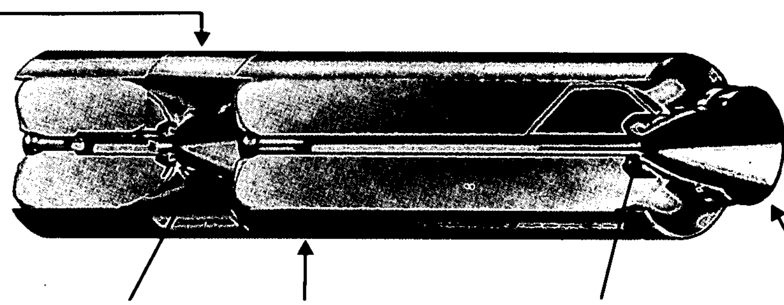
Figure 2
Composite Application in US Solid-Propellant Ballistic Missiles



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with the Soviets. We believe that Liu may now be applying his early experience to fabricate solid-propellant motor casings made of a Kevlar-equivalent composite material as well. [redacted] 25X1

[redacted] 25X1

Weapon Reentry Vehicles

China's composite materials specialists have shown a strong interest in, and keen understanding of, carbon-carbon composites and their ability to withstand the harsh environment found within a rocket nozzle or at the tip of a high-performance strategic missile reentry vehicle (see figure 3). The Beijing Research Institute of Material Technology (BRIMT), subordinate to China's Ministry of Astronautics Industry (MOAI), is the country's leading research institution for weapon reentry vehicle and space system structural design and the principal authority on carbon-carbon materials. [redacted] 25X1

Space Satellite Systems

The Chinese are anxious to apply composite materials to the design and fabrication of space satellites but, unlike Western satellite manufacturers, are not yet

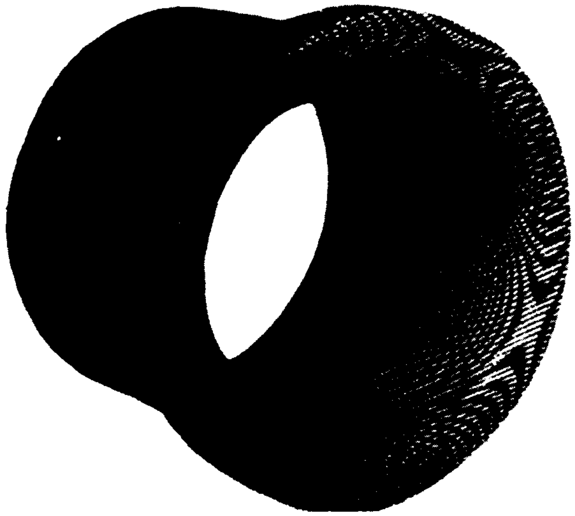

Figure 3a. *Rocket nozzle throat*

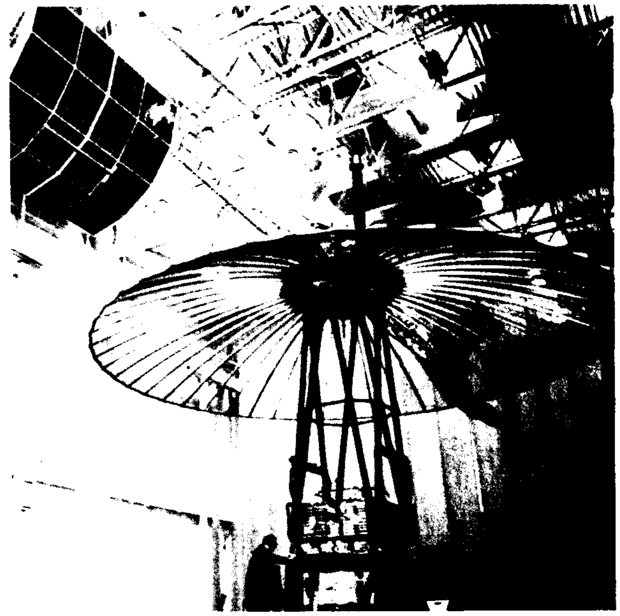

Figure 4. *Carbon fiber support truss in US-designed application technology satellite* (

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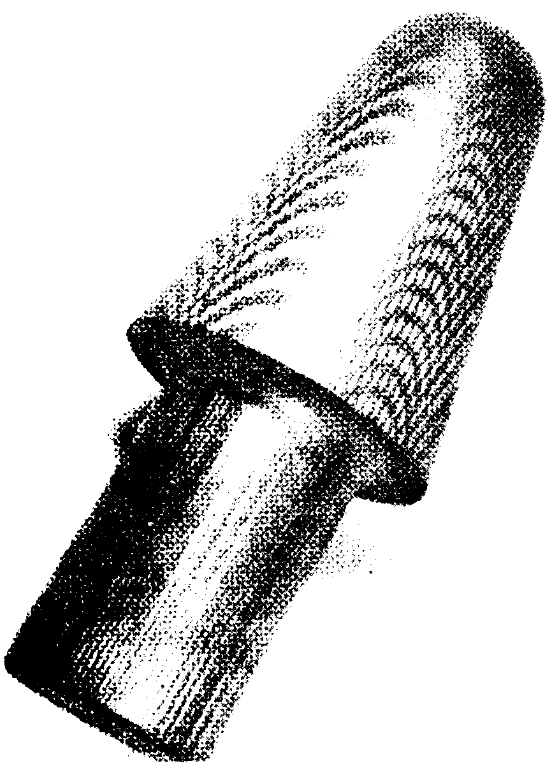

Figure 3b. *Carbon-carbon reentry vehicle nosetip*

using this material in existing systems (see figure 4). While acknowledging that they have the technology to produce carbon-fiber-reinforced plastics applicable to satellite systems design, the Chinese also admit having no experience in how it would fare in space over a long period.

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China has shown continuing interest in applying composite structures to satellite design. Chinese scientists have written several articles concerning vibration problems in satellites using composite structures and the benefits and drawbacks of using certain types of composite materials. Composite specialists associated with the Beijing Institute of Aeronautics (BIA), for example, have shown specific interest in using composite materials for protecting satellites against laser

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weapons. [redacted]

In mid-1984, Chinese space officials representing MOAI's Chinese Academy of Space Technology (CAST) invited a US expert on composite materials and spacecraft engineering to give a series of lectures on composite materials at facilities located in Beijing and Xian. The discussions included the theory of laminates, manufacturing processes, applications, future trends, and advanced composite application in spacecraft structures and communication satellites. The Chinese are also seeking a transfer of composite materials technology relating to spacecraft application as part of the direct broadcast satellite package that is being negotiated with several US and West German firms. [redacted]

Aircraft Structures

The use of composite materials in aircraft design has been a priority consideration in China for more than a decade (see figure 5). Development of carbon-fiber-reinforced blades for aircraft engines began in 1969, and the study of composite materials for aircraft components followed shortly thereafter. In 1975, the first non-load-bearing, carbon-fiber-reinforced starter box cap was installed for flight-testing. This was followed in 1978 with testing of an air induct wall plate using a composite hybrid of carbon and glass fiber. Since 1978, China's aviation specialists have turned increasingly to the West for technology and equipment to foster aircraft composite component design ambitions. [redacted]

China is particularly interested in US composite technology for improving the performance capabilities of its domestically produced aircraft. [redacted] the acquisition of composite materials technology was important for reducing the structural weight of China's aircraft, which were equipped with engines having a very low thrust-to-weight ratio. [redacted]

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Figure 5
Gr-Ep Composites on a US-Made AV-8B

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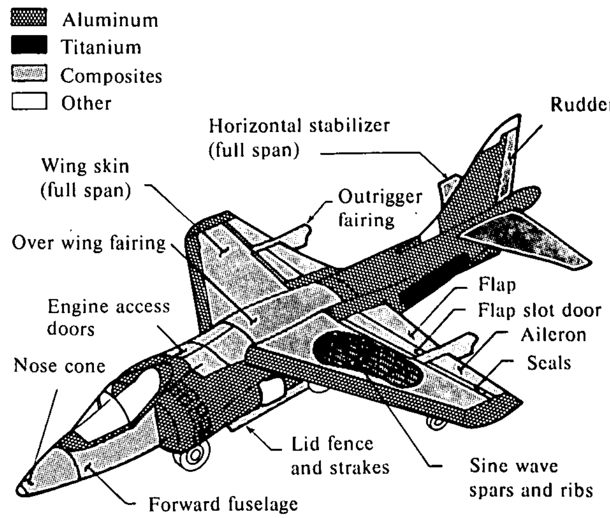

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[redacted] The Chinese also have expressed an interest in designing an aircraft comprised solely of composite materials [redacted] 25X1

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China also is looking to Sweden for composite materials technology applicable to the aviation industry. In 1982 an S&T exchange program was formalized between the two countries that allowed Chinese technicians to receive training in Sweden involving aircraft application of composite technology. In addition, the Chinese have been negotiating with companies in the Netherlands and Italy for composite technology. Discussions with the Netherlands included a visit to Fokker's Hoogeyeen plant, which is producing composite structures for the F-16 aircraft. Negotiations with Italy included a visit to China early this year by a team of composite fiber and avionic experts from

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Figure 6. Distribution of composite materials on the Chinese coproduced Dauphine helicopter [redacted]

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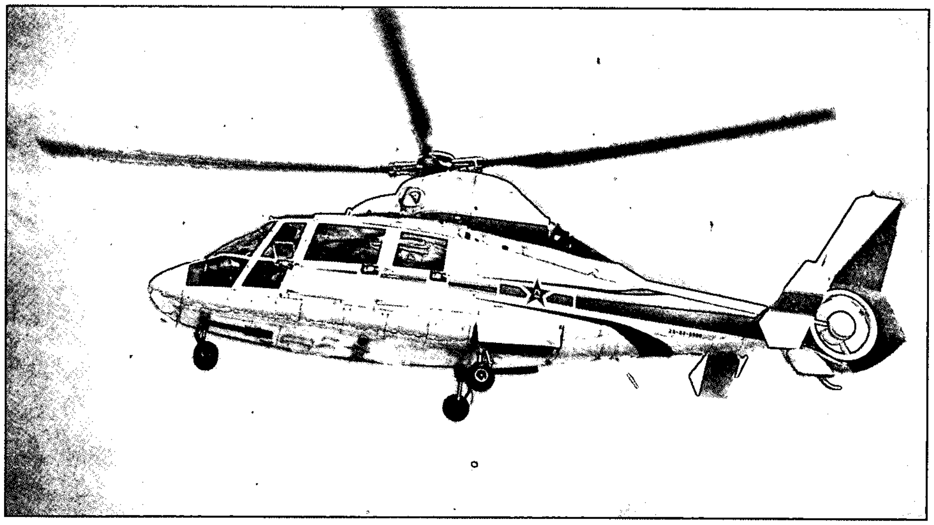

the aerospace firm Aeritalia, who were to hold discussions with Chinese aviation officials on aircraft design. [redacted]

Composite structural design for China's aircraft industry is undertaken by a small number of institutes, most of which are subordinate to the Ministry of Aeronautics Industry (MAI). A pioneer in the composite application effort is the Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI), which is involved in designing graphite epoxy parts for a new fighter aircraft including components such as the vertical stabilizer, rudder, and torque box. [redacted] in spite of the poor physical conditions of the institute and its lack of sophisticated equipment, it seemed capable of producing serviceable parts and had on display a number of sophisticated and well-designed composites. A similar assessment was made of the Beijing Institute of Aeronautical Materials (BIAM), which is reported to be one of China's foremost laboratories for developing and testing advanced composites for the aerospace industry. In addition to developing glass and carbon fiber structures for wing panels and aileron design, BIAM is engaged in boron/aluminum metal matrix composites (MMC) research and has recently acquired some hot isostatic pressing equipment for processing these materials into advanced composite structures. [redacted]

The Beijing Institute of Aeronautics and Astronautics (BIAA), although subordinate to the MAI, also is heavily involved in composite technology that supports the aircraft as well as missile and space industries in China. [redacted] the BIAA is particularly strong in computer-aided design techniques, including finite element analysis of composite materials—a technique used in predetermining the stress load of composite structures. The Aircraft Material Strength Research Institute at Jiaotong University in Xian also is heavily involved in testing the mechanical behavior of advanced composites for use in fighter aircraft. [redacted]

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Helicopter Parts

China gained access to a considerable amount of advanced composite materials technology when it signed a coproduction agreement with France's Aerospatiale for the Dauphine helicopter in 1980. Composite material used in the Dauphine constitutes more than 25 percent of the total structure, including glass and carbon fiber epoxies used in the rotor wing, rotor hub, tail rotor, and the vertical tail section. The body itself contains 59-percent composite material, including 28-percent aluminum-NOMEX honeycomb structure, and 13-percent conventional riveted aluminum (see figure 6). Currently, China acquires the composite material used in the Dauphine from Aerospatiale

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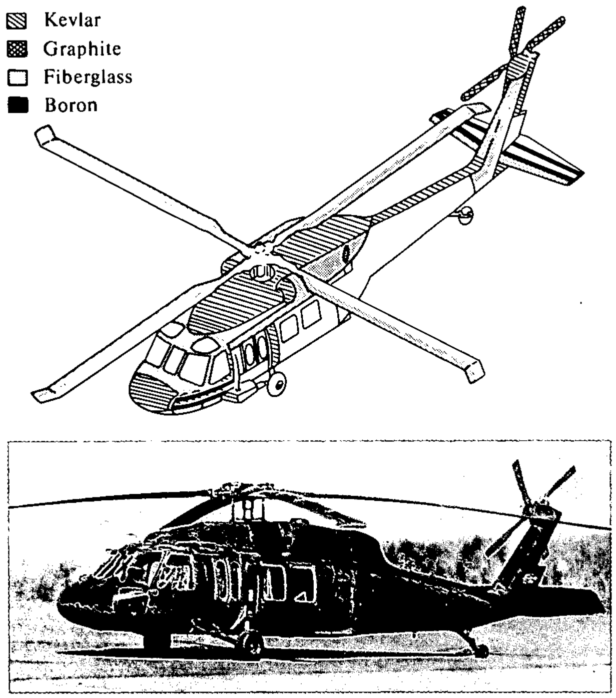
Figure 7
Composite Application in Chinese-Procured UH-60A (Black Hawk)-Type Helicopter



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in the form of preimpregnated cloth that is shipped to China in special temperature- and humidity-controlled containers. [redacted]

China has shown interest in coproducing the S-70 utility transport helicopter, which was purchased from the United States in early 1984. [redacted] The Chinese have made a number of visits to US helicopter-manufacturing companies that included tours of the composite materials fabrication centers. [redacted] 25X1 25X1

Other Applications

Other areas of Chinese interest include nuclear materials separation and deepwater pressure vessels. [redacted] the Institute of Nuclear Energy at Qinghua University, for example, reportedly is trying to develop composite parts for high-speed centrifuges that are used to separate fissionable from nonfissionable uranium. Officials at the institute have indicated an interest in US centrifuge research and use of composite technology. [redacted] As of late 1984, considerable work was being done at Shanghai's Jiaotung University on a deepwater rescue vessel that employed composites in addition to several high-strength steel and superalloys. This same technology can be applied to deep submersibles for antisubmarine warfare. [redacted] 25X1 25X1 25X1 25X1 25X1 25X1 25X1

Capabilities and Limitations

[redacted] while China has made significant progress in the field of advanced composite materials since 1979, its state of the art is still some five to eight years behind that of leading world producers. China has a number of research and manufacturing facilities that can develop and produce materials and structures with varying levels of sophistication, but material consistency and quality reportedly can vary from batch to batch and from one day to the next. [redacted] 25X1 25X1 25X1 25X1 25X1 25X1 25X1 25X1

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[redacted] China's composite materials program is essentially a two-pronged effort to upgrade and expand basic composite materials manufacturing capabilities and to develop and produce composite structures using both indigenous and foreign-procured material. Chinese military composite specialists have acknowledged that they cannot wait until their own industry is capable of producing sufficient quantities of high-quality composite fiber and resin. Consequently, China's foreign requirement is for both fabrication equipment and high-grade materials, as well as the manufacturing know-how and equipment to produce composite fiber and binder materials in volume. [redacted]

Processes Used

As late as the 1970s the technology China used to process fiber and resin into composite structures was considered to be generally adequate for manufacturing glass-fiber-reinforced products but lacked the sophistication for fabricating advanced composite materials structures. Hand layup methods dominated China's composites manufacturing as a means of ply orientation. Also referred to as contact molding, hand layup is the oldest and simplest process for forming glass-fiber-reinforced plastic. The fibers in this process are usually short, rather than continuous, and are used in relatively inexpensive applications that employ fabrication methods such as injection molding and sheet molding. Bag molding lamination methods also are used in China, particularly in the aircraft industry. The three types of processes in use were pressure bag, vacuum bag, and autoclave, with the latter two being the more popular. These bag molding methods primarily use glass fiber cloth as the principal reinforcement and epoxies, polyesters, silicones, or phenolics as a resin material. Various types of mold layup methods also were being used in China to produce complex and specialized components for various types of aerospace application. These processes include preform die molding, wet fabric molding, premix molding, prepreg molding, and displacement molding. The presses normally involved were four-stand hydraulic machinery with capacities ranging from 100 to 800 tons. [redacted]

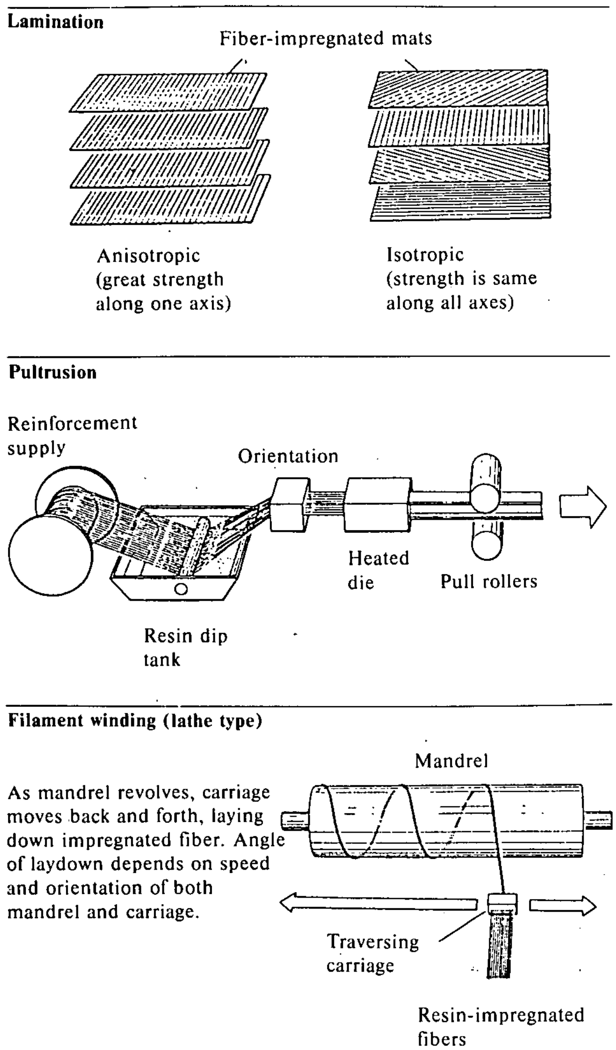
[redacted] 25X1 in its nondestructive testing of composites China used a variety of techniques: 25X1

- Ultrasonic testing was used and employed frequencies ranging from 100 kilohertz to 25 megahertz. This process was considered effective in testing for defects in composite lamination porosity and resin content.
- X-ray testing of composite structures was conducted to confirm the location of composite voids, delaminations, and crazing and to detect major changes in resin content and nonuniform fiber orientation. 25X1
- Electrical properties testing was used to measure composite hardness and moisture content.
- Microwave testing also was used to locate voids in the laminations and to determine spots where resins were either too concentrated or insufficient. It was further used to detect changes in the degree of hardness or moisture content of the material. Microwaves also were applied to testing composites made of complex honeycomb-layered structures. [redacted] 25X1

Technology Needs

China's push into advanced composites has generated a need for a wide range of technologies and equipment that is used to process continuous fiber such as carbon and Kevlar into high-strength structures. [redacted] 25X1 lamination, filament winding, and pultrusion—the drawing of continuous-fiber-reinforced material—are the three primary processes that China wants to introduce on a broad scale (see figure 8). In lamination, the prepreg—fiberous mats and similar materials that are impregnated with partially cured resin, such as epoxy—is stacked with the fiber oriented in the desired direction. When the laminate reaches the desired thickness, it is placed in an autoclave and cured under vacuum, which also will eliminate voids in the finished item. China is seeking prepreg manufacturing equipment as well as autoclaves to further its use of the 25X1

Figure 8
Methods of Producing Continuous Fiber Composites



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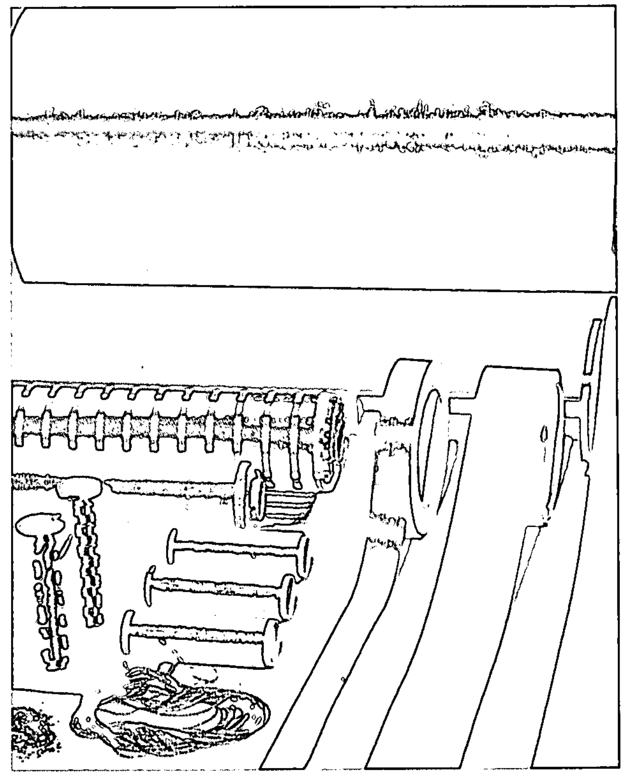

Figure 9. Graphite fiber products—cloth, yarn, and prepreg tape produced by a US composites manufacturer [redacted] 25X1

lamination method. Filament winding is another process China wants to expand that involves successively wrapping a long, resin-impregnated fiber filament around a rigid form to produce, for example, a cylindrical object such as a rocket motor casing. When the winding is finished, the form also is placed in an autoclave to be cured. The pultrusion process involves feeding resin-impregnated filaments into a heated die. The cured section emerging from the die is grasped and the remaining filaments are pulled through at a constant rate. The process is used for making complex shapes as well as for items with constant cross sections such as spars and reinforcement members in aerospace structures. [redacted] 25X1

Prepreg Equipment. China's search for Western prepregnation technology is driven primarily by military requirements and involves all the manufacturing processes currently being used, including solvent impregnation, melt impregnation, and film impregnation (see figure 9). The SNMTI, for example, has shown strong interest in acquiring Swiss prepreg equipment that uses a film impregnation process. This institute also is attempting to purchase US-made prepreg manufacturing machines capable of producing material 300 25X1

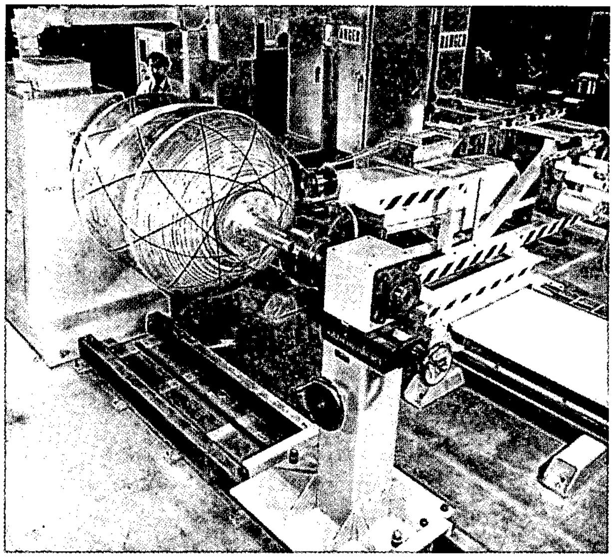

Figure 10. A filament winding machine making a rocket motor case [redacted] 25X1

millimeters (mm) in width. [redacted] 25X1

The Great Wall Industrial Corporation (GWIC), the import arm of China's ballistic missile and space industry, also is trying to obtain prepreg technology on behalf of the MOAI. In September 1983, a Chinese delegation led by a senior GWIC official and composed of engineers representing the China Space Technology Research Institute and BRIMT toured a number of Japanese companies that produce prepreg and the manufacturing machinery. [redacted]

Filament Winding. China has given priority to the acquisition of advanced filament winding machines since the late 1970s and has negotiated with suppliers in Japan, the United States, France, Switzerland, and West Germany (see figure 10). While successful in importing some equipment, the difficulty of importing this COCOM-controlled technology in the quantities currently required reportedly has prompted Beijing to muster its own resources for indigenously manufacturing the equipment. [redacted]

Both the Harbin Fiber-Reinforced Plastics Institute and SNMTI have attempted to obtain US equipment, including the former's interest in a filament winding machine having a product diameter of 50 to 400 mm; computer-aided filament winding equipment; and a heavy-duty winding machine capable of producing tubes 2,200 mm in diameter and 8,000 mm in length. [redacted] 25X1

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The product dimensions for this equipment (which was denied an export license by the United States) are remarkably similar to the configuration details of a CSS-NX-3 solid-propellant missile displayed at China's National Day parade in October 1984 (see figure 1). Although this missile airframe is probably made of steel, there is a strong possibility that the Lantian Complex and SNMTI in particular may be preparing to produce in volume a land-based version of the CSS-NX-3 that would involve a filament-wound rocket motor casing or airframe. [redacted] 25X1 25X1

The Chinese have acquired a variety of filament winding equipment that would enable them to produce missile nosecones as well as rocket motor casings, but, [redacted] machines that were purchased in the 25X1 25X1

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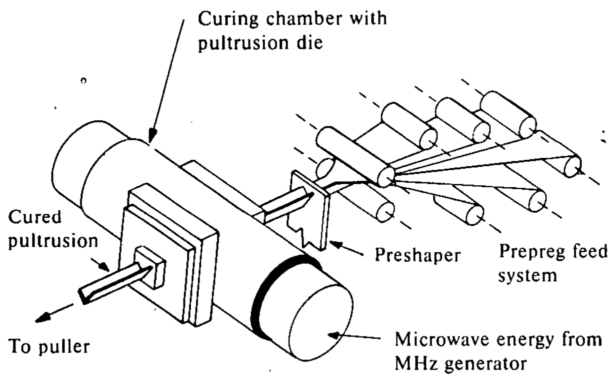
Figure 11
Schematic of Pultrusion Equipment That Uses Die Forming and Microwave Curing



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late 1970s are now considered obsolete by the Chinese. The Chinese are also assembling small prototype winding machines possibly involving acquired technology to produce what Chinese technicians refer to as *canisters* that are to be made of carbon and Kevlar-equivalent material. One filament winding center is in operation at the Lantian Complex; [redacted] Another filament winding center with a ballistic missile research and development function is located at [redacted] the Changsha College of Engineering [redacted]

Pultrusion. Because China's capabilities in pultrusion fabrication of composite structures are limited, it is currently emphasizing large-scale purchases of this equipment from a variety of Western suppliers (see figure 11). For example, British manufacturer Pultrex, Ltd., recently sold three state-of-the-art pultrusion machines to China, [redacted]

[redacted] A US manufacturer also has sold machines to China, including a laboratory model and at least three production models. [redacted] 25X1 25X1 25X1

Other. Additional equipment that is of priority interest to the Chinese includes nondestructive test instrumentation such as acoustical emission test systems, axio-torsional test systems, advanced materials analysis systems, spectrographic equipment for online testing of cured materials, and "instron" test equipment that measures stress as well as the physical properties of composite materials. The Chinese are also seeking advanced types of autoclaves, which in their simplest form are industrial pressure cookers that apply heat and pressure in a controlled and monitored environment (see figure 12). [redacted] 25X1 25X1 25X1 25X1 25X1

There is also considerable Chinese interest in advanced composite materials cutting techniques including laser and high-pressure water jet cutting systems (see figure 13). These can be used for cutting both cured and uncured composite materials including material used in rocket motors and missile nosecones. [redacted] 25X1 25X1 25X1 25X1 25X1

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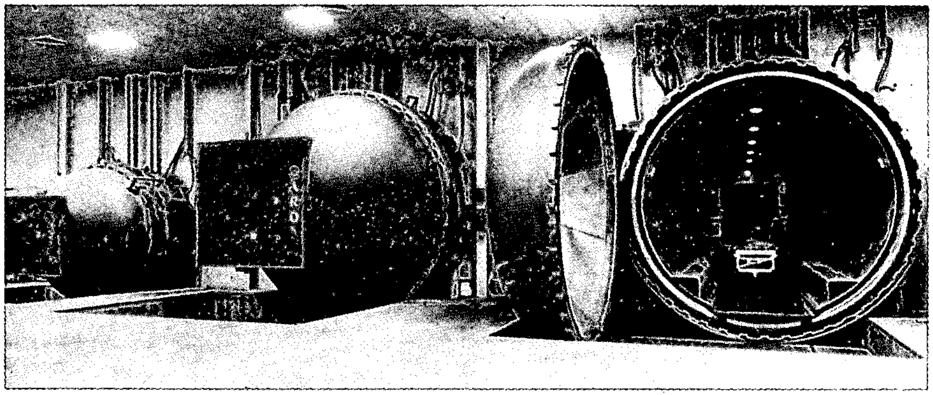

Figure 12. Autoclaves used in curing aircraft and rotor-blade components [redacted] 25X1

[redacted] Also of priority interest to the Chinese is the acquisition of advanced casting and molding machinery including hot isostatic press equipment for use in China's aerospace industry. [redacted]

Broad Trends in Materials Development

Although China's entry into the composite materials field began in 1953 when Chinese scientists, under the tutelage of Soviet technicians, started investigating the strength and anticorrosive characteristics of glass-fiber-reinforced plastics, research did not fully develop until the 1970s, when the military voiced an interest in this material. This early investigation set the stage for further research of fiber reinforcements and resins that together could form a composite with stiffness and the high strength-to-weight ratios needed by the military to support its aerospace programs. As shown in the table, the choice of composite materials research in China, as elsewhere in the world, is limited by the small number of reinforcement fibers that can be used, and which, with the exception of a Kevlar-equivalent aramid, must be formed from a precursor or substrate material. [redacted]

Fiber Research

Aramid (Kevlar). Chinese development of low-density, high-tensile-strength aramid fiber began in the mid-1970s through extensive study of US accomplishments in the field. In 1979, the Chinese Academy of Science (CAS), Beijing, claimed to have successfully trial manufactured a Kevlar material that was referred to as fiber B (the same designation that du Pont gave its Kevlar test product). [redacted] 25X1 25X1
[redacted] the Shanghai Institute of Synthetic Resins and the East China Institute of Chemical Technology also were involved in the trial manufacture of Kevlar-type material. [redacted] 25X1 25X1 25X1
[redacted] the Chinese were achieving considerable success in developing ultra-high-modulus aramid fiber and that emphasis was being directed to acquiring and developing production techniques for this material. [redacted] 25X1 25X1

[redacted] there is at least one manufacturing facility, located in Shanghai, that produces Kevlar-equivalent fiber, and possibly others located in Beijing and Nanjing. The quality of China's Kevlar-equivalent fiber is difficult to assess. Early 1983 [redacted] the Chinese were achieving a tensile strength for their aramid fiber that was very close to du Pont's Kevlar-49 product. The cost of this domestically produced aramid reportedly runs at about $100 per pound, far more than the US and Western equivalents. [redacted] 25X1 25X1 25X1

The shortfall in Chinese-produced aramid fiber is being supplemented through large-scale imports of Kevlar from a number of Japanese and Western suppliers.[5] Initially, these acquisitions were in small 25X1

[redacted] 25X1

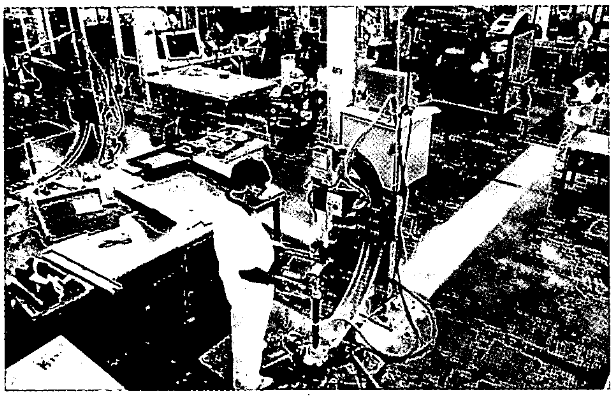

Figure 13. Water jet cutters in operation [redacted]

lot quantities, suggesting that military research and development requirements were the primary application of the materials. More recently, however, the Chinese—particularly GWIC—have been ordering production-level quantities. [redacted]

Boron. Development of high-modulus, high-strength boron fiber has been under way in China since the mid-1970s. [redacted] China was able to produce boron fiber with an average tensile strength of more than 400,000 pounds per square inch (psi). The production process involved deposition of heated boron trichloride gas and hydrogen on a tungsten wire 17 to 25 microns in diameter. When attempts were made to convert this process into regular production, however, numerous problems were encountered, including chemical impurities and cracks in the fiber. Because of its high development costs and the difficulties of introducing it into regular production, boron fiber had been given a low priority in Chinese research funding. Recently, however, China has expressed renewed interest in this technology, and has announced plans to purchase a complete boron fiber production system. [redacted]

Glass. The Chinese claim to be self-sufficient in glass fiber technology, having both E- and S-glass capability, which are filaments with extremely high modulus. [redacted] the glass fiber composites that were being produced in the late 1970s were used primarily for radar antenna coverings, fuel tanks, rocket thrusters, and a variety of commercial products. The composition of the fiberglass composites reportedly was not of uniform quality and had

China: Fiber Processing for Selected Composite Materials

Composite Type	Manufacturing Process Used
Boron epoxy, B/Ep	A tungsten or carbon substrate is drawn through a chamber filled with boron-trichloride gas. The filament is heated and the boron gas decomposes when it contacts the hot substrate to produce an external coating.
Graphite epoxy, G/Ep	Most high-performance carbon/graphite fibers are manufactured from a polyacrylonitrile (PAN) precursor using a process that involves controlled pyrolysis. The successive stages are: oxidation-heating in an oxidizing atmosphere at 200 to 250 degrees Celsius (C); carbonization-heating in a nonoxidizing atmosphere at 1,000°C or above, for the production of high-strength fiber; graphitization-heating in a nonoxidizing atmosphere to 2,500 to 3,000° C for high-modulus fibers. Finally, the surface of the fiber is treated with a process of controlled oxidation that promotes adhesion of the fiber with a matrix material such as epoxy to form the composite.
Aramid epoxy, Kevlar	A polymer solution is extruded through a spinnarette and dried to produce a Kevlar or Kevlar-equivalent fiber.
Fiberglass epoxy, Gl/Ep	Inorganic salts are melted and drawn through a bushing to form a single fiber. Small bundles of these fibers (yarns) may be then woven into fabric, filament wound, or formed into a unidirectional tape that has been impregnated with a resin such as epoxy. Large bundles of fibers (rovings) may be woven into fabric, chopped for fiber spraying, made into nondirectional mats, or used as a sheet-molding compound.
Boron/aluminum, B/Al	Boron/aluminum is one of several metal matrix composites (MMC) that consist of a metallic alloy—usually aluminum, magnesium, or titanium—and contain a reinforcement in the form of a particle, whisker, wire, or filament. The reinforcements are made from a variety of high-performance metallic, ceramic, and organic materials including boron and graphite.

[redacted]

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little application as a primary structure in aircraft design. A large-scale research effort was being mounted at that time, however, to make fiberglass composites of uniform quality and with a tensile strength of at least 100,000 psi. [redacted]

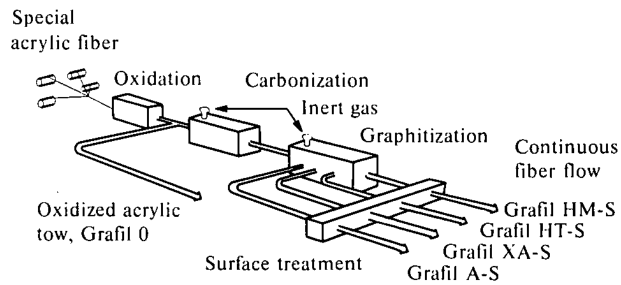
Carbon (Graphite).[6] Carbon fiber research and development in China has been under way since 1969. Key institutes engaged in carbon fiber research include the Polymer Institute of Zhongshan University and the Institute of Chemistry (under the Chinese Academy of Sciences). Both specialize in polyacrylonitrile (PAN)-based carbon fiber research. Research involving pitch-based carbon fiber material is centered at the Shanxi Institute of Coal Chemistry and the Thermal Energy Research Institute. [redacted]

Although interrupted by the Cultural Revolution, Chinese progress in indigenous development and manufacture of high-strength and lightweight carbon fiber has progressed steadily. [redacted] China is capable of producing carbon fiber with tensile strengths ranging from 250 to 300 kilograms per square millimeter (kg/mm^2) and with a tensile modulus of 22,000 kg/mm^2. Chinese material having these characteristics, [redacted] is comparable to carbon fiber available in the rest of the world. [redacted]

China has problems in maintaining consistent quality in domestically produced carbon fiber. [redacted] A problem that may be affecting the quality is that the Chinese adopted a process from West Germany that combines a PAN-based precursor with a catalyst containing tin in the fiber conversion stage. The tin converts the materials to carbon more quickly, but also forms oxide residuals on the fiber surface that inhibits bonding. Moreover, China has not improved on its PAN-based manufacturing technology, which was originally acquired from the British in the mid-1970s (see figure 14). [redacted]

[6] The term *carbon* is used throughout this report, although the terms *carbon* and *graphite* are used interchangeably in the industry. Generally, the term *graphite* refers to the more highly structured form of carbon that results from higher temperatures. [redacted]

Figure 14
Carbon Fiber Production Using Courtauld's (United Kingdom) Process



[redacted]

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The Chinese have attempted to develop carbon fiber using rayon as a precursor. Rayon has special properties that cause a slower rate of oxidation and much purer carbon fiber material, but it is a more costly process. China also is considering the use of pitch, which is very inexpensive, although the process of converting the pitch into a mesophase (liquid crystal), which is required before it can be further processed into a high-strength and high-modulus fiber, is complex. [redacted]

China is stepping up efforts to expand its existing PAN production capacity. A new PAN facility is being planned in Daqing that will have a capacity of 25,000 metric tons per year. A French firm, ELF Aquitaine is negotiating with the Chinese to build a major chemical complex in the Shantou Special Economic Zone, which would have facilities to produce PAN fibers, as well as polymers, resin, and polyvinylchloride. [redacted]

[redacted] there may be as many as eight carbon fiber manufacturing facilities in China, most of which use the PAN precursor process. The key carbon fiber production facilities are located

Figure 15
Selected Advanced Composite Materials Research, Development, and Production Centers

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in Anshan (Liaoning), Guangzhou (Guangdong), Jilin (Jilin), Lanzhou (Gansu), Liaoyuan (Jilin), Taiyuan (Shanxi), Tongliao (Nei Monggol), and Shanghai. These are mostly small operations, however, and probably have a total annual output of not more than 100 metric tons. The largest of the facilities reportedly is the Lanzhou Carbon Plant, while the best carbon fiber is believed to be produced at the Shanghai Carbon Plant. The facilities located in Anshan and Taiyuan reportedly are using pitch as a precursor for manufacturing carbon fiber. 25X1

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In addition to building new plants, China intends to expand and upgrade these existing facilities. For example, a Japanese firm has agreed to upgrade the Liaoyuan Carbon Fiber Plant, [redacted]

Resin Matrices

China divides its composite materials production into two main types—thermoset and thermoplastic—according to the resin matrix that is used. Thermoset resins are preferred over thermoplastics as a binding material because once formed they do not soften with heat—an important feature in high-temperature composite fabrication. Specialty epoxies, polimides, and polyphenol quinoxalin (PRQ) are among the various thermoset resins currently available in laboratory quantities within China. Those that are in regular production include biophenol A and cycloalephatic epoxies and polyesters. The Chinese have followed US technology closely in this area and have often copied US developments, sometimes refining the technology. An example is the high-performance epoxy PRQ, which is no longer available in the United States for toxicity and commercial reasons but is very available in China. [redacted]

The main thermoset resins that China uses in making composite materials fall into four categories: polyester resins, epoxy resins, phenol resins, and polyimides. [redacted]

Polyesters. Most of the polyester resins produced in China have high polyester densities. These resins, however, generally could not be used at more than 150 degrees Celsius. Another significant drawback of Chinese-produced polyester resin composites is that they have low-alkali, corrosion-resistance properties. In the early 1980s, however, the Chinese were trial-producing a Cisphenol A-323–type unsaturated polyester resin, which promised significant improvement over existing materials. [redacted]

Epoxies. China has placed considerable emphasis on the production of epoxy resins because of their performance capabilities. The most extensively produced general purpose epoxy resins were made from Bisphenol A and epichlorohydrin; the second most commonly produced material is the epoxy Novalacresin.

Although there is significant demand in China for epoxy resins, the scarcity of raw materials for production and the high costs involved have hindered widespread utilization. To supplement current production of quality epoxy resins, the Chinese have turned to Japan, the United States, and Western Europe. In addition, several Japanese firms also are cooperating in a joint-venture epoxy resin project that will provide the Chinese with an initial capacity of 3,000 metric tons per year of bisphenol liquid and solid epoxy resins with capabilities for further expansion. [redacted]

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Phenolics. Although Chinese-produced phenolic resins do not have the characteristics of domestic epoxy resins, they reportedly are made in much greater quantity because of their low production costs and high heat-resistance properties. Use of this resin in composite materials development has been thus far limited because of the marginal quality of the material. Greater emphasis is now being placed on improving phenolic resins because of their growing use as a matrix material for military-related carbon composite structures. [redacted] 25X1

Polyimides. We know little of China's high-temperature-resistant polyimide resin research and development capabilities. [redacted] there are some polimides available in laboratory quantities. The Chinese have claimed, for example, to have solved a problem the United States had in the late 1970s with a NASA-developed polimide that dealt with the use of a specific solvent. The United States had been using ethyl alcohol as the solvent, but the Chinese discovered that methanol alcohol with water added had solved this problem. [redacted]

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Thermoplastics. The primary thermoplastic resin used in China for fiberglass-reinforced plastic applications has been nylon. Domestically produced 1010 nylon is widely used because it can endure temperatures up to 80 degrees Celsius and as low as minus 60 degrees Celsius. Alternatives to nylon include polycarbonate, linear polyester (terylene), polyethylene, and polypropylene. The linear polyester thermoplastic resins were in widest use and held the greatest interest because of lower costs. [redacted]

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A substantial research effort also is under way in China to study the applications of carbon-fiber-reinforced thermoplastic resins such as polytetrafluoroethylene (PTFE), polysulfane, and polycarbonate. In addition, the Chinese apparently are looking into advanced composite thermoplastic materials such as PEEK, a newly developed British polymer that possesses superior toughness, high thermal resistance to common solvents, and low moisture absorption characteristics. Moreover, PEEK can be processed rapidly, without the curing agents and autoclaves required for thermosets. Research on this material involves the Beijing Institute of Aeronautical Materials (BIAM), which is reported to be one of the foremost Chinese laboratories charged with the development and testing of advanced composite materials for the aerospace industry. [redacted]

Metal Matrix Composites

Metal matrix composite (MMC) materials have been under technical investigation in China since the mid-1970s. Chinese-produced MMCs consist of a standard metallic alloy—typically aluminum or titanium—that contains reinforcement additives in the form of particles, whiskers, wires, or filaments. These reinforcements are made from a variety of high-performance metallic, ceramic, or organic materials such as boron, silicon carbide, and graphite. The most popular reinforcement material used widely in China has been a silicon carbide ceramic. A variation of this reinforcement is Borsic, which includes the use of a thin coating of silicon carbide over a boron-clad tungsten filament. [redacted]

Recently, the Chinese have shown a strong interest in improving their graphite/aluminum and boron/aluminum MMC technologies. From papers presented at international carbon conferences, it appeared to some specialists in the field that China was about five years behind the more advanced countries in graphite metal matrix technology, but was anxiously seeking to narrow this gap. [redacted] a strong interest in adopting new methods of coating carbon for metal matrix usage. The Chinese also have shown a desire to concentrate their MMC fiber-reinforcement research on graphite and boron—technologies that are expected to be developing rapidly in the international metal matrix field. [redacted]

China's MMC technology is an area that has extensive military application but little commercial utilization. This is substantiated in China by the fact that most Chinese R&D in this field is performed by institutes and laboratories subordinate to the NDSTIC, the MOAI, or the MAI. [redacted] 25X1

China's technology and equipment requirement for the fabrication of MMC components varies according to the structure of the reinforcement. Continuous filament MMCs, for example, are characterized by the presence of long fibers of reinforcement within a metallic matrix. These continuous-filament-reinforced MMC parts can be produced in several ways. These processes involve sandwiching parallel 25X1
fibers between metal foil and bonding this material into a single mass. [redacted] 25X1

Chinese development of discontinuous-fiber-reinforcement MMC is characterized by the presence of relatively small particles of reinforcing material spread uniformly throughout the metallic matrix. The most common method of making discontinuous reinforced MMC in China appears to follow standard powdered metallizing procedures where a matrix metal powder is blended with the powdered reinforcement. This mixture in turn is either forged, extruded, or cast to achieve a near-net shape. Hot isostatic pressing (HIP) is a more advanced application of this molding process and is a technology that ranks high on China's current shopping list. The structures themselves have a variety of applications in areas where high-temperature resistance is critical, such as jet 25X1
turbine fan blades and ballistic missile components.
[redacted] 25X1

Carbon-Carbon Materials

Carbon-carbon composites are a special class of high-temperature material in which a substance such as polymer or pitch is pyrolized to form an inert carbon matrix around a preform of carbon fiber. The initial 25X1
step in the manufacture of carbon-carbon composites determines the ultimate configuration of the end item, 25X1
that is, two dimensional or multidimensional. Two-dimensional carbon-carbon composites consist of layers of carbon or graphite fabric with an organic

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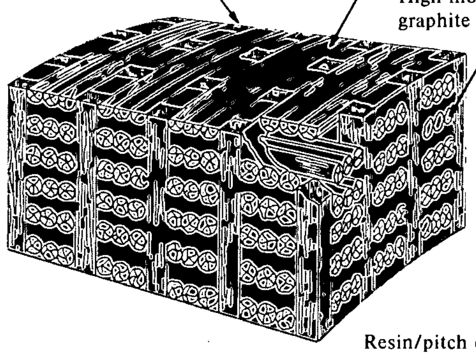
Figure 16
3-D Orthogonal Weave of Carbon-Carbon Composite



[redacted]

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matrix material. These materials are used primarily for aircraft brakes and rocket motor components such as throats and exit cones. [redacted]

The manufacture of multidimensional composites such as those used in weapon reentry vehicle nosetips, however, requires further weaving of the preforms and a rigidization process involving yarn and resin (see figure 16). The densification and carbonization of this multidimensional preform are achieved through chemical vapor deposition (CVD) and low-pressure or high-pressure processing. The most advanced process, called pressure impregnation carbonization, involves HIP technology and equipment. Chinese-produced three-dimensional composite reportedly is prepared by the high-pressure, impregnation-carbonization process. This process is based on preliminary pyrolytic infiltration, on multiple pitch impregnation carbonization at high pressures, and on graphitization cycles. Weaving of the material apparently involves the use of domestically designed looms, some of which were displayed at a composite materials exhibit held in Shanghai in late 1980. The research and development of this multidimensional carbon-carbon composite material has been a priority effort in China for at least 10 years. [redacted] 25X1

[redacted] the microstructure of 3-D carbon-carbon composite material currently being developed in China is identical to weapon reentry vehicle nosetips being fabricated in the United States [redacted] the Chinese have been placing much greater emphasis on carbon-carbon research and are thus significantly further ahead in this area than in any other sector of advanced composite research. [redacted] 25X1 25X1 25X1 25X1 25X1

China's rapid progress in the carbon-carbon area can also be attributed to the materials and technology that it acquires from abroad. [redacted] the Chinese are regularly obtaining significant quantities of T-300 PAN from a Japanese firm for use in carbon-carbon composites research. Composite materials specialists have visited the United States periodically over the years to solicit information, compare manufacturing processes, and acquire new technologies and materials relevant to their field of research. [redacted] 25X1 25X1 25X1 25X1 25X1

Carbon-carbon research in China also has benefited through the Sino-US student exchange program. For example, Zhao Jiaxing, one of China's leading authorities on carbon-carbon composites and a deputy director of the Non-Metallic Materials Department at BRIMT, came to the United States in the early 1980s as a visiting scholar. During the course of his stay,

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Zhao reportedly gleaned all the carbon-carbon-related information that was available in open literature and sought the opinions of others on the technology. [redacted]

Prospects

China's push in advanced composite materials could have significant and long-term impact on the pace and scope of its modern weapon system development and manufacture. Advanced composites can provide China performance advantages for its intermediate-range and intercontinental ballistic missiles, improved targeting accuracy of weapon reentry vehicles, broad applications in space-related structures, higher performance and load-carrying capacities for fighter aircraft and helicopters, more sophisticated techniques for processing weapons-grade uranium, and new dimensions in the design of undersea platforms. When China can achieve the capability to develop and apply lightweight composite materials to components and structures that comprise these various weapon systems depends, in large part, on how rapidly and extensively advanced composite materials technology, fabrication equipment, and manufacturing processes are introduced and absorbed. [redacted]

Materials Production

The main variable in forecasting when China will be able to manufacture composite fiber and binder materials in quantities sufficient to meet its long-term needs is, in our judgment, dependent upon how Beijing acquires the capability to upgrade and expand its existing materials base. If Beijing is successful in obtaining one or more of the composite fiber and resin materials production lines now being negotiated with firms in COCOM and non-COCOM member countries, startup production could begin within two years after procurement. [redacted] if China were to acquire only one of the sophisticated composite fiber production lines currently being negotiated for, the Chinese could easily replicate the equipment and manufacturing process to meet its long-term requirement for that particular type of reinforcement material. [redacted]

If China is forced to turn to covert acquisition of composite materials manufacturing technology, we believe it will be three to four years before full production is reached. The delay arises from the complexities of arranging covert purchases and the fact that support from the supplying firms—company technicians assisting in installation, pilot production, and training the Chinese work force—is not normally as thorough in covert transactions as in normal commercial deals. [redacted] 25X1 25X1

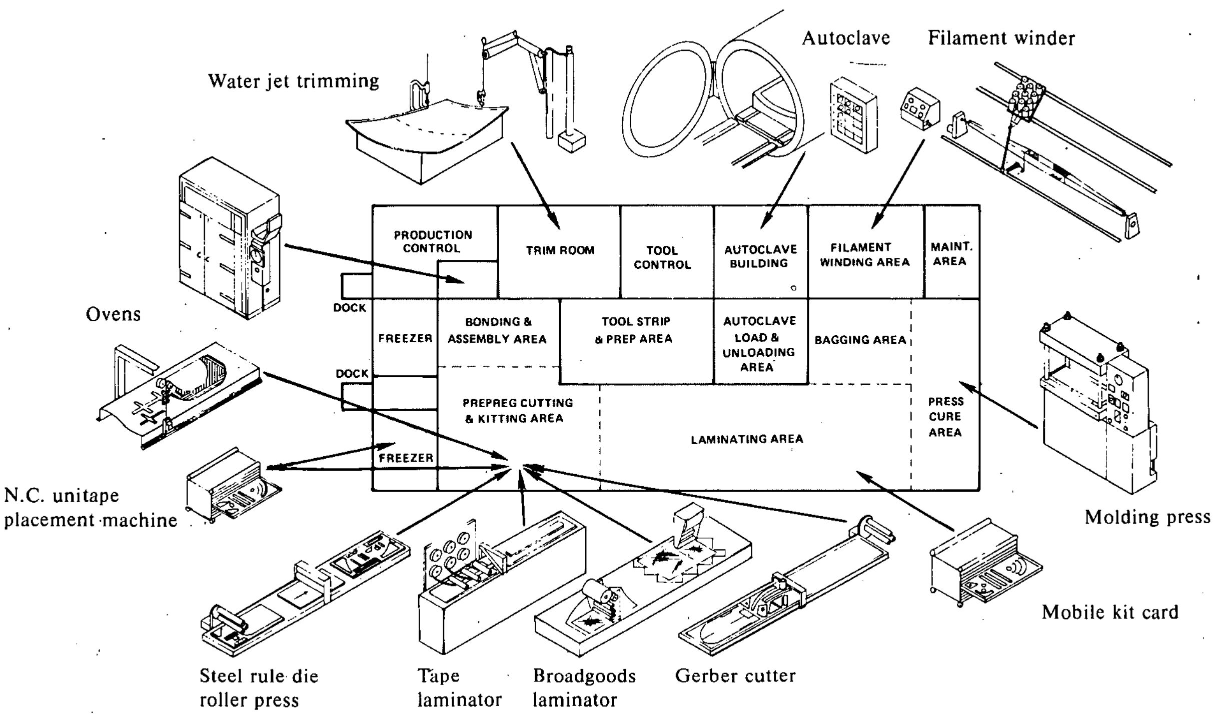
The priority China clearly is giving to obtaining foreign assistance in its composite materials expansion effort suggests that it is unlikely to try to rely on domestic resources to develop a large-scale manufacturing capability. Should China choose to go it alone, we suspect the estimate of foreign specialists that it would take five to eight years to meet domestic needs is probably the best guess. [redacted] 25X1

Structure Development and Application

The development and application of advanced composite materials to components and structures that will be used in China's weapon systems are likely to start slowly and pick up speed as the availability of both indigenously produced and foreign-procured materials and fabrication equipment increases. The process will probably move quickly because China's composite structural engineers and scientists have not been content to rely solely on indigenously supplied materials and equipment in their investigation of advanced composite materials application in weapon system manufacture. [redacted] 25X1 25X1

[redacted] China could be preparing its Lantian solid-propellant ballistic missile complex for serial manufacture of strategic missile rocket motor systems and components [redacted] The facility has also acquired an unknown number of high-pressure water jet cutting 25X1 25X1 25X1 25X1 25X1 25X1 25X1

Figure 17
Configuration of a Modern Composite Materials Fabrication Center



[redacted] 25X1

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machines that are used not only in trimming the material of an advanced composite rocket motor casing but are also needed to shape the propellant within the motor casing itself. [redacted]

[redacted] China is at the crossroads between development and application of advanced composite materials [redacted] increased funding and facility expansion for composite research, development, and production at major military industrial installations. Researchers at the Lantian Complex, for example, acknowledge that they have adequate funding for upgrading and expanding their composite materials facilities, and the Shenyang and Xian aircraft plants also are reported to be undergoing initial construction or major expansion of their composite centers (see figure 17). The Northwest Polytechnic University at Xian has a new advanced composite materials fabrication center and the Beijing Aeronautical Manufacturing Technology Research Institute is expanding its composite research facility as more funds have become available. [redacted]

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Equipment Requirements

There is little indication that China's composite materials program will be significantly delayed by the lack of fabrication equipment needed to process the materials into various component and structural parts. China already has purchased either covertly or legally most of the equipment that is unique to the composite materials fabrication process. A major boon for the Chinese, however, is the type of transaction that has been arranged with a US company for high-speed water jet cutting equipment whereby China not only acquires the machines but also the manufacturing rights to produce and distribute the equipment within China. We believe that similar transactions for other types of processing equipment would eliminate a major obstacle in China's ability to move rapidly into the advanced composite materials field. 25X1

Quality Control

An area that China is not likely to overcome quickly in its advanced composite materials development effort is quality assurance and testing. China has a poor record in general for quality control of its industrial products, and its testing of infrastructural materials—resins, fibers, and composite products—is not likely to fare much better. Although China has acquired significant amounts of nondestructive testing machinery over the past several years, its use of this equipment for testing composite specimens or components could be stymied if similar quality and reliability techniques were not employed throughout the entire downstream manufacturing process. The Chinese recognize that maintaining product reliability is a serious problem and are anxious to hire foreign composite materials specialists as consultants to the industry. In the meantime, China could be forced to experience through trial and error many of the problems that Western industry has overcome only through establishment of a rigid quality control system. 25X1

Appendix A

China: Selected Composite Materials/Structures Research and Development Facilities

Location	Name	Subordination	Research Function
Anshan (Liaoning)	Anshan Institute of Thermal Energy Research	Ministry of Metallurgical Industry	Research and development of pitch-based carbon fiber.
Beijing	Beijing Aerodynamics Institute (BAI) (701 Institute)	Ministry of Astronautics Industry	Thermodynamics of ballistic missiles and reentry bodies.
	Beijing Institute of Aeronautical Materials (BIAM)	Chinese Aeronautical Establishment (CAE)	Advanced composite application in missile and aircraft design.
	Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI) (625 Institute)	Ministry of Aeronautics Industry	Advanced composite materials application in aircraft design.
	Beijing Institute of Chemistry (BIC)	Chinese Academy of Sciences	High-polymer chemistry and composite fiber R&D, including PAN-based carbon fiber and Kevlar-equivalent material.
	Beijing Institute of Electrical and Mechanical Engineering (BIEME)	Chinese Aeronautical Establishment (CAE)	Advanced composite materials application in aircraft, missile, launch vehicle, and satellite design.
	Beijing Institute of Mechanics (BIM)	Chinese Academy of Sciences	Nondestructive testing of composite specimens.
	Beijing Research Institute of Materials Technology (BRIMT)	Ministry of Astronautics Industry	Advanced composite application in weapon reentry vehicles, missile nosecones, rocket engines, and satellites.
Changchun (Jilin)	Changchun Institute of Optics and Precision Mechanics	Chinese Academy of Sciences	Application of composite materials to laser-related research.
Changsha (Hunan)	Changsha Institute of Technology (Changsha Engineering College)	National Defense Science, Technology, and Industries Commission (NDSTIC)	Advanced composite materials application in solid-propellant ballistic missiles, weapon reentry vehicles, spacecraft, and high-speed centrifuge design.
Guangzhou (Guangdong)	Polymer Institute of Zhongshan University	Chinese Academy of Sciences	R&D of PAN-based carbon fiber.
Harbin (Heilongjiang)	Harbin Fiberglass-Reinforced Plastics Institute	Harbin Fiberglass-Reinforced Plastics Institute	Composite fiber application in aerospace structures.
Jilin (Jilin)	Jilin Research Institute of Chemical Industry	Chinese Academy of Sciences	Carbon fiber research and application development.
Lantian (Shaanxi)	Shaanxi Non-Metallic Materials and Technology Institute (SNMTI)	Ministry of Astronautic Industry (Lantian Solid-Propellant Ballistic Missile Complex)	Composite materials R&D for ballistic missile application.
	Northwestern Chemical Propulsion Company/Materials and Processes Institute	Ministry of Astronautic Industry (Lantian Solid-Propellant Ballistic Missile Complex)	Advanced composite materials application in solid-propellant ballistic missile design.
Shanghai	Shanghai East China Institute of Chemical Technology	Ministry of Education	Development of Kevlar-equivalent composite fiber.
	Shanghai Fiberglass-Reinforced Plastics Institute	Shanghai Municipality	Carbon, graphite, and Kevlar fiber research.
	Shanghai Institute of Synthetic Resin	Shanghai Municipality	Composite matrix research.

China: Selected Composite Materials/Structures Research and Development Facilities (continued)

Location	Name	Subordination	Research Function
Taiyuan (Shanxi)	Shanxi Institute of Coal Chemistry	Chinese Academy of Sciences	R&D of pitch-based carbon fiber.
Xian (Shaanxi)	Aircraft Materials Strength Research Institute (623 Institute)	Ministry of Aeronautics Industry (Northwest Polytechnic University)	Advanced composite materials application in aircraft design.

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