

Issues of Importance
to U.S. Civil Aviation
and Civil Aircraft Manufacturers

TECHNOLOGY READINESS

***KEY TO LONG-TERM MARKET STRENGTH
OF U.S. CIVIL AIRCRAFT MANUFACTURERS***

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.

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INTRODUCTION

The civil aircraft industry has been a consistent "economic winner" for the United States, contributing positive trade balances year after year. In 1988, the U.S. enjoyed an aerospace trade balance of \$17.9 billion. Over 70 percent of that surplus can be attributed to the worldwide success of U.S. civil aircraft, engines and parts.

Aside from its trade contributions, the civil aircraft industry contributes to the nation through technology spinoff and a wide range of industrial technological capability. It provides jobs for over 330,000 workers - approximately one-quarter of aerospace employment.

The commercial transport sector has been the strength of U.S. civil aircraft manufacturing in recent years. A record backlog and strong passenger growth projections indicate that will continue. Increased shipments of piston rotorcraft in 1988 and an anticipated 1989 upturn in unit sales of turbine helicopters - plus strong sales of business jets and single engine piston aircraft by general aviation manufacturers - are other promising signs for the civil sector. This positive picture helps offset the less optimistic prospect for the aerospace defense sector. Until recently, U.S. military orders provided the impetus for growth in the industry's workload; however, civil orders now drive backlog growth.

Civil aircraft industry prospects *are* good. But it would be a mistake for the United States to assume that the industry's market position is indefinitely assured. Foreign competition is strong and growing. Other countries recognize the important role aerospace plays in developing a nation's industrial and technological capabilities. Aerospace, including civil aircraft manufacture, contributes enormously to national economic well-being through technology spinoffs and a diffusion of technological capability to other industrial sectors. This awareness - combined with the pressures of financing new aircraft and engine projects and of competing for sales in a growing market that is now largely outside the United States - has fostered a global industry of many highly capable players.

Civil aviation trade issues - particularly foreign government support of manufacturers - have received considerable attention in recent years. In a number of instances, the fact that civil aircraft manufacturers abroad receive direct government support influences the United States' business position. But matters relating to U.S. policy and its implementation also have a strong influence on U.S. civil aviation and U.S. civil aircraft manufacturers.

This paper is one in a series on civil aviation issues. The series is published in an effort to look beyond present success and assure that a world-class U.S. civil aircraft industry remains on the leading edge.

TECHNOLOGY READINESS: KEY TO LONG-TERM MARKET STRENGTH OF U.S. CIVIL AIRCRAFT MANUFACTURERS

SUMMARY

While technology alone does not equate to business success it is certainly the keystone for U.S. civil aircraft manufacturers. However, numerous factors are at play which may affect the U.S. long-term technological position in civil aeronautics.

The competition for U.S. civil aircraft manufacturers has grown in strength both technically and financially—and market share has declined for U.S. civil transport, helicopter and general aviation manufacturers. Much of the success of industries in other countries has come with the help of national governments and strong government involvement in aircraft RT&D programs. Government support has fostered a long-term view in R&D and, for example, has assisted Airbus in its strategy of offering technological advances in new large commercial jet transports.

The formation of international consortiums to share cost and risk, and gain market access, has also contributed to the transfer and development of aerospace technological capability. The economic integration of Europe appears to lay the groundwork for even higher levels of investment there, and greater focus in aeronautical research and development.

Current market realities could affect U.S. technology development over the long-term. Following deregulation, operating cost has become so important to commercial airlines that it is now a primary determinant in technology application decisions. While sufficient potential for technological advance exists, cost conscious customers are forcing more conservative, risk-averse technology development decisions.

As a matter of national policy, western Europe, Japan, and certain developing countries have especially strong government involvement in aircraft RT&D programs. The United States has no comparable comprehensive civil aircraft RT&D program involvement. The United States has a well-established aeronautical basic and applied research and general advanced technology

program. It also has technology development programs for the acceleration of generic technology for product design and application, but these are relatively small and weakly-linked to design and development. With U.S. companies focused on near-term technology development for the marketplace, and government focused primarily on longer term basic and applied research, there is a critical gap between technology availability—and its readiness for application with low technical and financial risk. Technology “readiness for application” is a key to being competitive since advanced technology can take three to four years or longer to reach readiness for application and another three to four years to reach the customer. In aerospace, the cycle can easily be as long as 10 to 15 years. Yet, to a degree, the United States has neglected this important area of technology development and validation.

Within the context of the United States’ basic approach to business, action should be taken to maintain and improve U.S. competitiveness in this critical industry. This may require significantly more cooperation in technology development. Market leadership—once lost—is costly and difficult to regain.

CONCLUSIONS

- Technological capability in aeronautics is no longer predominantly a U.S. domain. Expertise can be found worldwide and governments, including those in Europe and Japan, provide financial and political support to their industry and favor targeted (application oriented) technology activity.
- The internationalized civil aircraft marketplace—and the huge financial requirements of aircraft and engine production—make cross-national technology and production arrangements a re-

quirement for doing business. At the same time these business relationships often entail transfer of technology, making preservation of a U.S. leadership role more important and also more difficult.

- As worldwide competition increases, the steadily decreasing content of U.S. components in foreign manufactured aircraft can become a long-term problem for U.S. suppliers, and can further diminish their capability to invest in market-enhancing R&D.
- The European Economic Community's goal of an integrated economy by 1992 should further strengthen the business posture of European competitors and put added pressure on the U.S. industry to form relationships with foreign manufacturers. U.S. leadership in these relationships will depend to a significant degree upon the expertise (including technological) brought to the relationships.
- Increased worldwide competition produces downward pricing pressures, which ultimately affect the ability to invest in advanced research and development. Government support reduces pressures on foreign civil aircraft industries to minimize costs or achieve profitability—or even to recover the cost of capital—and encourages the application of high risk technology to gain market share.
- In the United States, risks associated with applying new technology, plus the airlines' requirements for proven systems and for aircraft price and operating cost reductions, are forcing the conservative application of technology. But in the competitive market of the future, aircraft sales may well depend upon the application of advanced technology that has had sufficient attention to risk reduction and cost effectiveness through appropriate technology development.
- Despite government policy support for technology development (validation), there has not been a concerted effort to fill the technology readiness gap, e.g., to pursue those developments that provide the data base needed for early, low risk application of advanced technologies that can provide technological leadership. General plans for accomplishment of goals have not been implemented. Funding—and the single-year funding approach—is not adequate for U.S. leadership in civil aeronautics.
- A more aggressive, high-potential commercially oriented civil aviation R&T program is needed. For the most effective use of resources, the kind and level of technology programs supported in industry (directed at product development) and government (directed at development of generic technology) should complement each other. The U. S. government must continue its in-house basic and applied aeronautical research programs and its support of related university and industry programs for enhancement of basic research and development of advanced technology. To complete the cycle from research to commercial application, there should be a mechanism for joint government/industry development - through application readiness - of selected technologies with commercial potential.
- U.S. incentives for industrial technology development are adversely affected by tax, depreciation and credit rules/regulations, and low profitability. There is no direct evidence that this has curtailed short-term, low-risk technology investment in civil aerospace. However, the lack of incentives for long-term R&D and the lack of government activity in generic technology development constitute perhaps the most important inhibiting factors in retaining competitive preeminence in future world markets for the U.S. civil aircraft industry.
- U.S. anti-trust rules are ill-suited to deal with truly internationalized industrial sectors. In the case of aerospace, these rules unduly restrict the U.S. industry from the option of cooperative U.S. civil product development, in contrast to foreign government policies that favor such action. This is especially important in the case of high-cost, high-risk programs such as supersonic transports and civil tiltrotor transports.
- The limitations on technology development funding, and the high cost of applying new technology in aerospace, are strong arguments for more concerted and cooperative efforts among industry and between industry and government.

RECOMMENDATIONS

- Industry and NASA should consider ways to better advise, focus and participate in R&T and technology development/validation programs.
- NASA, with industry assistance, should reexamine its programs (general aviation, rotorcraft, subsonic and supersonic transports, and the national aerospace plane) to assure good program balance and seek to increase funding support for technology development/validation.
- Industry should work with the Department of Commerce and other government agencies to develop the means for more effective collection and assessment of foreign civil aircraft activity, including R&T.
- Industry should advise where there is urgent need for government action to provide incentives for industrial investment for new, long- and near-term R&T and technology development/validation, and where there are needs to reassess anti-trust rules to allow selective cooperation on civil aircraft product development.

TECHNOLOGY READINESS: KEY TO LONG-TERM MARKET STRENGTH OF U.S. CIVIL AIRCRAFT MANUFACTURERS

Following World War II, U.S. manufacturers built a dominant lead in aviation, both civil and military. This leadership was maintained well through the 1970s. In the late sixties, however, a number of European countries exerted special efforts to place themselves in a more competitive position. They were successful in gaining market share in both civil and military aviation. In some segments of the industry, the European nations have been joined in their success by countries, such as Brazil and Indonesia, that have more recently entered the ranks of the industrialized nations.

In the civil sector, the United States still retains market dominance, particularly in large commercial transports; however, it has lost significant market share to the European consortium Airbus. Market losses have been even greater for producers of general aviation aircraft and rotorcraft for the civil market.* The successes of other countries have often come with the help of national governments, as well as through the formation of international consortiums to reduce financial risk and broaden the technological, production and sales base for their aircraft.

In addition to increased foreign competition, U.S. civil manufacturers face a market environment which has changed in other ways. One important factor has been the impact of airline deregulation. Operating cost is now so important to airlines that it has become a primary driver for technology development and application. While sufficient potential for technological advance exists, cost conscious airline customers are forcing conservative, more risk-averse technology development

decisions. For American manufacturers, technology application timing has become a chancier matter, due in part to the decline of U.S. government support of basic aeronautical research and technology validation. Meanwhile, foreign government support of their industry has assisted in the early application of advanced technology and fostered a long-term view in their research and development (R&D) programs.

U.S. suppliers of systems and components to major commercial aircraft programs face competition similar to that of U.S. prime equipment manufacturers. Foreign suppliers have overcome the limitations of small domestic markets by the opportunity to sell to multinational aircraft programs. These second and third tier producers have enhanced their technological depth through "niche" specialization, and in the long term represent formidable competition for U.S. firms.

In the civil aircraft marketplace, increased competition from the European Community and elsewhere is a certainty and joint R&D projects are becoming an important element of the European competitive strategy. Although technology alone does not equate to business success, it is certainly the keystone. Important questions facing U.S. manufacturers are whether or not current market trends and pressures will diminish U.S. strength in aviation technology, and if so, what can be done about it?

U.S. Technology Policy

Leadership in aeronautics has been U.S. national policy for more than seven decades, and the pursuit of technology and its application has been an integral part of this policy. This is reflected in the acts establishing the National Advisory Committee for Aeronautics (NACA) in 1915 and later the National Aeronautics and Space Administration.^{4,5} The need to maintain aeronautical research and technology leadership was reinforced in the 1980s by three studies by the President's Office of Science and Technology Policy (OSTP).^{6,7,8} The first study calls for preservation of the role of the United States as a leader in aeronautics technology and application. The other two define the nation's aeronautical R&D

* In 1980, the U.S. share of large commercial jet transport orders was 88 percent, while share of deliveries was 89 percent. In 1988, U.S. share of orders was 76 percent, and of deliveries, 74 percent. In 1980, sales of U.S. civil turbine rotorcraft represented 80 percent of the world market; in 1986, that share had dropped to 43 percent. In the general aviation sector, the United States experienced a trade deficit in 1988 for the eighth consecutive year. Imports into the United States of general aviation aircraft doubled between 1985 and 1988, and accounted for about 54 percent of all such planes sold in the United States. General aviation imports include large commuter aircraft, a sector of the market in which the United States does not compete.^{1,2,3}

goals and an agenda for achieving them . . . "in view of tremendous challenges from abroad (and) tremendous opportunities for advances and leadership . . ." The later studies identify specific goals related to subsonic, supersonic and transatmospheric flight.

The OSTP studies and others point to the importance of technology and, in particular, technology readiness for application.⁹ They point to a critical "gap" between technology availability and its readiness for application with low risk from both technical and financial considerations (Figure 1). The data base in many important aeronautical technology areas has not been developed to the degree that technology can be applied with high confidence for meeting performance, schedule and cost estimates. Technology "readiness for application" is a key to being competitive since advanced technology can take three to four years or longer to reach readiness for application and another three to four years to reach the customer.* In fact, the cycle can be as long as 10 to 15 years.

U.S. civil aircraft manufacturers and their subsystem and component suppliers rely on business profits to provide capital for near-term R&D and longer-term research and technology (R&T) development. Generally, they rely on the government for long-term generic aeronautical R&T. In contrast, the governments of competing foreign countries work closely with their companies and tend to focus on technology for early application while also pursuing longer-term research and technology development.^{10,11,12,13,14} Over the long term, maintaining a competitive posture for U.S. manufacturers may well depend upon maintaining an effective technology devel-

opment and application effort, i.e., speeding up technology development and shortening the time between advanced technology development and product definition and application (Figure 1).

Joint U.S. government and industry work on advanced concepts, such as the unducted turbofan and the tiltrotor, are directed at filling the technology development gap. However, in recent years these types of programs have been few in number, causing concern over long-term U.S. competitiveness.

In the past, technology fallout from military R&D programs may have been a fertile source of advanced technology for U.S. civil aircraft applications. With the increasing divergence of military and civil operational requirements and specifications, military R&D will offer significantly fewer benefits for civil aviation. Possible exceptions may be in some areas of propulsion and rotorcraft technology where military and civilian requirements overlap.

The question of U.S. leadership in the application of new technology may be compounded further by the need for conservatism in applying technology to current airline needs. In today's highly dynamic aviation industry, characterized by airline deregulation and privatization, the application of new technology is dictated by its cost effectiveness for the airline customer. While new technology may ultimately determine manufacturer success, in the short term, airlines are unwilling to pay extra for advanced technology options.

CIVIL AIRCRAFT TECHNOLOGY DEVELOPMENT IN THE UNITED STATES AND ABROAD

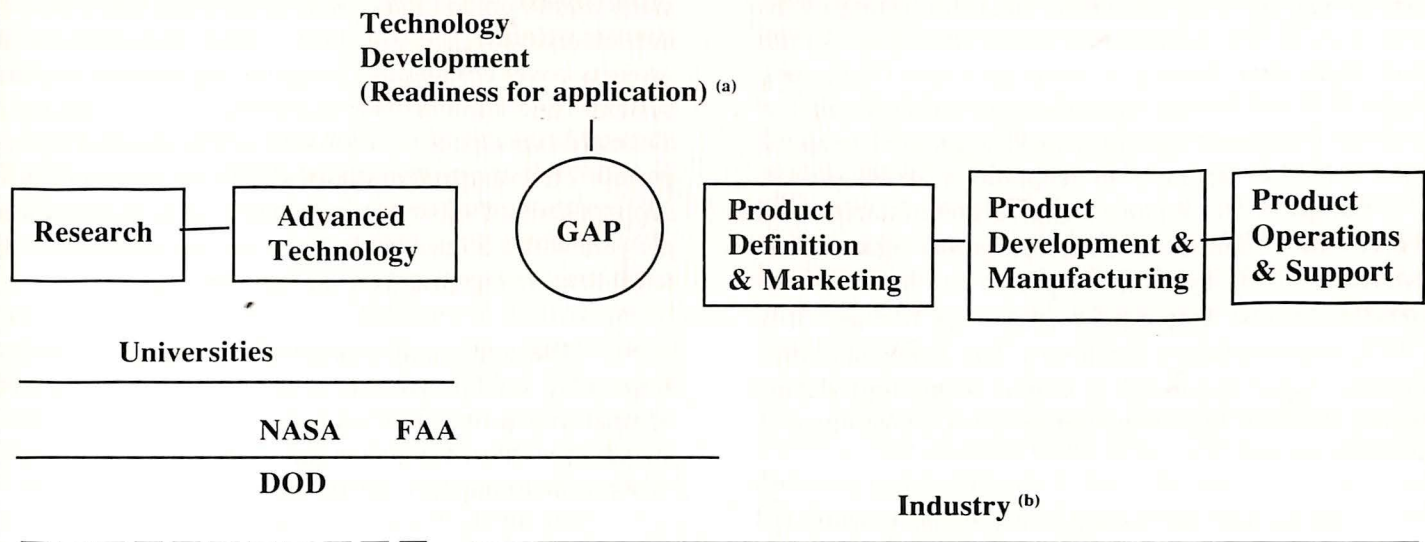
As the civil aircraft industry has internationalized, the flow of knowledge among partners in various aircraft and engine projects means that a nation's technological lead, where it exists, will likely be brief at best. Further, Europeans' post-war policies, directed toward development of a strong national defense and civil aerospace capabilities, have resulted in essential parity with the United States in research, development and production, including near parity in research facilities.¹⁵

* *Research & Technology Development* - activities primarily aimed at producing physical understanding, new concepts, design data, and validated design procedures for aircraft systems, subsystems, and components. Activities range from theoretical analysis to laboratory investigations to flight-testing experimental aircraft.

Technology Demonstration - activities primarily aimed at demonstrating improved subsystem or system characteristics to provide the development and manufacturing decisionmaker with the confidence that the anticipated improved level of performance is achievable in a new system.

System Development - activities aimed at producing a specific aircraft or aircraft system for operational use.

Figure 1
THE TECHNOLOGY DEVELOPMENT GAP



(a) Program Planning Includes:

- Selection of technology development candidates and program plans
- Program management and funding
- Implementation and data dissemination

(b) Industry Planning Includes Consideration of:

- Market and customer requirements
- Costs, financing and competition
- Selection and pursuit of specific programs

Source: Maggin, B., *Advanced Aeronautical Technology and Its Impact on the Competitive Position of the U.S.*, National Research Council, October 1985.

Foreign Aeronautical Technology Development

Foreign producers have aggressively pursued new aircraft developments for both current and projected markets as well as for longer-term potential. A rough measure of foreign interest in support of civil R&D is the percent of the gross national product (GNP) invested: in 1985, the United States invested about 1.9 percent and West Germany and Japan about 2.5 percent of GNP in civil R&D, although total civil and military R&D for all three countries was about 2.6 percent of GNP.¹⁶

Some of the technical areas in which other countries are making significant strides include the British and French application of computational fluid dynamics to the design of advanced high aspect ratio supercritical wings, and integration of high-lift systems on such wings.* In addition, the West Germans are applying active laminar flow control to commuter and other aircraft designs, although the United States holds the research lead in laminar flow control technology. The nations of western

* NASA, *Foreign Technology Assessment*, Operations Research Inc., NASW, 4138 (Washington, D.C., June 21, 1988).

Europe may conceivably lead the United States in application of polymer matrix composite structures and are aggressively applying advanced metallics, though U.S. technology in this area may be more advanced. In the latest flight data display technologies and flight-deck design, U.S. and foreign manufacturers are apparently at parity but Europeans have been more aggressive in application and the Japanese in technology development. U.S., European and Japanese engine manufacturers are involved in a number of co-development agreements. Concerted efforts by Rolls Royce in the late 1960s to extend its turbine temperature technology to match that of U.S. manufacturers essentially has been achieved. Recently, Japan expanded its engine technology development effort in high temperature alloys, castings and ceramic materials.

At present, the United States leads in advanced propfan technology development and in-flight testing through joint NASA/industry programs. Any lead in the development and application of high-temperature engine materials (or of the propfan engine) must be considered minimal because of the continuing working relationships among the various engine manufacturers worldwide.

In the area of advanced concepts of high-speed, air-breathing engines, research supported by the U.S. National Aerospace Plane program keeps the United States in the forefront, although all major European countries and Japan have active programs involving new approaches and/or concepts for trans-atmospheric propulsion systems. Related computational methods and analytical techniques linked to high-quality experiments in combustion and in high temperature gas dynamics are advanced in England, France and Germany, and are being pursued in Japan. Technological differences between nations appear to be related to the experimental and/or computational facilities available for research.

The Europeans plan to increase their aircraft market share over the next 20 years to some \$65 billion from roughly \$45 billion today. They anticipate gaining a larger share of the civil market than of the military market (a 32 percent civil market share for the period 1987-2010 compared with a 23 percent share from 1980-1986). To do this, they are planning programs that will broadly improve technology in aerodynamics, structures and materials, design, manufacturing, computation and acoustics. Specific targets have been developed by the Commission of the European Community based on a study conducted by nine European aircraft manufactur-

ers. Called European Cooperative Measures for Aeronautical Research and Technology (EUROMART), the study lists 60 potential cooperative projects; nine of these are detailed sufficiently to allow work to start.¹⁷ The lead projects cover aerothermodynamics, all-electric aircraft systems, and laminar-flow technology. These projects alone are expected to cost some \$1 billion over a 15-year period. The commission study calls for a buildup of R&T support above the current investment of \$436.6 million per year with a 25 percent increase immediately and a 50 to 60 percent increase over the next five years.*

There are many examples of cooperative RT&D actions by foreign groups to enhance their collective competitive position in aircraft, related systems and materials. One example is the formation of a French consortium to improve performance of titanium alloys.¹⁸

If these plans move forward, the technological posture of the Europeans will present an even greater challenge to the United States than exists at present.

U.S. Technology Development: Current U.S. R&T Planning

The nation's civil and military aeronautical research, technology and development (RT&D) programs evolve from a complex set of interactions between government (NASA, FAA, DOD, Congress, and the Administration), industry (airframe, engine and systems companies), professional organizations and academia. In the civil aircraft arena, the bulk of the generic, longer-term research and advanced technology (R&T) effort is carried out by NASA, whose programs are defined and developed through a broad range of mechanisms: advisory committees, in-house and contracted analyses and reviews, administration and congressional studies, and industry studies and analyses - all of which help form NASA's proposed program and budget plans for administration and congressional review and approval. Industry complements and builds on NASA's civil aircraft R&T through its own privately funded efforts whose primary focus is near-term technology development and application. However, industry has a vital interest in advanced long-term R&T pertinent to the definition and development of future generations of aircraft.

* For comparison, the NASA FY 1988 Aeronautics R&T budget was \$333 million. The Administration's budget proposal for 1989 was for \$404 million, and for 1990, \$463 million.

This interactive process has provided the U.S. civil aircraft manufacturing industry with the technological foundation for leadership. But is the United States today taking the actions necessary for retaining technological leadership?

Aeronautical Policy Direction - The Office of Science and Technology Policy, in its most recent statement of aeronautical policy direction for the nation, identified goals in three specific aeronautical research areas: subsonic - "a new generation of superior U.S. aircraft;" supersonic - "long distance efficiency and environmental capability;" and transatmospheric - "to secure future options."^{19,20} OSTP also recognized that "The most critical area (to accomplishment of these goals) is technology validation (development) . . . (in which significant technologies are advanced) into risk-acceptable readiness . . . (for) product application and production."

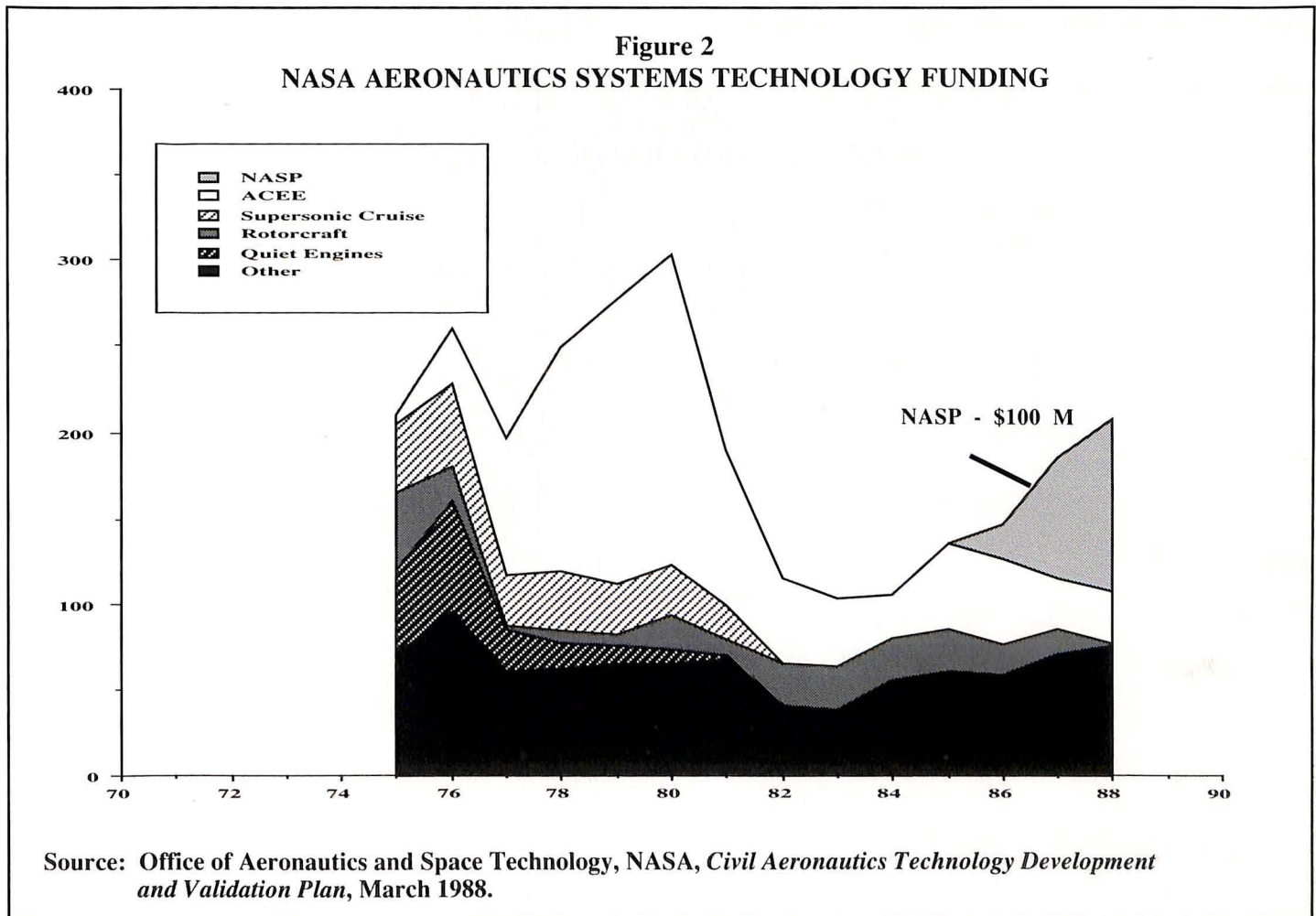
Within the context of research and technology, technology validation or development is generally the

most time-consuming, costly part of R&T. But the work is vital, having the potential to reduce project delays and costs, and ultimately, lost sales. Many studies address the need for technology development.^{21,22,23,24,25,26}

In this context, the OSTP takes the position that NASA's role is to "focus on long-term fundamental research," and NASA's base R&T program supports this philosophy. However, NASA also has a "system technology" program directed at amplifying the technology base in critical areas to help reduce the risk associated with the application of advanced technology to new developments.*

Figure 2 displays the history of NASA funding for its major systems technology (technology development) programs through 1988. Also shown is funding for the National Aerospace Plane (NASP) program which, since FY 1985, has been a separate budget item.

* NASA's term "Systems Technology" equates to Technology Development (Figure 1).



In recent years, the systems technology effort has been constrained by budget and administration pressures as has the total NASA aeronautics R&T budget. The aeronautical R&T budget has slowly increased from \$265 million in FY 1982 to about \$333 million in FY 1988. Considering inflation, there has been little, if any, increase in the total R&T program, with serious reductions in systems technology. In the face of growing aircraft complexity and competition, reduction in funding for the NASA program is a concern from both near- and long-term considerations.

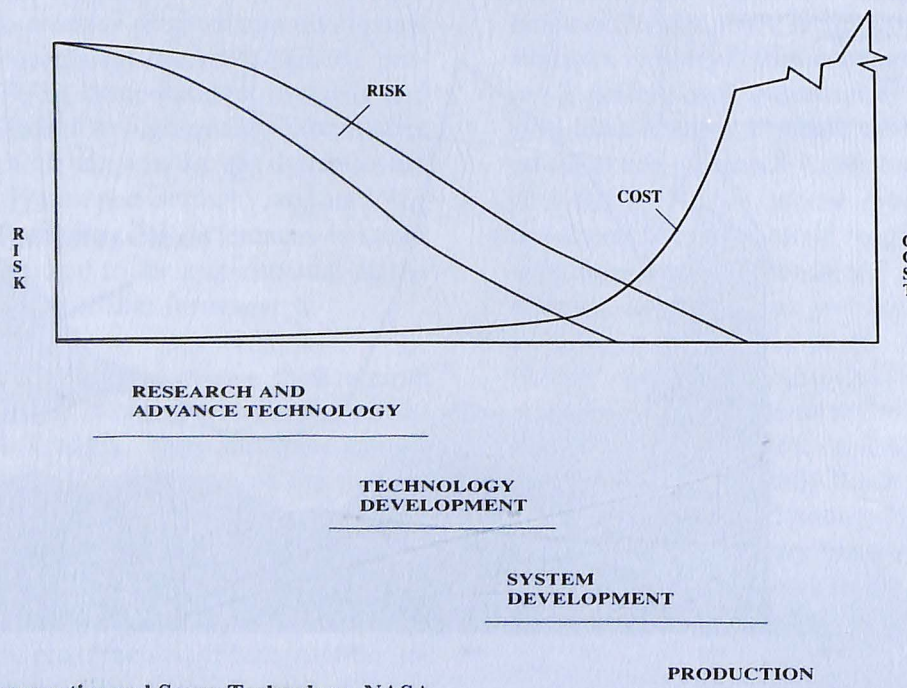
Government Planning to Fill the Technology Development Gap - Within budget constraints, NASA has helped define R&T and the technical problems, issues and viability of the advanced aircraft called for in the OSTP reports. NASA's work includes special studies of composite materials R&T, wind tunnel needs, a technology development and validation plan, and assessments of foreign technology and technology competitiveness.^{27,28,29,30,31} With DOD and FAA, NASA has studied commercial applications and technology development requirements of civil tiltrotors and high-speed transports.^{32,33,34} With DOD, it has studied National Aero-

space Plane advanced technology and technology development needs. Nonetheless, without budget and personnel increases, NASA cannot fully implement the OSTP policy. In real terms, the aeronautical budget has lost ground. In constant 1980 dollars, the FY 1988 aeronautics budget was 75 percent of the budget in 1980.

NASA - assisted by DOD, FAA, the Department of Commerce and industry - has developed a technology development and validation plan for the Senate Committee on Commerce, Science and Transportation.³⁵ Building on NASA's ongoing base R&T program, the plan focuses on filling the technology development gap. The work proposed is argued in part on the message presented in Figure 3, which presents an assessment of the risk in applying technology versus the state of the technology. The plan addresses three classes of aircraft: Subsonic Transport, Civil Tiltrotor/Commuter Propulsion, and High-Speed Transport.* Planning is divided into two development segments: (1) near-term - 1 to 7 years; and (2) far-term, 5 to 10 years.

* NASA notes that R&T and related technology development for other aircraft classes, i.e., private helicopters, commuters and business aircraft are addressed in the Base R&T program.

Figure 3
AIRCRAFT RT&D RISK-COST PROFILE



Source: Office of Aeronautics and Space Technology, NASA, *Civil Aeronautics Technology Development and Validation Plan*, March 1988.

Table I
NASA TECHNOLOGY DEVELOPMENT
PROGRAM CONTENT

Subsonic Transport

- Ultra-high-bypass ratio propulsor
- VHB with advanced core
- Composite primary structures
- Innovative fuselage & wing structures
- Laminar flow and fuselage turbulent flow reduction
- High aspect ratio laminar-flow wing and turbulent drag reduction
- Power-by-wire and fly-by-light

Civil Tiltrotor/Commuter Propulsion

- Advanced material and structures and cost-effective fabrication
- Pressurized fuselage and reduced maintenance
- Rotor/wing performance and noise improvements
- Operations effectiveness in high-density airspace
- Commuter propulsion improvements
- Alternative low heat-rejection cycles

High-Speed Transport

- Variable cycle engine with advanced core
- Supersonic flowthrough fan with advanced core
- Supersonic laminar flow, turbulent drag reduction, sonic boom minimization, and configuration integration
- Advanced materials
- Innovative design concepts, high temperature structures, and cost-effective fabrication
- Integration controls, advanced cockpit and active controls

Source: Office of Aeronautics and Space Technology, NASA,
Civil Aeronautics Technology Development and Validation Plan, March 1988.

The proposed program includes:

Subsonic Transport

- *near-term* - validation of critical technologies and developing high-payoff technologies with strong emphasis on cost effectiveness
- *long-term* - validation of most-promising next-generation technologies

Civil Tiltrotor/Commuter Propulsion

- *near-term* - development and validation of existing military technologies for the civil tiltrotor including operations in the National Airspace System and development of technology for small turbine engines
- *long-term* - validation of small turbine engine technology

High-Speed Civil Transport

- *near-term* - development of high-leverage enabling technologies, definition of validation candidates, and strong emphasis on environmental compatibility
- *long-term* - validation of enabling technologies, establishment of design data base, and assistance to FAA in defining certification criteria.

The major elements of the program plan are noted in Table 1. The plan builds on existing R&T and its implementation requires a cooperative government-industry effort.

This technology development, "gap-filling" plan has not been funded, nor has a program definition, development and implementation process been structured for an acknowledged critical step toward maintaining U.S. aeronautical technology leadership.

Industry Planning to Fill the Technology Development Gap

Industry, besides doing its own technology applications R&D, continues to provide counsel to NASA, FAA and other government agencies concerning aeronautical R&T needs.

In 1983-84, the Aerospace Technical Council of the Aerospace Industries Association (AIA) undertook to define aerospace technologies with great payoff potential

for the 1990s for both civil and military aircraft and spacecraft.³⁶ The goal was to "encourage a bolder, longer term research and development strategy - in a drive for clear-cut U.S. product superiority in the world marketplace." The study presents a conceptual plan for gaining this posture through industry collaboration and joint ventures. The civil aircraft related technologies identified by AIA included aerodynamics, structures and materials, acoustics, propulsion, avionics, flight controls, and subsystems for subsonic transports (long and short haul) and rotorcraft. Selected technologies of special interest included transonic aerodynamics, computational fluid dynamics, computational electro-magnetics, vortex flows, powered lift, laminar flow and control, composites, and high speed, long-range rotorcraft systems. The work addressed in the AIA study represents the research and advanced technology elements of Figure 1.

The AIA continued its studies of technologies to enhance industry's technological position. Its effort resulted in identification and development of "roadmaps" for key "high-leverage, enabling technologies" for future civil and military aerospace programs.³⁷ Nine technologies were first identified: composite materials, very large-scale integrated circuits (VLSI), software development, propulsion systems, solid rockets, advanced sensors, optical information processing, artificial intelligence, and ultra-reliable electronics. Computational science and superconductivity were later added to the list and VLSI dropped because of the already considerable attention being given to this important technology.

Elements of AIA key technology areas that relate to civil aircraft are noted in Figures 4A, 4B and 4C. For example, commercial aircraft sensor requirements may differ from those of military aircraft and lead to sensors directly applicable to commercial transport needs - passive optical sensors and optical communication busses that are very reliable, fault tolerant and low cost. Additionally, the AIA software roadmap's parameters envision considerable support in the achievement of ultra-low cost commercial aircraft and fail-safe air traffic control.

Significant parts of the R&T activity proposed by the AIA key technologies effort are not active parts of NASA's programs, but possibly should be. Notably, little attention is given in the NASA program to manufacturing, materials, integrated circuits, software and artificial intelligence.

AIA has been working to obtain validation of the roadmaps and cooperation in the requisite technology development programs. Teams of technologists from industry, government and academia have reached a consensus on the roadmaps and are proceeding to develop them in more detail. A national plan will be formulated around the Key Technologies with the intent of coordinating and accelerating their development. In order to accomplish this, AIA has set up a foundation, the National Center for Advanced Technologies (NCAT), a part of which is the Aerospace Technology Policy Forum. The Policy Forum will seek to foster more cohesive national policies regarding technology development as well as creative ways of encouraging cooperative R&D planning and implementation. Members from industry, government and the university community may address issues such as tax credits, increased support for IR&D, or regulatory changes.

The AIA studies and the NASA technology development and validation plan complement each other. The AIA studies address: (1) critical research and advanced technology that amplifies NASA's aeronautics R&T in the classical aerodynamics, structures and propulsion areas, and (2) R&T that has been given little attention in NASA's aeronautics program. The NASA study for the Senate addresses technology developments responsive to national goals that have a high potential for payoff, and are considered critical to technological leadership. All the plans envision joint government, industry and academia participation.

What Is Needed Now

To convert plans into real programs, the involved parties need to address the question of a management structure for continued planning, review and assessment of overall progress with respect to civil aeronautics goals. This does not exist today. Such a structure is also needed to obtain working agreements - including agreements on the commitment of resources for program implementation.

NASA may be in the best position to provide this management function from program integration and coordination perspectives. NASA could also have a stronger role in technology development to fill the current "gap." There is an obvious need to develop an effective means of identifying and implementing technology programs in a continuous rather than a reactive process with each new competitive crisis.

The limited government and industry resources available, and the high cost of applying new technology to new or derivative aircraft programs argues strongly for more concerted and cooperative efforts to develop technology to the point of readiness for applica-

tion. Such cooperation is consistent with the United States' traditional view of the roles of government and industry and is needed to assure the United States a strong competitive position in the international market for civil aircraft.

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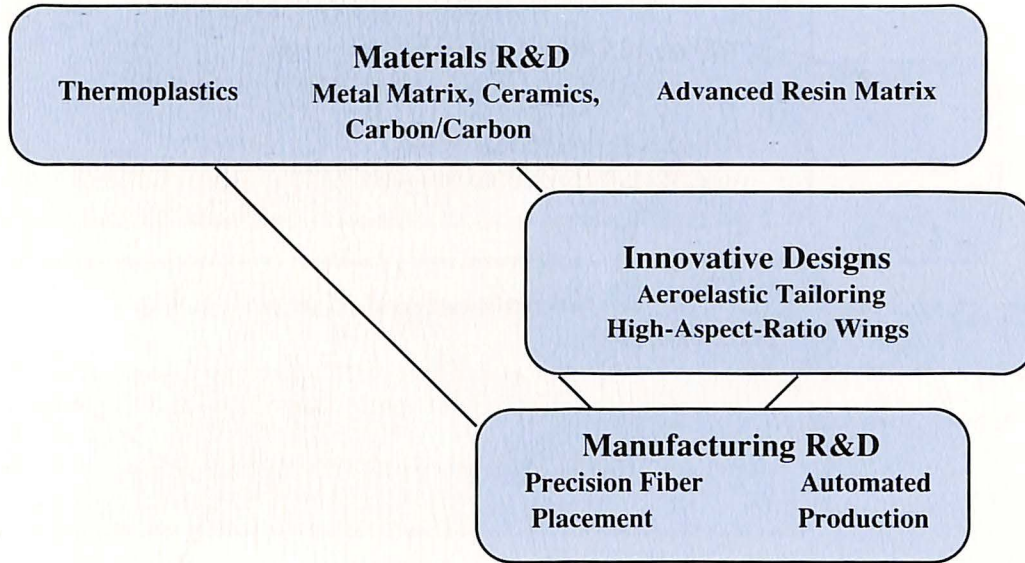
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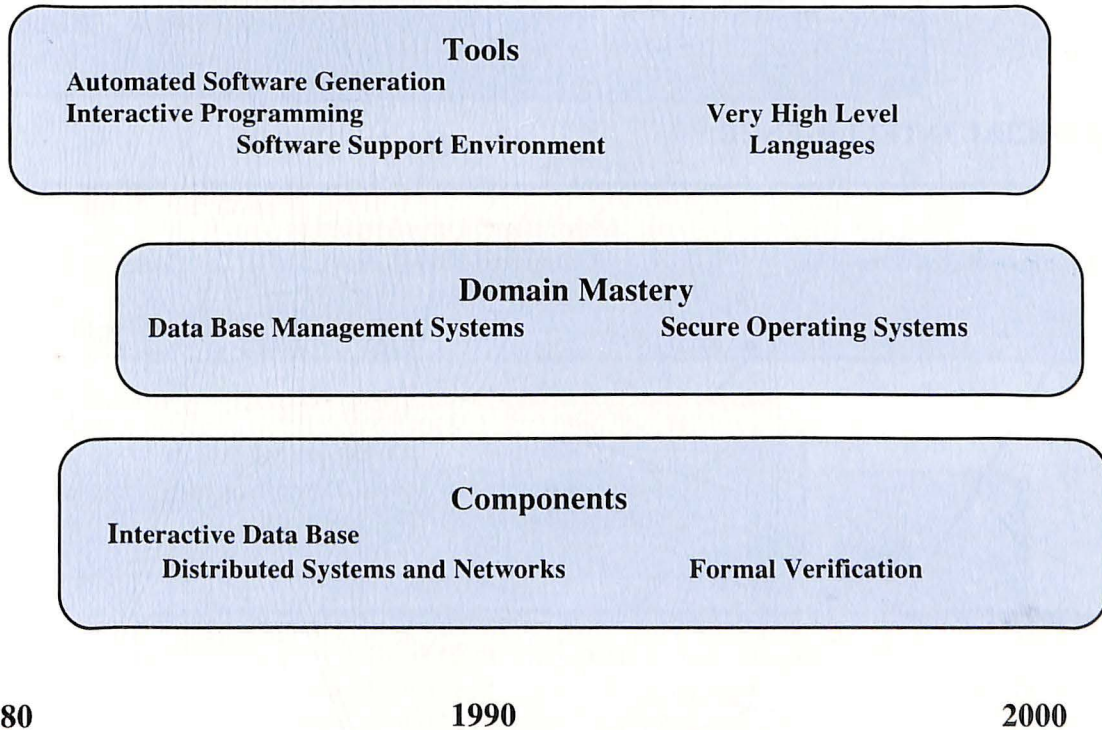
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Figure 4A
AIA 1990s TECHNOLOGY DEVELOPMENT ROADMAPS
RELATED TO CIVIL AIRCRAFT

• **COMPOSITE MATERIALS**



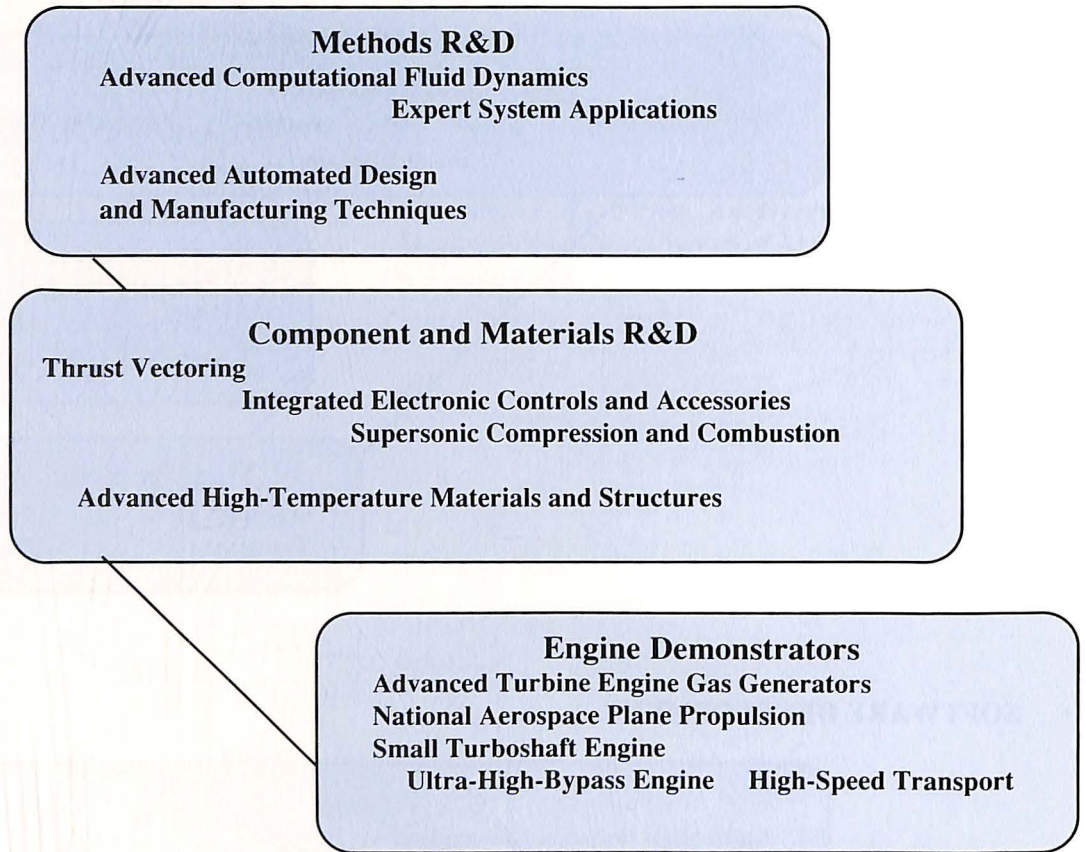
• **SOFTWARE DEVELOPMENT**



SOURCE: *Key Technologies for the 1990s, An Overview*, A Report of the Aerospace Technical Council of AIA, November 1987.

Figure 4B
AIA 1990s TECHNOLOGY DEVELOPMENT ROADMAPS
RELATED TO CIVIL AIRCRAFT

• **PROPULSION SYSTEMS - AIRBREATHING ENGINES**



• **ARTIFICIAL INTELLIGENCE**

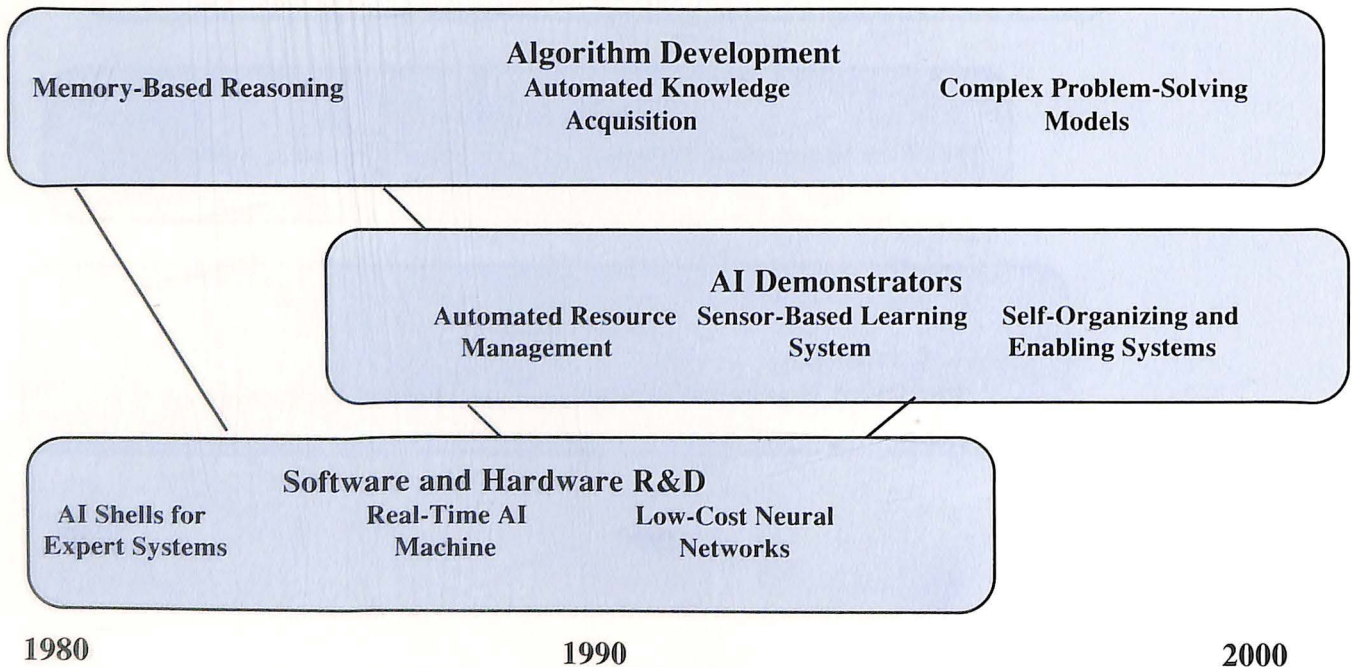
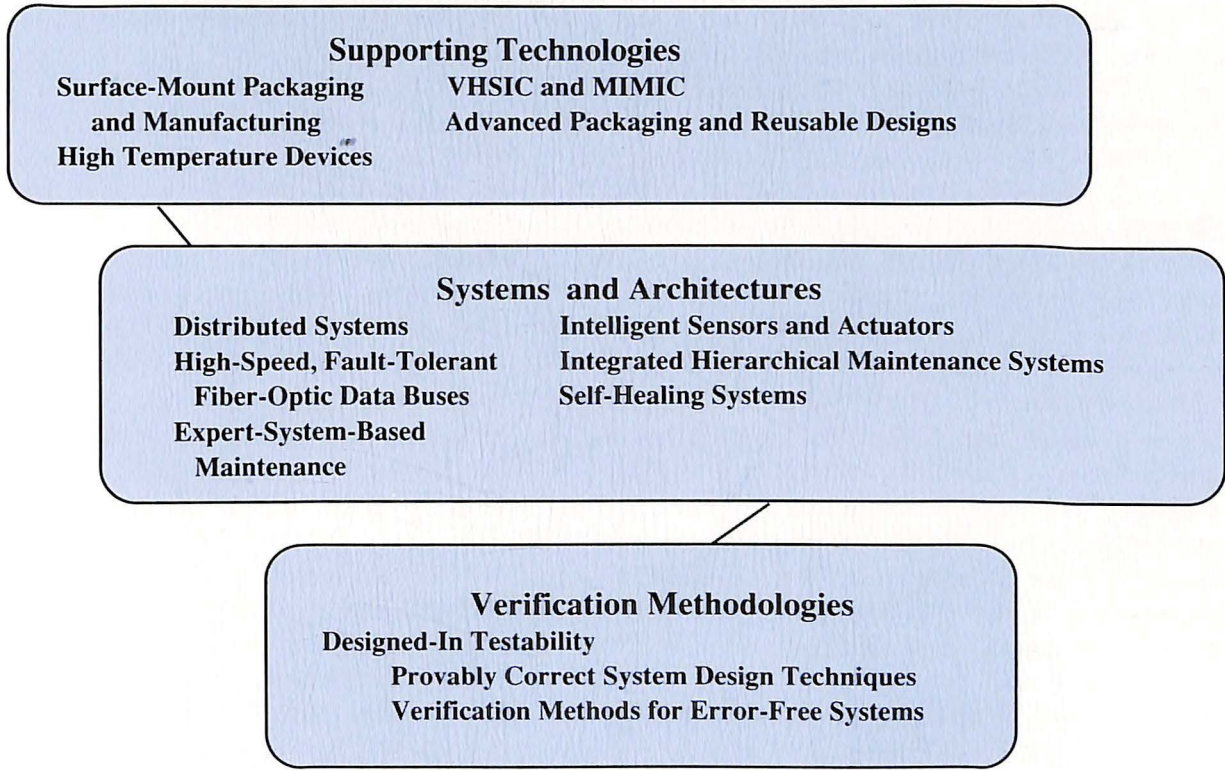


Figure 4C
AIA 1990s TECHNOLOGY DEVELOPMENT ROADMAPS
RELATED TO CIVIL AIRCRAFT

• **ULTRA RELIABLE ELECTRONIC SYSTEMS**

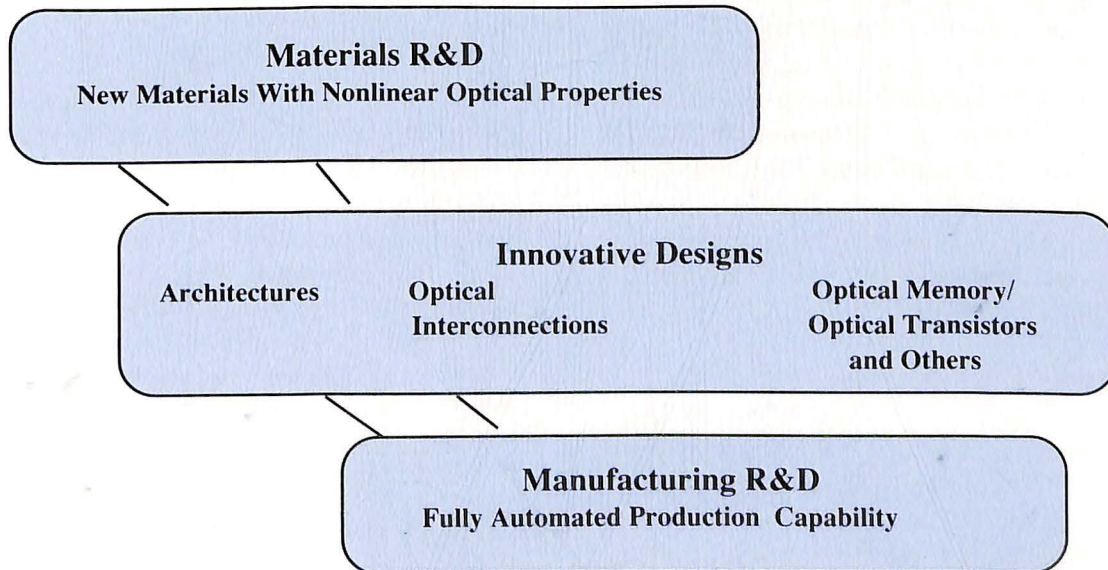


1980

1990

2000

• **OPTICAL INFORMATION PROCESSING**



1970

1980

1990

2000

U.S. AND FOREIGN AIRCRAFT MARKET AND TECHNOLOGY STATUS: A REVIEW

Commercial Transports

The post-World War II (WWII) "cold war" prompted the U.S. to undertake a large military aircraft program which contributed to leadership in both civil and military aeronautics. Building on the successful use of jet engines on large military aircraft, U.S. manufacturers applied jet engines to civil transports. The Boeing 707, the first truly successful commercial turbojet transport, evolved from that effort. The Boeing prototype was not chosen for the military transport program but was subsequently altered during a privately-funded development program to meet civilian requirements. Boeing's family of 2-, 3-, and 4-engine transports evolved after that in conservative steps rather than through bold application of advanced technologies. Douglas Aircraft, later McDonnell Douglas, pursued this same approach and developed a commercially-successful family of turbojet transports. Convair and Lockheed dropped out of the civil transport business—Lockheed relatively recently after limited sales of its L1011, 3-engine, wide-bodied transport.

The European aircraft industry revived through individual country efforts following WWII, but was also assisted by cooperation with U.S. manufacturers through the North Atlantic Treaty Alliance (NATO). U.S. technology was transferred through: joint development, licensed production and coordinated aeronautical R&D, both civil and military. The British de Havilland Comet turbojet and Vickers Viscount turboprop in the early 1950s, and somewhat later the French Caravelle turbojet, ushered in the era of jet-powered transports. None of the aircraft were commercial successes for their manufacturers. In 1962, the Anglo-French Concorde treaty initiated close collaboration on major civil aircraft projects in Western Europe. The French-British Concorde supersonic transport which resulted is still in service, although it is not a commercial success.

The first real European challenge to the U.S. commercial aircraft industry was launched in 1965 with a collaborative program to develop a European wide-body jumbo jet, Airbus. After initially unsuccessful negotiations, the major partners (Great Britain, France, Germany, The Netherlands, and Spain) reached investment, finance and work sharing agreements. Today, despite

financial losses estimated to be greater than \$10 billion, Airbus can offer a family of aircraft models. The consortium has been technically and operationally, but not economically successful. There is now pressure from several government sponsors for the consortium to function as a commercial enterprise and show a profit. However, Airbus continues to require significant government subsidies. The Airbus program has helped expand and diversify the aeronautical R&D capabilities of the partner states. It has also reduced European dependence on American civil transport and subsystem suppliers. Although U.S. content in early Airbus products was estimated to be some 30 to 35 percent of their value, U.S. content in later products has been steadily declining. In 1980, Airbus had only a 7 percent share of large commercial jet transport orders. In 1987, its share of orders had grown to a substantial 27 percent.*

The new large transports being developed by Boeing, Douglas and Airbus for delivery in the 1990s will be generally similar to their current transports. The emphasis is on reducing the purchase price of derivative aircraft—incorporating extensive use of new materials such as composites and aluminum lithium through production techniques, and design commonality to help control the cost of ownership—rather than developing new designs. Performance improvements gained from wing design and propulsion system refinements have already been introduced in new models and will receive further attention.

Derivative designs are the present focus because they are less costly to develop and certify. New designs or systems will be carefully assessed as to their commercial value in the marketplace from operating cost and/or service considerations. To this end, manufacturers are stressing commonality of components and systems, as well as reliability, in their aircraft families.

At the same time, the Airbus A320, a narrow-body twin jet transport certificated and placed in opera-

* Drexel Burnham Lambert, *Research Report*, January 25, 1989. It should be noted that market share of orders can vary considerably from year to year. Thus, in 1988, Airbus received 18 percent of jet transport orders compared with 27 percent the previous year.

tion in Europe in early 1988, incorporates a number of state-of-the-art technology features including: a high-performance supercritical wing; an excellent high-lift system; wide use of composite materials in secondary structures, and a digital side-stick, fly-by-wire manual and automatic flight control system. In these areas, the Europeans are ahead of U.S. manufacturers in the commercial application of new technology.

Civil aviation manufacturers around the world consider an advanced supersonic transport to be the next likely major transport advance. However, advanced supersonic transports have many technological problems.^{1,2} U.S. manufacturers have indicated that there must be a clear economic benefit before they could make a commitment to the launching of any all new airplane, subsonic or supersonic. Boeing has, accordingly, postponed a program with the Japanese to launch a new propfan aircraft.

General Aviation

The general aviation market is made up of piston- and turbine-powered business and private aircraft, and commuter aircraft of 70 passengers or less and weighing under 40,000 pounds. Foreign producers have increased their share of the U.S. market - less in terms of unit shipments than in sales dollars. A majority of the more active foreign aircraft manufacturers are government-owned or controlled. In some cases, specific aircraft market sectors have been targeted to promote national prestige. Inroads in the commuter aircraft market have been due in large measure to the fact that, with few exceptions, U.S. firms chose not to enter this market.

Foreign-manufactured general aviation aircraft make extensive use of U.S. manufactured engines, avionics, and other subsystems and components. Their quality has improved with increasing experience in design, production and servicing.

The cost of product liability insurance places a large financial burden on domestic general aviation manufacturers while foreign manufacturers are shielded from extra-territorial application of U.S. tort laws. In addition, there are a greater number of U.S. aircraft in the world fleet that must be covered; foreign manufacturers have less liability exposure since their U.S. sales are relatively recent. In some cases, U.S. producers have abandoned light-plane programs where insurance costs have esca-

lated to the extent that revenue potential does not cover the costs of doing business.

Most general aviation R&T in the U.S. has been related to cost reduction and operating safety, areas left to industry and the Federal Aviation Administration (FAA). NASA research has not been aggressive or extensive due in part to the relatively low priority given to advanced technology in this industry segment. The general upgrading of technology has come from aeronautical R&T that was not specifically general aviation-oriented with two unique and recent exceptions. Several business and small private aircraft manufacturers have developed unique configurations and extensively applied composite materials in an effort to increase performance, reduce costs, and increase market share. Manufacturers have invested in new fabrication and testing techniques, and run considerable risk with regard to certification because of the general lack of experience with composites including a lack of expertise concerning them within the FAA.

U.S. general aviation manufacturers desire to maintain a strong position in what was once a technologically low-key, but is now a relatively technology-intense, industry. This may be due to the fact that the most significant manufacturers are now owned by large conglomerates who project growing markets and have the resources to invest in aggressive design and development programs.

In general, foreign technology in general aviation is the equivalent of that of the United States. Foreign as well as U.S. manufacturers are pursuing new designs, making extensive use of composites and tailoring propulsion systems for this class of aircraft. For example, the Beech "Starship," an all-composite, 6-seat business aircraft, the outcome of a multimillion dollar development program (now undergoing certification), has a foreign counterpart, the Avanti, being developed by an Italian-led consortium.

Rotorcraft

The worldwide civil rotorcraft industry has declined considerably since peaking in 1980. The U.S. industry has maintained a significant share of the market but has lost ground to the French manufacturer, Aerospatiale.³ Of the eight major helicopter manufacturers, four are in the United States and are subsidiaries of large companies with extensive aerospace and industrial interests. The four European firms — Britain's Westland,

France's Aerospatiale, West Germany's MBB, and Italy's Agusta—are government owned and supported. There are numerous consortiums in the rotorcraft industry.

The growth of the civil market has been slow compared to that of the military, and rotorcraft technology development has been paced by military requirements, allowing the U.S. industry to maintain a technological lead. However, civil design requirements focus on operating cost, maintainability, noise alleviation and passenger comfort concerns while military designs emphasize maneuverability and survivability in war zones. Civil rotorcraft thus require a dedicated design and development effort tied to projected markets. This important civil business segment has and will continue to attract competition from Western Europe and Japan.

Currently, defense budget pressures have limited spending on vertical lift R&D, and the small, uncertain civil market has tended to dampen industry interest in in-house development of new technology. However, civil sales have picked up. This may be due in part to a shrinking pool of used rotorcraft and in part to the decline in the value of the U.S. dollar.

One of the latest U.S. rotorcraft developments is the Boeing/Bell Osprey V-22 tiltrotor for the Department of Defense (DOD). This program resulted from extensive R&T that culminated in the NASA/DOD XV-15 research airplane, focused on technology development. The Osprey and derivative designs have been the subject of FAA, NASA and DOD study to determine the civil application of aircraft that operate like helicopters for takeoff and landing and tilt their twin rotors vertically for high-speed forward flight.⁴ A European consortium—EUROFAR—has been organized to study the tiltrotor for European and world markets.⁵

Other advanced U.S. rotorcraft work includes the McDonnell-Douglas Helicopter's NOTAR (no tail rotor) system aimed at improving safety and reducing noise, and the DOD/NASA jet-powered X-wing research aircraft built by Sikorsky, which takes off and lands like a helicopter. The X-wing can fly at high speeds with the rotor locked and functioning like a wing. There are no comparable foreign projects. The DOD is also supporting programs that make extensive use of composites for rotorcraft structures.

The United States has a broader, deeper base of rotorcraft aeromechanic technology than exists in Europe. Advanced flight control research sponsored by the U.S. Army and NASA has made the United States a clear leader in this field. This work includes: active rotor-control for reducing rotordynamic loads and vibration, and fly-by-wire systems that provide better control of the aircraft and that simplify the task of control for the pilot. However, foreign manufacturers have demonstrated the capability to assimilate technology quickly and convert it to both military and civil hardware.

It is believed that U.S. helicopter engine technology is generally superior to that of foreign manufacturers. However, here, as in the flight control area, close working relationships between U.S. and foreign manufacturers serve to minimize any technological lead. The U.S. gear-driven power transmission technology appears to be ahead of foreign competition with better efficiency and maintainability, and lower noise levels. U.S. military crashworthiness design standards are used throughout the world and give the United States unquestioned leadership in this area.

FOOTNOTES

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FACTORS INFLUENCING U.S. AVIATION TECHNOLOGY DEVELOPMENT

The realities of the marketplace must be taken into account in attempting to answer the question: What is required for U.S. aviation technology leadership?

Factors which are currently shaping the marketplace include:

- strong foreign competition - frequently related to government support and participation
- industry internationalization
- the development of the European Economic Community
- outlook for resolution of trade issues through GATT
- U.S. business environment, and
- cost/market influences, including airline deregulation

Foreign Competition

Competition will remain strong in all segments of the aircraft industry and will intensify in the long term. The increasing number of European and other international consortia will foster more unified, competitive, and frequently government-supported, organizations with greater resources to invest in R&D, and in the marketing and sales of advanced aircraft products.

Strong competition exists not only for U.S. prime manufacturers but also for subcontractors and suppliers. With fewer financial resources for R&D investment—resources that must be raised in private capital markets—subcontractors may be especially vulnerable to marketing pressures, and to sharing technology in order to enter markets or maintain market share.

The reality in the civil aircraft industry is that, with the largest share of the market now overseas, U.S. firms are forced to form global ties.

Internationalization

The need to seek markets overseas is one factor forcing industry internationalization. The other is the large costs and risks required for the design development,

production and marketing of new advanced-technology airplanes—including the long time needed to reach market, and thus market assurance, and the uncertainties and risks of achieving profitability. Arrangements to meet such a market situation include joint ventures with equity participation such as the Airbus Industries consortium. Another is a cross-national network of major subcontractors working under the direction of a single designer-developer. This is the approach of McDonnell-Douglas for its MD-11 commercial transport. Major foreign subcontractors on four continents supply components of the MD-11, as well as U.S. subcontractors. As new companies mature in the less developed countries, they have and are likely to continue to team up across international borders. For example, Brazil has joined with France on a helicopter development program and with Argentina on a new commuter airplane design. More international collaborations will focus on research and technology development rather than simply production sharing.

Globalization is just as evident in the engine sector. Aircraft engines have become prime candidates for international consortia because of the considerable cost and time required for development and the uncertainties of eventual compatibility with or application to aircraft being developed.

International business relationships generally involve some element of technology sharing and thus tend to shorten the period of time during which any one country can maintain dominance in a particular technology.

The European Economic Community

In 1992, the European Economic Community plans to replace its bilateral and multilateral intra-community trade arrangements with a single market without trade borders or barriers, and with unified financial and tax structures.¹ The EEC will then be more nearly equivalent to the United States as an economic entity. The planned economic integration of Europe should provide impetus to joint undertakings among European nations, by relieving cumbersome administrative and management problems. It is likely that cooperation will focus ever more strongly on avoiding competing programs, improving industrial cooperation, and the more efficient use of combined R&D and manufacturing resources.

Many current joint U.S.-European co-development ventures are based on the technological assets each partner brings to the project. Whether the emergence of an integrated European regional capability in aircraft development and technology will affect these relationships remains to be seen. It is likely that U.S. collaboration with European partners in the civil aircraft industry will continue, especially where the U.S. partner has definitive technology to contribute.

Outlook for GATT

Under the General Agreement on Tariffs and Trade (GATT) rules and the Civil Aircraft Agreement, multilateral trade agreements govern trade in civil aircraft, provide for duty-free entry of all civil aircraft products into signatory countries, and establish certain disciplines concerning government financial support to their aircraft industries. Despite the agreements, many governments continue to erect barriers to free aircraft trade through subsidies and pressures on purchasing decisions. Interpretation of treaty language remains the basis for continuing disagreement and discussions among competing countries. In addition, a number of countries with growing aircraft production capabilities—Brazil and Indonesia and Australia, among them—have not signed the agreements.

Progress on resolving some of these important issues through GATT has been extremely slow and—while it is important to press for resolution—U.S. firms cannot count on a lessening of competitive pressure through negotiated solutions. Rather, technology investment will continue to be of major importance as a competitive factor and will serve to make U.S. firms attractive partners in international business relationships.

The GATT itself has yet to deal with a host of new trade issues including the multilateral treatment of the important services area. Bilateral agreements between nations (including the U.S.-Canada Free Trade Agreement) and regional agreements such as the European Free Trade Area raise questions about prospects for multilateralism in trade matters.

Bilateral arrangements—sales accompanied by offset, worksharing, investment and other agreements—are not new to civil aviation. It is yet to be seen how the broader international agreements will affect the industry.

U.S. Business Environment

The economic climate of the United States, particularly disincentives for saving and the high cost of capital for investment, is generally recognized as contributory to a short-term perspective on the part of U.S. businesses. Low profit margins resulting from greater world competition, and the lack of incentives to invest in R&D with long-term market potential, are enormous handicaps over the long term.

The aerospace industry as a whole experienced a considerable increase in its taxable rate (over 21 percent) as a result of the 1986 corporate tax changes.² In addition, it has experienced little benefit from incentives to increase R&D spending since its level of R&D funding has historically been high.

Overly restrictive policies on technology exporting and licensing, which ignore foreign technology availability, inhibit sales and allow competitors to gain business.

Anti-trust regulations, while now permitting many joint research arrangements among industry, still limit what might be possible and advisable in terms of product development cooperation. New approaches could stimulate greater industrial spending on technology application.

Incentives to investment with a longer-term perspective may be even more important to U.S. suppliers of civil aircraft subsystems and components than to original equipment manufacturers.

Cost and Market Influences

The civil aircraft industry worldwide has and is continuing to undergo profound changes. Airline deregulation and privatization, large reduction in fuel prices, fluctuating interest rates, the changing value of the dollar, and environmental concerns are just a few of the dynamic factors that influence the industry and make business predictions difficult. Increasing worldwide competition has produced downward pricing pressures in a generally inflationary economic environment. Holding down aircraft selling prices while maintaining profitability has made reducing costs (through technological improvements in all aspects of aircraft design, development, and manufacturing) a priority for manufacturers. New tech-

nology and its application *must* be cost effective.

Foreign manufacturers, operating with government support through subsidies or ownership positions, have less incentive than their U.S. counterparts to minimize costs or to achieve profitability. Indeed, to gain market share, foreign manufacturers have used the strategy of developing more aggressively than their U.S. competitors with little apparent regard to cost. In today's market, airlines are unwilling to pay extra for advanced technology options; however, these options are attractive if the price need not reflect the manufacturers' costs.

The Impact of Deregulation

U.S. airline deregulation and the trend to deregulate and privatize the airline industry abroad has profoundly changed the civil aircraft transport marketing environment. In a price-and route-regulated industry, the market emphasis was on aircraft performance, plus passenger comfort and amenities. Under deregulation, airlines often have high debt ratios and are under-financed. Aircraft and engine leasing has become a popular method of fleet acquisition by capital-poor airlines.

Aircraft operators now demand and need aircraft with high operational and maintenance efficiency. Such features as the two-crew cockpit and commonality of on-board equipment and flight systems have become more important to operators and drive the design of new models.

The increasing public demand for air travel and the aging of airline fleets worldwide insure a continuing demand for new, technologically upgraded aircraft. Crowded skies and inadequate capacity at key major airports have increased the market demand for larger aircraft for both trunk and feeder/commuter operations and, possibly, for a new kind of civil aircraft, the tiltrotor, to increase service effectiveness in congested areas with city-center to city-center operations.

While these changes have spurred the need for new and upgraded aircraft, they also, taken together, have introduced an instability into the market and forced on U.S. manufacturers a more conservative approach than formerly in its application of advanced technology.

With few exceptions, such as business aircraft, the industry places emphasis on product cost reduction

through the use of low-risk, short-term technology developments. The pressure on U.S. manufacturers to keep prices down inhibits the introduction of new, costly technology unless it provides significant performance improvement or operating cost reduction. It is also the judgment of U.S. manufacturers that aircraft purchasers/operators are reluctant to buy advanced technology or systems that are not fully proven.

Market and cost pressures reflective of the current competitive environment in the civil aircraft industry tend to lead to reduced profits, which could be reflected in reduced investment in RT&D, especially longer-term R&T. This does not appear to have been the case until now. U.S. industry realizes that R&T is critical to market leadership. However, there is industry and government concern that too little is being invested in the vigorous pursuit of what is variously called systems technology, technology validation or technology development to fill the technology readiness gap. Of specific concern is building the technology base that provides the ability to apply advanced technology with low risk and high confidence in performance, reliability and cost estimates.

FOOTNOTES

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