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High-Technology Materials: A Key to Industrial Competitiveness and Strategic Capabilities

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A Research Paper

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GI 83-10167
July 1983

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High-Technology Materials: A Key to Industrial Competitiveness and Strategic Capabilities [redacted] 25X1

A Research Paper

This paper was prepared by [redacted] Civil Technology and Industry Division, Office of Global Issues. Comments and queries are welcome and may be directed to the Chief, Technology Analysis Branch, OGI, [redacted] 25X1 25X1

Secret
GI 83-10167
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Approved For Release 2008/01/14 : CIA-RDP84S00558R000400150003-2

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High-Technology Materials: A Key to Industrial Competitiveness and Strategic Capabilities
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Summary

Information available as of 23 June 1983 was used in this report.

Advanced materials are becoming increasingly important to the economic and military strength of industrialized nations. They are enhancing the competitiveness and performance of a wide range of civil products and military weapon systems. Markets, both civil and military, potentially affected by advanced materials—transportation, electronics, computers, telecommunications, machine tools, and weapon systems, among others are cumulatively worth hundreds of billions of dollars annually. Moreover, the flow of dual-use advanced materials and associated manufacturing processes from civil to military applications, already sizable from military to civil, is growing to the extent that large civil markets may attract substantially more R&D investment than military programs can support. Although opportunities are great, risks are high because of sizable development costs and uncertain markets. 25X1

Industry experts believe that four classes of advanced materials merit special attention:

- Electronic materials—especially new semiconductor materials such as gallium-arsenide.
- Electro-optical materials—such as fiber optics and sensors for a wide variety of information applications.
- Fiber-reinforced composites—strong, lightweight structural materials used in transportation applications.
- Structural ceramics—used in a variety of high-temperature applications, such as fuel-efficient diesel engines for automobiles, trucks, and military tanks.

Significant commercial applications already exist or seem likely within this decade. 25X1

Leading foreign governments, looking to high technology to improve their long-term industrial competitiveness, are moving quickly to develop indigenous capabilities in these key classes of advanced materials. Japan and France, in particular, are undertaking unprecedented national programs for R&D. In the short term, they are encouraging firms to be aggressive in installing production capacity for some of the most promising new materials, even in the face of weak demand. Given the high stakes involved, serious overcapacity in the production of advanced materials and fierce competition for sales could develop. 25X1

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Foreign successes in advanced materials have several important economic and strategic implications for the United States:

- *Industrial Competitiveness.* Foreign leadership in advanced materials can translate into strong competitive leverage for products in world markets. Foreign governments may apply measures, such as direct funding and subsidies, that permit domestic manufacturers to take more risks in the application of advanced materials than their US competitors. Furthermore, foreign suppliers may give preferential price or availability concessions on advanced materials to other domestic manufacturers, enhancing their product competitiveness relative to US manufacturers.

- *Dependency.* To the extent that dual-use advanced materials—those with military as well as commercial importance—and manufacturing processes are developed and applied more rapidly in Japan and Western Europe for commercial reasons, the United States may find itself dependent on foreign sources of supply for materials important in military as well as commercial applications. Market uncertainties and potential excess world capacity may discourage potential US suppliers from developing new materials and building production capacity. Hence, the relevant production technology—design and manufacturing capabilities, production experience, and know-how—for key military applications may never be established.

- *Technology Transfer.* Emergence of strong foreign capabilities in advanced materials complicates US efforts to control the flow of such technology to the Communist countries. Enforcement of COCOM restrictions on the transfer of advanced materials technologies becomes more difficult as the number of possible sources of these technologies increases. The Soviets have been seeking a number of dual-use materials technologies, including those for production of carbon-carbon materials and carbon fibers.

- *Technology Diffusion.* Similarly, it will be difficult to control the diffusion of dual-use materials technology among non-Communist countries. [redacted] 25X1 25X1

Advances in materials also pose competitive problems for US industry. Certain mature industries, such as steel, face problems that may affect demand and jobs. Many of the new materials are nonmetallic and are gradually replacing metals in a wide variety of applications. Demand for metals could slacken or even decline. [redacted] 25X1

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Introduction

This paper inaugurates the Agency's coverage of advanced materials in non-Communist countries. [redacted]

[redacted]

Materials have always been the cornerstone of industrial development, a concept aptly captured in the nomenclature for man's earlier ages: stone, copper, bronze, and iron. Exploitation of these materials has spurred industrial progress, resulting in significant performance improvements in civil products and in military weapon systems. In the 20th century, advances in structural and electronic materials have allowed man to transport himself around the world and into space and to transmit, manipulate, and store his information. Now, as the developed world looks to high technology to revitalize its industries and to reestablish its military advantage, it appears that advanced materials will play a major role. [redacted]

The commercial and military impact of the materials now emerging from R&D laboratories will be significant. Soon, even better and cheaper materials will be available. The decade-long increase in energy costs, which, for example, drove commercial aircraft fuel costs to roughly half of the operating costs, triggered a widespread effort to develop and exploit advanced materials to improve fuel efficiency in vehicles. Coincident with this development were the quicker-than-ever advances in manufacturing processes—which have yielded new parts and reduced production costs of old parts, making them competitive in a wider variety of applications. Coupled with ongoing improvements in semiconductor-based microelectronics, these factors contribute to a pace in advanced materials development that is unprecedented. [redacted]

High Commercial and Strategic Stakes

The importance of advanced materials considerably exceeds their sales value as commodities because of their important leverage in civil and military applications. These materials can have a tremendous impact on the competitiveness of products cumulatively worth hundreds of billions of dollars annually. Moreover, some materials can impart unique advantages to military weapon systems. (Some of the most promising applications are described in the table.) Once such materials can also be made cheaply, their competitive impact will be magnified considerably, and they will become the workhorse materials of tomorrow. (See glossary for types, definitions, and details.) [redacted]

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Advanced materials enhance equipment performance and/or product competitiveness in one or more of the following applications: 25X1

- In special components critical to system performance. Although unit prices may be small relative to overall system costs, the value of such components to the system is high. Example applications are: semiconductor-based memory chips and microprocessors, the single light-emitting crystal in a laser, and composite "Chobham" armor (defending against shaped charges) in modern tanks. 25X1

- As substitute materials in equipment, providing either greater durability or lower operating costs. Examples are: fracture-resistant composites in helicopter rotors and lightweight materials in fuel-efficient automobiles.

- In components for improving human health, such as body replacement parts with ultimately incalculable benefits. [redacted] 25X1

Many of the applications most affected by advanced materials are found in the transportation and information sectors. In civil and military transportation

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Selected Advanced Materials and Applications

Material	Application	Advantage	Timing	Comment
Structural				
Metals				
Single crystal	High temperature turbine blades in aircraft jet engines	Strength; resistant to fracture at high temperature	Currently available	
Amorphous	Transformer cores	Easily remagnetized without loss of structural strength	Under development; being field tested	Economics may be marginal
Lightweight alloys	High-stress parts in airframes and automobiles	Fuel efficient in vehicles	Under development	Costs barrier to widespread use
Ceramics	High-temperature [a] engines in automobiles and tanks	Fuel economy	The uncooled, ceramic engine is a 21st-century application	Raw materials inexpensive and widely available
	Automobile parts such as turbocharger rotors, cylinder liners and heads, and pistons	Lighter and more durable than metals at high temperatures	Currently used in operating prototypes	Brittleness barrier to wide use
	Cutting tools	Wear resistant	Widely available	High cost of tool breakage limits use to special applications
Engineering plastics	Vehicle dashboards and equipment shells	Cheaper than nonplastics; tough, corrosion resistant at moderate temperatures	Continuing developments; some high-performance plastics no longer advanced	Consumer dislike barrier to extensive use
	Construction; modular housing	Inexpensive	Increasingly available	Large Third World market
Composites		Strong and stiff relative to weight		Effects of aging not well understood
Fiber-reinforced plastics (including carbon-carbon)	Aircraft, automobile, high-speed train bodies	Strong and lightweight; hence fuel efficient in vehicles	In commercial aircraft, safety fears hold back use in wings and fuselage	High cost of parts fabrication barrier to widespread use
	High-stress parts; helicopter rotors, aircraft wings, and brakes; automobile drive shafts and leaf springs; casings for rocket motors for jet engines	Fracture resistant under high stress	Increasingly available	
	Stealth aircraft	Poor radar reflector	Long-range potential	
Metal matrix	Automobile engine blocks	In castings, much stronger than unreinforced metals	Currently in working prototype	May outcompete more publicized ceramics
	Piston heads in automobile engines	Greater durability at high temperature	Current application	

Selected Advanced Materials and Applications (continued)

Material	Application	Advantage	Timing	Comment
Functional				
Advanced semi-conductors				
Gallium-arsenide	Electronic circuits, lasers, sensors, receivers	Switching speed of devices significantly faster than silicon	Already used in military applications	
Optical	Fiber optics (glass)	Speed-of-light, RF [b] emission-free means of transmitting information	Already replacing metal wires	
	Lasers		Widely available	As costs fall, industrial use may increase rapidly
	Optical-computing elements	Ultrahigh speed	A next-century application	
	Sensors	Index of refraction of electro-optics sensitive to pressure, temperature, sound, and magnetic field	Early in development	Notable military interest, such as for submarine detection
Membranes	Chemical industry	Chemical separation processes inexpensive and pollution free	In development	Numerous potential applications; market could expand rapidly
	Water desalination	In development		
	Body replacement parts: artery, vein walls		Minor use to date	

[a] The higher the operating temperature of an engine, the better its fuel efficiency. Ideally, the weight and expense of cooling systems can be eliminated.
[b] Radiofrequency emissions in conventional communications often degrade system performance and risk compromise of transmitted information.

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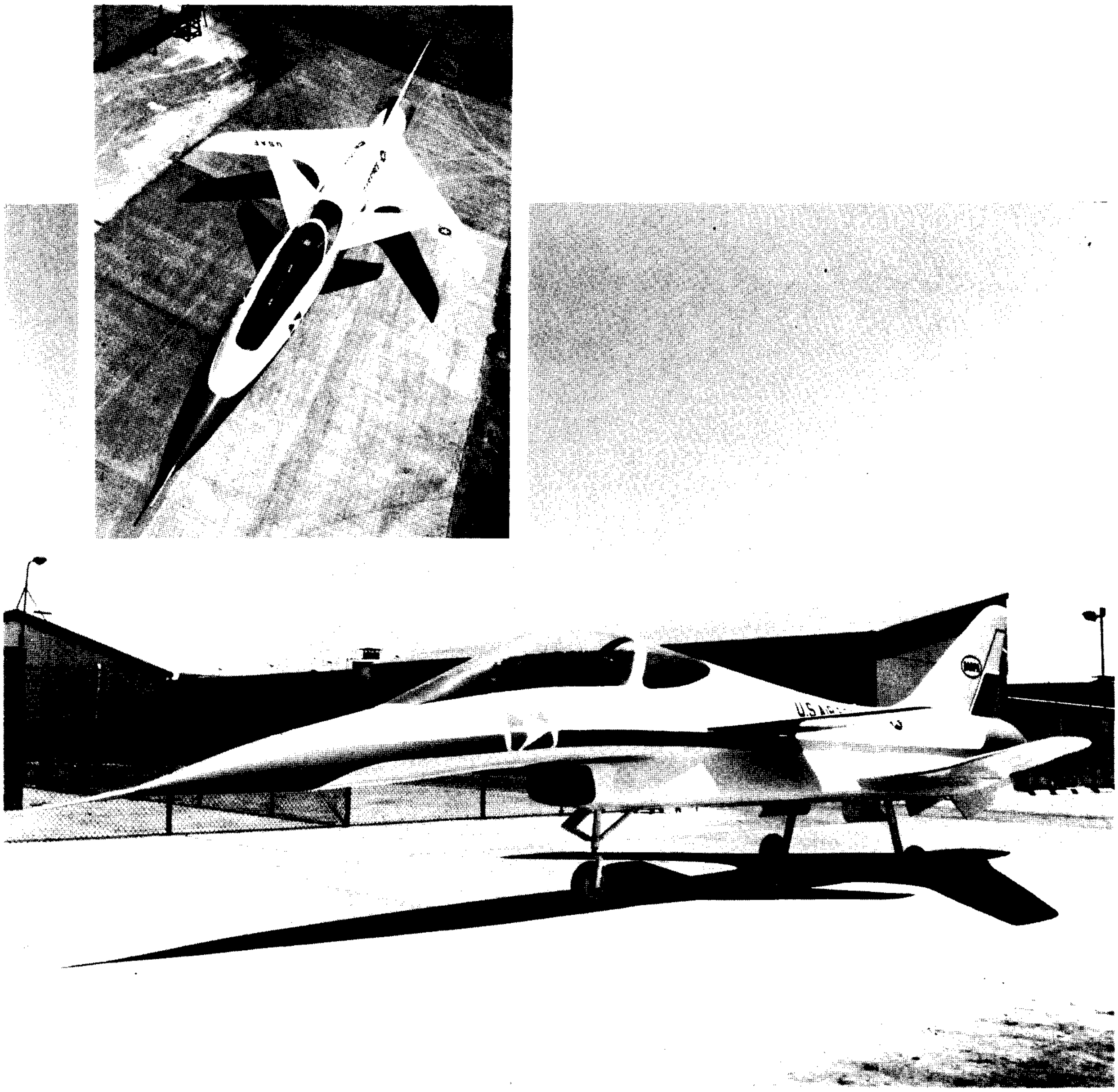
applications, researchers are looking to improve the performance, durability, and fuel efficiency of vehicles through innovative use of advanced materials:

- Uniquely configured, ultrathin wings made of fiber-reinforced plastic composite material give at least one advanced research aircraft significantly greater maneuverability than current-generation aircraft (figure 1).

- Diesel engines with the pistons, manifolds, cylinder heads, and liners made of ceramics can be operated at high temperatures, improving thermodynamic efficiency, horsepower, and fuel consumption. Experts anticipate increases of 30 percent or more in fuel mileage in automobiles, trucks, and tanks. Moreover, as technology advances permit higher engine operating temperatures, cooling systems can be made smaller and lighter, and eventually may be eliminated.

- Durable single-crystal turbine blades will help stretch the operating lifetime of commercial aircraft jet engines, as well as permit their operation at higher temperatures.

Figure 1
Advanced Research Aircraft Made Possible With Composite Materials



Use of composites: Wings–100%
Airframe–55%

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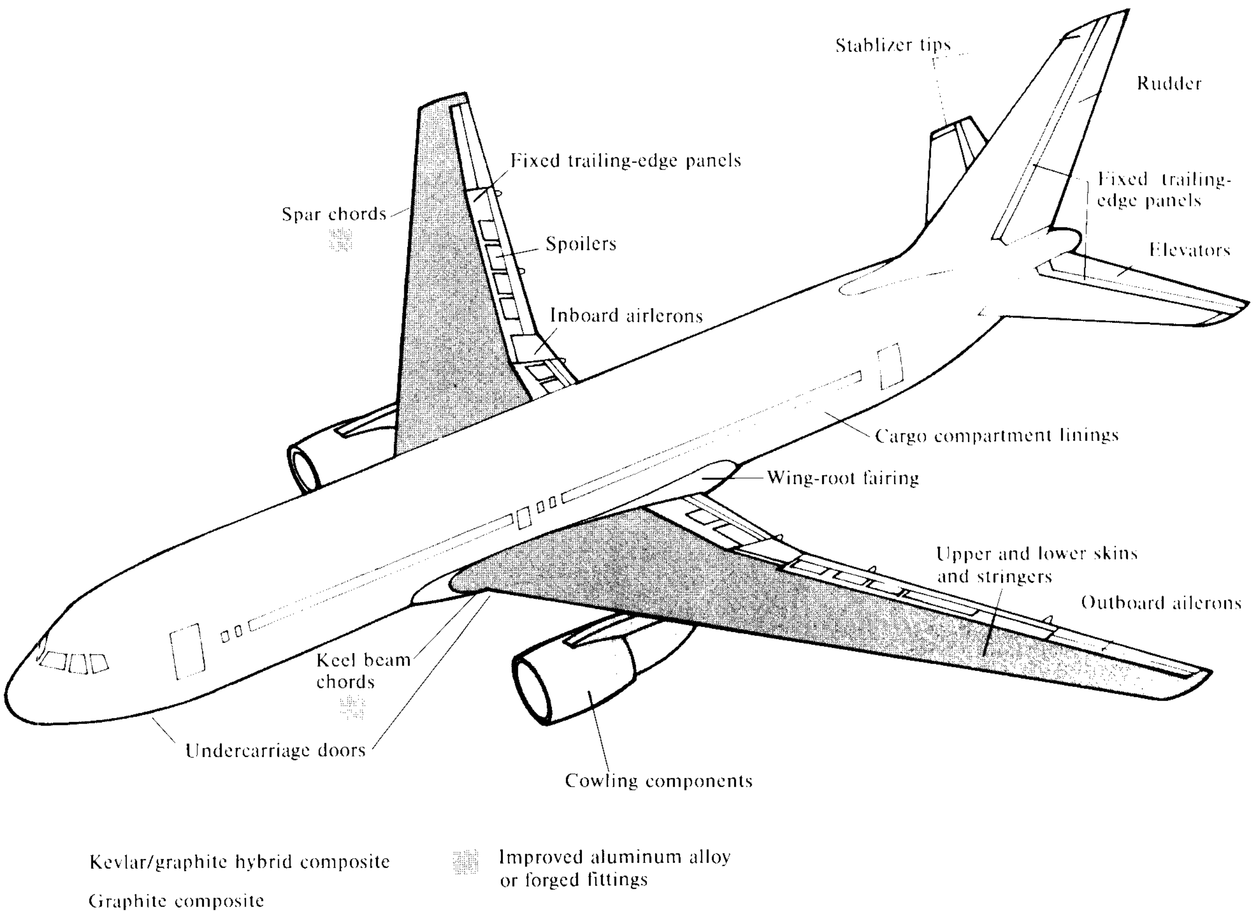
Figure 2
Use of Advanced Materials in Commercial Aircraft



Advanced materials in the Boeing 767 are designed to produce a light, durable, and fail-safe structure with low cost of ownership.

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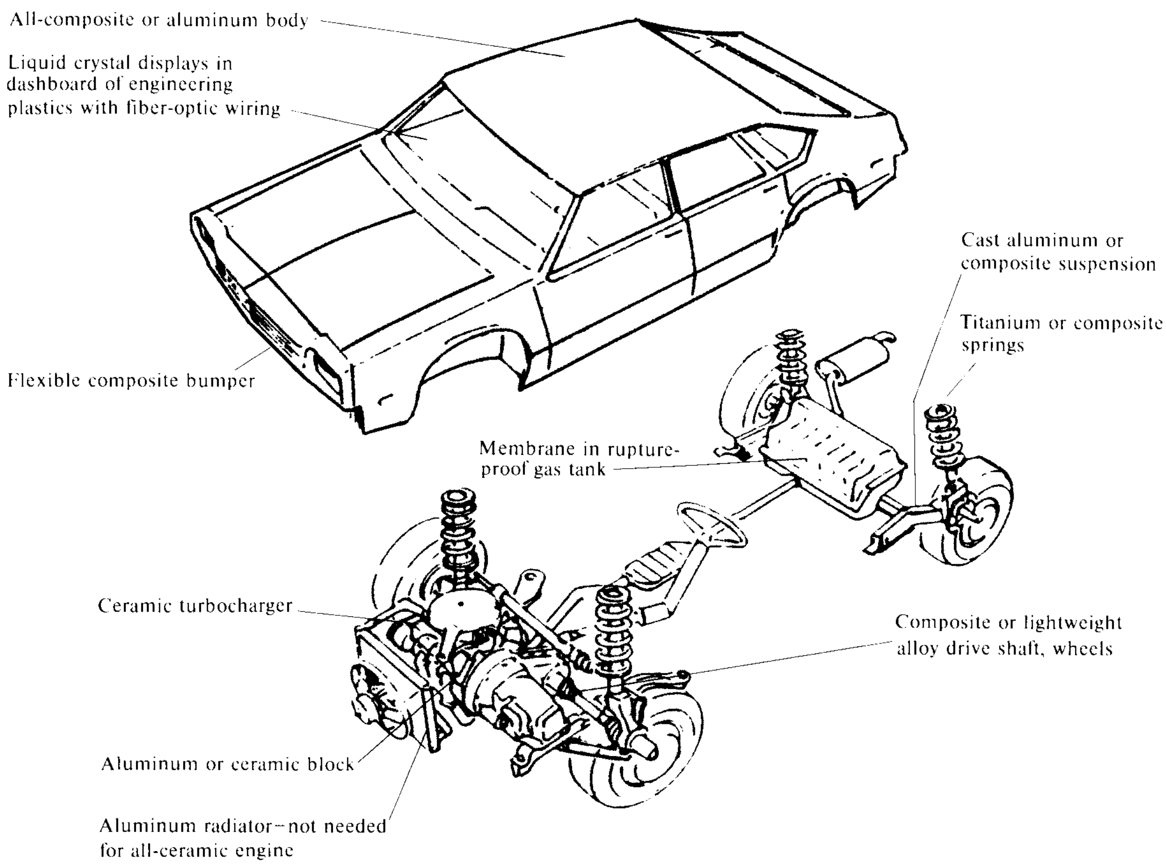
- In civil airframes, composites may be near the threshold of a major increase in use. The newest airframes (such as the Boeing 767) already use composites extensively in secondary structures, such as elevators, spoilers, rudders, and engine cowlings (figure 2). Sizable rewards await airframe manufacturers who can safely and economically use composites extensively in the primary structures—main wings and fuselage—of large commercial aircraft.
- Automobile bodies will become lighter through more extensive use of engineering plastics, composites, and advanced alloys (figure 3). Enormous capital already invested in metal-stamping equipment, however, is one barrier to rapid change to nonmetallic materials.

Figure 3
Selected Potential Uses of Advanced Materials in Automobiles



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Advanced nonmetallic structural materials also promise some relief from dependency on Third World suppliers of strategic mineral additives to metal alloys.[redacted] 25X1

In civil and military information applications, researchers are looking to increase computing speeds, expand memory capacities, and reduce power requirements for electronic components by exploiting advanced materials. As silicon-based semiconductors approach theoretical performance limits, researchers are experimenting with faster semiconductor materials such as gallium-arsenide (roughly an order of magnitude faster) and indium-antimonide (three orders of magnitude faster when used in optical switches). Optical fibers made of silicon glass are outcompeting copper wires in communications applications because of greater message-carrying capacity; the same diameter cable is capable of carrying at least an order of magnitude more messages simultaneously. Electro-optical sensors hold great promise for monitoring a wide variety of conditions—temperature, pressure, and electromagnetic radiation, among others—important in a wide variety of applications, such as target-homing antitank projectiles and intelligent robots.

Additionally, advanced materials have the potential for competitive impact on a variety of products and on the industrial base itself. Examples include:

- Membranes, to significantly lower energy requirements for many chemical processes and reduce costs of depolluting effluent from manufacturing plants.
- Photovoltaic materials, for inexpensive, pollution-free generation of electricity.
- Materials that enhance the quality of life, such as nontoxic, fire-retardant plastics, fibers to replace carcinogenic asbestos, and body replacement parts.

Sometime in the next century, combinations of components and equipment based on advanced materials could be integrated into systems with dramatically enhanced capabilities. For example, "smart," highly maneuverable, and perhaps relatively inexpensive missiles—using advanced sensors and microprocessors for navigation and target homing plus lightweight structural materials and fuel-efficient propulsion systems—may revolutionize military aircraft.

Reaching a High-Risk Market

The problems and risks in bringing new materials and products to the market are often sizable. Costs, timing, and marketing are all critical factors. Development is costly and time consuming—often substantially exceeding a decade—with no guarantee of technical success or economic feasibility. Rewards for innovative companies include proprietary technology advantages—patented materials or manufacturing processes—that can be converted into quasi-monopolistic production of high-value-added materials or products. Possibilities of spinoffs from commercial to military applications can be an additional incentive.

Materials researchers face different risks depending on whether they are principally suppliers or users of advanced materials. Market uncertainty is the greatest risk to suppliers of innovative materials—especially of structural materials. Sizable multiple markets are often necessary before suppliers will devote resources to the development and production of advanced materials. Prospective suppliers desire accurate estimates of markets in order to size production facilities appropriately to achieve economies of scale without building excessive capacity. Potential users, however, are seldom able to forecast accurately their needs for new materials. A number of suppliers, burdened with financial pressures, therefore often find it expedient to license technology, even to overseas competitors. 25X1

The Two-Way Civil-Military Relationship

Countering the historical trend, the flow of dual-use advanced materials and associated manufacturing processes from civil to military applications is growing. Cost and durability requirements are the driving factors: 25X1

- *For some advanced materials, large civil markets can attract substantially more R&D investment than military programs can support, achieving economies of scale and driving down production costs of devices and equipment sooner than might occur otherwise, as has happened most prominently in microelectronics.*
- *Although performance requirements for materials are typically higher in military applications, requirements for durability are often significantly higher in corresponding civil uses; jet engines for commercial aircraft, for example, are expected to last an order of magnitude longer than those for military aircraft.* 25X1

Civil developments in materials technologies are increasingly important to the military for several reasons:

- *Use of inexpensive components lowers the cost of weapon systems.* 25X1
- *Military R&D funds can be focused on narrower objectives and hence more effectively used.*
- *Skills, know-how, and experience gained on civil programs are transferable to military programs.*
- *Civil production facilities provide surge capacity for the military in times of national emergency.*

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The risks for the materials users (product manufacturers) are somewhat lower than for the suppliers because they understand their product markets better. But timing in product development and market entry can be critical. At one extreme, companies that fail to apply advanced materials technology at an early stage may be hard pressed to catch up with competitors, as their technically outdated or overpriced products slump in market share. At the other extreme, overaggressiveness in application of advanced materials can be disastrous. The Rolls-Royce bankruptcy and bailout in the 1970s by the British Government resulted in part from using unproven turbine blades made of composite material in a new jet engine. [redacted] 25X1

Industry Structure

The importance and pervasiveness of advanced materials in civil and military applications have driven many corporations, as well as most governments, to be active in materials R&D. In the conventional sense, however, there is no materials industry per se and no major players dominate the field. In the United States alone, research groups pursuing advanced materials number in the hundreds, if not the thousands. Most groups reside within manufacturing firms—some of which are multinationals—or in universities affluent enough to afford the necessary research equipment. Additionally, a few independent laboratories specialize in pursuing materials research for both single and multiple clients, including foreign participants. [redacted] 25X1

[redacted] 25X1

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Government involvement in materials R&D, once rather selective, is on the upswing. The US Government has pursued materials R&D only for advanced military, nuclear, space, and more recently, energy-related applications. Success or failure in developing and exploiting other advanced materials has been left primarily to the free enterprise system. Overseas, this government/private industry pattern has been mirrored to a large degree, but this is changing. Some foreign governments, particularly the Japanese and French, are no longer willing to leave national progress in materials R&D to the uncertainties inherent in private-sector investment decisions. [redacted] 25X1

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The engine (now the RB211) was for the then new wide-body jumbo jets. [redacted] 25X1

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Western Europe. The French announced in late 1982 their national program for materials development funded at 1 billion francs ($140 million)[2] for three years. Under the Mitterrand government's new plan for industrial revitalization, the French are counting heavily on newly nationalized companies to take the

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[2] Converted at rate of 7 francs = $1.

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lead in such research. [redacted]

Implications for the United States

Industrial Competitiveness. Foreign developments in materials technology have long-term competitive consequences for US industries. Foreign superiority can lead to proprietary application of advanced materials and manufacturing processes that translate into product performance and manufacturing cost advantages in a number of industries, enhancing the competitiveness of foreign products in world markets. In particular, foreign firms may gain several advantages:

- Some foreign firms may barter advanced products with US firms to gain additional materials technology, making them potentially competitive across an even broader spectrum of products in the future. [redacted]

- Foreign governments may apply measures that permit domestic manufacturers to take more risks in the application of advanced materials than their US competitors. Measures could include direct funding, subsidies, tax breaks, and loans backstopped by guarantees that will save unsuccessful companies from bankruptcy.

- Foreign suppliers may give preferential price or availability concessions on advanced materials to other domestic manufacturers, enhancing their product competitiveness relative to US manufacturers. Should this happen, US product manufacturers would become vulnerable to the actions of foreign materials suppliers. For self-protection, US product manufacturers may find it necessary to bear the extra costs of stockpiling or manufacturing considerable quantities of the advanced materials they need; US semiconductor manufacturers, for example, are already doing this with polysilicon for semiconductor devices. [redacted]

[redacted]

Market uncertainties and potential excess world capacity may discourage potential US suppliers from developing new materials and production capacity. Hence, the relevant production technology—design and manufacturing capabilities, production experience, and know-how—for key military applications may never be established. [redacted]

Technology Transfer. Emergence of strong foreign capabilities in advanced materials complicates US efforts to control technology transfer—the flow of such materials and manufacturing processes—to the Communist countries. Enforcement of COCOM restrictions on the transfer of advanced materials technologies becomes more difficult as the number of

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possible sources of these technologies increases. Many of these technologies are dual use; they could be important militarily as well as commercially. A variety of evidence indicates the Soviets have been seeking a number of such technologies, including those for production of carbon-carbon materials, carbon fibers, and Kevlar (a duPont trade name). 25X1

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Irrespective of foreign successes, advances in materials also pose competitive problems for US industry, especially certain mature industries, such as steel. Many of the new materials are nonmetallic and are gradually replacing metals—steel, aluminum, and copper, for example—in a wide variety of applications. Demand for metals could slacken or even decline. 25X1

Appendix

Glossary [3]

Advanced materials
Manmade, high-value-added, nonliving materials that enhance the performance of the products or equipment in which they are used. Some experts make a distinction by application as to whether a material is high technology. *Superalloys,* for example, having been used in aircraft for years, may be considered high-technology materials by some only when applied to automobiles.

Amorphous metals
New, unconventional, noncrystalline metals, also known as glassy or rapidly solidified metals.

Carbon-carbon materials
A variety of *fiber-reinforced plastics* formed at low temperatures, then baked at high temperatures to increase strength and heat resistance. Primary use has been in aircraft brakes, rocket nozzles, and reentry vehicles.

Carbon fibers
By far the most commonly used short structural fiber in *composites,* specifically in *fiber-reinforced plastics.* High-temperature carbon fibers are properly called graphite fibers. Most carbon fibers are *PAN*-based; breakthroughs in processing *pitch* may be needed to make carbon fibers widely competitive with cheap glass fibers.

Ceramics
Nonmetallic, nonorganic materials. Compared to most metals, ceramics such as brick are attractive for structural applications because they are lightweight, resistant to corrosion and abrasion, durable at much higher temperatures, and under static loads are nearly as strong. The chief disadvantage is their brittleness; they are susceptible to fracture, especially under dynamic loads. This weakness is partially inherent in the tightly bonded atomic structure that contributes to positive characteristics, as with diamonds. Ceramic-matrix *composites* reinforced with ceramic or metal fibers may prove to be fracture resistant.

Coatings
Advanced coatings is an exploding subfield, both in new materials and manufacturing processes. A modern jet engine, for example, typically contains about a half dozen high-technology coatings for corrosion and abrasion protection. Among the more exciting future prospects are protective materials directly applicable to decaying structural materials, such as rusty steel and concrete. New process equipment, such as "electron beam epitaxy" machines, can be used to modify surfaces or to apply ultrathin, precision-thickness coatings of a wide variety of materials.

Composites
Combinations of two or more individual materials, joined to enhance strength. The three basic types of composites are reinforced (for example, fiberglass), laminar (for example, plywood), and ultralight honeycomb-like structures. The most common reinforcing materials are *fibers.* Bonding between fibers and matrix materials is critical. Matrix materials may be organic (for example, polymers), metal, or ceramic. The only common commercial composites are *fiber-reinforced plastics.*

[3] Terms in italics are defined elsewhere in glossary.

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Crystals

Solid materials with an orderly atomic structure. Crystals are important in both structural and functional applications. Single-crystal metal parts are stronger than their conventional counterparts; the latter are weakest along the boundaries between their numerous crystals. Functionally, many materials, such as *semiconductors*, can reliably transmit light or electrons only when they are in crystal form.

Fibers

Fibers, often in *crystal* form, are used structurally to strengthen materials and functionally, in *fiber optics*, to transmit information. Fibers may either be short (as in fiberglass) or continuous (as in fiber-optics or filament tape). The chief benefit of reinforcing fibers is to stop crack propagation, a problem common to most metals, *plastics*, and *ceramics*. Of the high-technology organic fibers, the most important are *carbon fiber* and *Kevlar* (a duPont trade name). The latter has many uses, including projectile trapping applications: bulletproof vests and jet engine casings (trapping broken turbine blades).

Fiber optics

Continuous fibers, usually made of silicon glass, capable of transmitting information-carrying light in a bendable path. Made into cables, these fibers are replacing metals (mostly copper, some aluminum) in communications applications.

Fiber-reinforced plastics (FRPs)

Plastic (or resin) matrix material reinforced with fibers. Fiberglass is the most familiar example of a composite—glass fibers randomly oriented to stiffen a resin matrix. A typical composite airframe part is made of several dozen laminations of FRP material in which continuous fibers are laid in a single direction. In successive laminations, fibers are oriented at different angles for greater strength. Most part fabrication is done expensively by hand (partly because production runs for aircraft tend to be small), prior to hours-long curing in ovens (called autoclaves). High-temperature FRPs are known as *carbon-carbon* composites.

Gallium-arsenide (GaAs)

An advanced *semiconductor* material, which has several uses in electronics: memories, logic circuits, laser sources, sensors, and communications transmitters and receivers. In the first two applications, GaAs is ideally preferable to the now commonly used silicon because it is inherently about five times faster. In manufacturing, however, it is considerably more difficult to achieve required purities with GaAs than with silicon.

High-technology materials

See *advanced materials*.

Kevlar

High-strength, continuous fiber made by duPont. Kevlar is used in many applications, including jet engine casings and bulletproof vests.

Materials technology

As used in this paper, collectively: *advanced materials*, associated manufacturing processes, and know-how.

PAN

Acronym for polyacrylonitrile, a synthetic fiber from which most *carbon fibers* are made. Substantially more expensive than *pitch*.

Pitch

Inexpensive residue from oil refineries, which researchers worldwide are seeking to cheaply convert into high-quality *carbon fibers*.

Photovoltaics Materials that convert light (sunlight being of primary interest in terms of major applications) to electricity. Costs have fallen, but these materials remain about an order of magnitude away from being competitive as an alternative source of energy.

Plastics Organic materials made from crude-oil hydrocarbons. Despite the runup in oil prices during the last decade, *plastics* remain considerably cheaper than metals. Engineering plastics are those with higher performance properties that qualify them as *high-technology materials.*

Semiconductors Materials, such as *gallium-arsenide*, that allow electric current to move within them under certain controllable or exploitable conditions. Precision applications that do not tolerate errors, such as memory chips and logic circuits, require high-purity semiconductor materials. As the term is commonly used, it refers only to this latter, narrower group of semiconductor materials. Notwithstanding, there are additional high-technology semiconductor materials, such as indium-antimony, being used in other high-technology applications.

Strategic minerals Commonly used phrase (and literally something of a misnomer) for selected chemical elements, such as cobalt and chromium, typically found only in certain minerals, and used to make high-quality steel and *superalloys.*

Superalloys High-temperature steel alloys containing sizable amounts of nickel and/or other alloying elements, such as cobalt, obtained from *strategic minerals.*

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