Recent Trends in U.S. Aeronautics Research and Technology (1999)
Commission on Engineering and Technical Systems

A CLEAR INFLUENCE: TRENDS IN AERONAUTICS R&T

Although a strong national program of aeronautics R&T may not, by itself, ensure the competitiveness of the U.S. aviation industry, the committee agrees with earlier studies [4] that without it, the United States is likely to become less competitive in aeronautics relative to countries with stronger programs. Aviation is an R&T-intensive industry. Maintaining a successful, state-of-the-art aeronautics industry has required that a higher percentage of net sales be invested in R&T than other industries associated with rapid innovation and application of scientific advances, such as pharmaceuticals and scientific instruments (Figure 4). [5]

Some aeronautics R&T programs have produced “breakthroughs” that are immediately usable. NASA’s low-drag cowl for radial engines and “coke-bottle fuselage” to reduce transonic drag rise are examples from the past. In the Department of Defense, more recent aeronautics breakthroughs include shaping for stealth; multi-axis thrust vectoring exhaust nozzles integrated with aircraft flight-control systems; fly-by-wire flight control technologies; high-strength, high-stiffness fiber composite structures; and tilt-wing rotorcraft technology. Many of these advances have been achieved in partnership with NASA R&T programs and are finding widespread use in both military and commercial aircraft. [6]

More often, aeronautics R&T advances are evolutionary, and a substantial number of years can pass before the aviation systems making use of these advances enter service. Modern aircraft are complex “systems of systems,” and advances in one discipline, such as aerodynamics, may require an advance in another discipline, such as structures, before they can be applied in a new aircraft design. Years of validation, testing, and certification are, therefore, usually required before a new aeronautics R&T development can be exploited.

Figure 5 shows that aeronautics R&D funded by U.S. industry dropped by almost 50 percent between 1988 and 1991, followed by reductions in sales and employment. Figure 6 shows that the Administration’s funding requests for NASA aeronautics R&T have been steadily reduced each year since 1994. Figure 7 shows a similar decline in Department of Defense funding for aeronautics R&T. As the two traditional sources of support for aeronautics R&T, industry and government, have been falling in the United States, government support for aerospace R&T in the European Union has been growing (Figure 8). [7]This correlates in time with Europe's increasingly successful economic challenge to the United States in aeronautics.

National Research Council. 1992. Aeronautical Technologies for the 21 st Century. Aeronautics and Space Engineering Board. Washington, D.C.: National Academy Press.

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Figure 4 , as labeled, shows funding for research and development (R&D), which is quite different than R&T. This report uses R&T to denote basic and applied research and technology demonstration (e.g., "6.1" and "6.2" and "6.3" funding within the Department of Defense), whereas R&D can include all aspects of product development. The focus of this study is R&T. However, in some cases, the committee was unable to obtain data on R&T levels and trends. In those cases, the report relies on data for R&D (as in Figures 4,5,6, and 8). Although the R&D data depicted in these figures is not the same as R&T funding, they represent the best data available to the committee and are useful for purposes of trend analysis and comparative studies of R&D among different industries, as shown. Each chart uses one term or the other, and the charts that depict R&D funding are used only to show trends over time or to contrast levels of R&D among different organizations.

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IGURE 6 NASA aeronautics and R&D funding history (in millions of FY 1998 constant year dollars).

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The applicability of many aeronautical technologies to both military and civil aircraft illustrates the dual-use nature of aeronautics R&T, which is discussed further in Appendix A .

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European governments do not release data on how much *aeronautics* R&T they support, so the committee relied on data for aerospace R&D, which includes aeronautics R&D.

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LIKELY CONSEQUENCES IF TRENDS ARE

NOT REVERSED

As already noted, a competitive aeronautics industry is important in terms of both national security and economic factors, such as employment and the nation's balance of trade (Figure 9).

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Militarily, a dominant aeronautics capability projects a U.S. global presence and influence as no other technology does, or will do, for the foreseeable future. No other capability allows for the rapid projection of force over long distances or is as flexible in providing combat air support for ground forces. The United States needs a strong aeronautics capability to meet its international commitments and responsibilities in an uncertain and volatile global political environment. This future capability rests solidly on today's aeronautics R&T investment.

With regard to economic factors, a recent market study (summarized in Figure 10) projects a worldwide civil aircraft market of $810 billion over the period 1999 to 2008. The study showed that large civil transports account for over one-half of this market. The remainder is comprised of regional/corporate airplanes, military airplanes, and civil and military rotorcraft. In addition, $274 billion in gas turbine engine sales are projected over the same period, more than one-half for aviation uses, [8]and the projected market for aircraft retrofitting and modernization is $20 billion. In total, the world market for aeronautics products is expected to exceed $1 trillion over the next 10 years, and most of it will be captured by companies (and countries) who have made and continue to make sizeable investments in aeronautics R&T.

The market study cited above provides information only on the primary economic benefits from goods and services associated with aeronautics R&T. Secondary benefits are also accrued. For example, investments in air traffic control systems worldwide are expected to range from $41 to $58 billion. [9]Also, the technology to develop efficient gas turbine engines has been used to develop gas turbine engines for other uses, such as ship propulsion and emergency electrical generation in critical buildings. In fact, examples of the general applications of aeronautical technology abound. These secondary benefits not only add to the gross national product, but they also enhance national security, the economy, and the general quality of life.

Government aeronautical test facilities are another area of concern. The construction, maintenance, upgrading, and use of some of the nation's specialized aeronautical testing facilities, typified by large-scale wind tunnels, are company or university assets, but most have been built and operated by the government—NASA or the U.S. Air Force, for example. Many facilities have been or are being closed down, the U.S. government has backed away from proposals to construct major new facilities, and U.S. aircraft companies are increasingly going overseas to perform wind-tunnel testing of new U.S. designs. [10]

The committee believes that aeronautics in the United States can ill afford to lose highly educated, motivated engineers and scientists. This core group is essential for advancing the state of the art and developing innovative new generations of vehicles and systems. The knowledge and understanding of aeronautical engineers who have had first-hand experience with flight hardware is lost if it is not passed on—on the job—from one generation of practicing aeronautical engineers to the next. As a result of industry consolidations and the end of the Cold War, the number of new commercial and military development programs for military and commercial aircraft has been significantly reduced. In this environment, developing experimental aircraft is one approach for maintaining the skills of aircraft designers. Furthermore, in the experience of committee members, the cutting edge of aeronautics R&T is most attractive to young, talented engineers and scientists. Therefore, continued reductions in aeronautics R&T would damage the personnel base required to maintain a robust, competitive aeronautics industry capable of supporting U.S. national security and economic interests.

Although knowledgeable observers may differ in their assessments of the degree of the severity of the consequences, the committee wishes to point out that continued reductions in funding for aeronautics R&T may have irreversible consequences. Once the position of the United States in aeronautics is lost, it will be exceedingly difficult to regain because of the difficulty in reassembling the infrastructure, people, and investment capital.

RECOMMENDATIONS

This committee agrees with the findings of many previous studies: [11]

Aeronautics as an ongoing enterprise is important to national security, the national economy, and the quality of life in the United States.

Aeronautics R&T is important to the aeronautics enterprise in the United States.

The committee concluded that consolidations in the aeronautical industry, especially in the airframe development and manufacturing industry, the end of the Cold War, and the increasing globalization of the aircraft industry do not affect the general requirements for facilities and other resources essential to effective aeronautics R&T. In some instances recommendations from the earlier studies have taken on greater urgency. The continuing decline in the U.S. market share for commercial jet transport aircraft, recent regional conflicts, and the Air Force's decision to devote more of its assets to space developments and operations in an era of declining overall budgets have made the needs for strong support for aeronautics R&T more urgent.

The committee agrees with the conclusion reached by other studies that government funding of aeronautics R&T is worthwhile. [12] In particular, the committee endorses the three key goals identified by the National Science and Technology Council: [13]

Maintain the superiority of U.S. aircraft and engines.

Improve the safety, efficiency, and cost effectiveness of the global air transportation system.

Ensure the long-term environmental compatibility of the aviation system

The committee endorses NASA's response to these challenges, in which it defined three pillars, supported by 10 technology enabling goals (see Box 1). The second and third goals of the National Science and Technology Council can be considered as broadening the old "higher, farther, faster" pure performance objectives of the past. Where the National Advisory Council for Aeronautics (NACA, the predecessor to NASA) and the military were once the primary federal organizations involved in aeronautics R&T, now the Department of Defense, NASA, the U.S. Department of Transportation (including the Federal Aviation Administration), and the National Science Foundation all have significant R&T programs related to aviation. The focus of each program is determined by each agency's missions, legislative charter, and annual budget appropriation. The importance of coordination among these agencies is increasingly important for at least three reasons:

The result of the overlapping responsibilities arising naturally from greater density of aviation operations and the growing sophistication of flight systems, which are increasingly dependent on electronics, optics, and computers.

The burgeoning costs to develop increasingly capable aeronautical systems under the pressure of constrained budgets.

The widespread acceptance in the military of “dual-use science and technology” (combining civil and military applications) and commercial-off-the-shelf equipment and systems for military applications. As stated by the National Science and Technology Council, “Nationally we have the infrastructure—government, industry and universities— to maintain leadership. We must now renew our focus on partnership to meet national challenges and accomplish national goals.” [14]

The committee recommends that major improvements be made in the coordination of aeronautics R&T activities among NASA, the Department of Defense, the Federal Aviation Administration, industry, and academia. An overarching organization for national aeronautics R&T is needed to speak for national values, ensure efficient use of resources, make cooperative actions more productive, and eliminate duplication where it is not an effective motivator of competition. Successful collaborative programs (e.g., AGATE, NRTC, and IHPTET [15]) should be examined to identify characteristics adaptable to this purpose. [16]

Aeronautics is an R&T-intensive enterprise. The committee is convinced that continued reductions in government support of aeronautics R&T would jeopardize (1) the ability of the United States to produce preeminent military aircraft and (2) the ability of the aeronautics sector of the U.S. economy to remain globally competitive. A rigorous proof of this conclusion requires detailed military, technical, and economic analyses that the committee was unable to complete during this brief study. However, the committee is greatly concerned that ongoing reductions in R&T, which seem to be motivated primarily by the desire to reduce expenditures in the near term, are taking place without an adequate understanding of the long-term consequences. The committee recommends that the federal government analyze the national security and economic implications of reduced aeronautics R&T funding before the nation discovers that reductions in R&T have inadvertently done severe, long-term damage to its aeronautics interests.

In addition, for the United States to succeed in the globalized world aviation market, the nation requires clearly defined national objectives for aeronautics R&T. These objectives should be established considering our national requirements and how they can best be satisfied with active participation from industry and government developers as well as the military and commercial technology users of aeronautics R&T results. Continuing inputs from these four components are crucial to the implementation of technologies needed to keep the United States militarily secure and globally competitive.

Appendix A
Additional Factors Influencing the Committee's Findings and Recommendations

IMPACT OF AERONAUTICS ON NATIONAL SECURITY

History since World War I has demonstrated that a superior aeronautical capability is usually determinative in military operations, and it will be the key to our ability to wage future wars, large or small. Advanced aeronautical systems will enable us to achieve our military objectives while minimizing American casualties. Surface forces, including civilians, cannot be secure without "control of the skies." Friendly bases will not always exist and prepositioned forces will not always be in place. A quick response to distant points of conflict requires air transportation.

Knowing where the enemy is and knowing his capabilities are crucial to successful war fighting. Airborne reconnaissance and intelligence operations continue to be essential capabilities of air power, even in the presence of improving space assets. The disruption of enemy supply lines and communications, antitank and antiartillery actions, and attacks on enemy fortifications are all critical to military operations. Search, rescue, and rapid movement of wounded to hospitals are also tremendously important airborne capabilities, not only because of the lives saved—the overriding consideration—but also because of the effect on the morale of those who must go in harm's way.

IMPACT OF AERONAUTICS ON THE NATIONAL ECONOMY

In earlier sections of this report economic factors were cited as evidence of the importance of aeronautics to the nation. The contribution, however, of the aeronautics industry to the gross domestic product (GDP) may be the best measure of an industry's importance to the economy. Broadly defined, the U.S. aviation industry contributes approximately $436 billion per year of total output (direct and indirect) to the U.S. economy (Table 1). The net contribution to GDP has been estimated to be $259 billion, or 3 percent, of GDP.

In addition, as an employer, the combined aeronautics and space industry, which are inseparable in terms of fundamental disciplines, have significant research related employment in manufacturing, maintenance, and repair s services throughout the United States.

Total Output

Contribution to GDP *

Air transportation (including air freight)

$205 billion

$80 billion

Aircraft manufacturing

$134 billion

$94 billion

Tourism

$94 billion

$85 billion

Travel agents/freight forwarders

$3 billion

N/C

Government

$2 billion

N/C

Total

$438 billion

$259 billion

N/C=Not Calculated.

*Induced economic impacts are not included in the reported results. The difference between total output and the contribution to GDP is inter-industry transactions.

Source: L.Anderson, NASA Glenn Research Center presentation to the NRC, “Impact of Aviation on the Economy,” June 1999.

IMPACT OF AERONAUTICS ON THE QUALITY OF LIFE

As a means of travel, flight may appear as just one more step in an evolution that progressed from foot, to the use of animals, boats, ships, railroads, and automobiles, and, finally, aircraft and spacecraft. But because of the increases in speed aircraft have made possible, the effect of that speed on economic productivity and the accessibility of long-distance travel have made the effect of air travel on the quality of life more revolutionary than evolutionary.

As one result, tourism is now the world’s biggest business. More people travel over large distances to vacation than ever before. And for people who must travel, air travel has effectively increased their life span by reducing the time spent traveling.

In the mid-1990s, roughly 6,000 commercial air carrier aircraft, large and small, were in use, along with about 115,000 general aviation aircraft, mostly for “personal” use rather than as “executive” business aircraft. [1]See Figure 11 is an indication of how many people fly commercially, for business and pleasure. These aspects of aeronautics profoundly affect the quality of life for U.S. citizens.

Noise and noxious effluents from aircraft engines, along with the noise produced aeroacoustically by rotors, propellers, and the turbulence of landing gear wheel wells during takeoff and landing, are environmental aspects exacerbated by the exponential growth of aircraft operations taking place in the United States and worldwide. Adverse effects around airports have already been responsible for retiring certain older transport aircraft and requiring the re-engining of others. For those who live and work in the vicinity of airports, the effect of aircraft on the environment will certainly influence both the convenience and economics of their businesses and the general quality of their lives. Aeronautics R&T can reduce the environmental impact on the air-side operations at airports; in the long term, a short-haul civil tilt-rotor operating from satellite airports has the potential to improve the ground-side environment.

GLOBALIZATION

The globalization of the aeronautics industry has been increasing steadily. Cross-border relationships are driven by (1) the need for capital formation; (2) access to markets; and (3) synergies created by specific combinations of corporate strengths. In the propulsion sector, for instance, cross-border relationships include a risk and revenue-sharing partnership between Pratt and Whitney and MTU [2](Germany); CFM International, which is a joint venture between General Electric Aircraft Engines and Snecma (France); and the ownership of Allison by Rolls-Royce (Great Britain). In each of these cooperative ventures, the U.S. component of the relationship had to “win” its position in the partnership by having the capability to bring state-of-the-art technology to the program and to perform competitively. NASA and Department of Defense aeronautics R&T have helped U.S. companies develop state-of-the-art technologies and, in so doing, have helped create high-quality U.S. jobs, contributed to a positive balance of trade, and have created other economic benefits in the aerospace sector of the economy. This is a positive outcome of aeronautics R&T that should receive continuing recognition on the part of funding agencies.

IMPACT OF INDUSTRY CONSOLIDATION

The U.S. aerospace industry has been changed markedly in this decade by mergers of both major defense contractors and large commercial transport manufacturers. These mergers have been driven by the reduced defense market, the need to reduce the cost of products by eliminating duplicated overhead functions (e.g., payroll, purchasing, contracts) and underused manufacturing facilities, and the increased cost and complexity of commercial and military aircraft, including the integration of related systems (e.g., avionics). This consolidation of manufacturing companies appears to arouse congressional resistance to the use of government funds to support aeronautics R&T, which opponents sometimes label as “corporate welfare.” In fact, the global competition in aircraft markets precludes any claim that the large commercial transport industry is monopolistic. For example, the competition to the Boeing Company is supplied by Airbus Industries, which develops technically advanced and competitive jet transports with the help of the governments of England, France, Germany and Spain. The Eurofighter program is another example of joint multi-government/industry cooperation to achieve technical excellence and competencies. Further, the total number of wage earners adversely affected by the industry consolidation process is not nearly as large as the changes in company names suggest. Lockheed Martin, for example, still has a division in Fort Worth, Texas (formerly part of General Dynamics), the Skunk Works in Palmdale, California, and a division in Marietta, Georgia (formerly Lockheed). The Boeing Company still operates the military projects division and Phantom Works in St. Louis and a transport division in Long Beach, California (all three formerly McDonnell Douglas), in addition to its operations in Seattle, Washington, and Wichita, Kansas. The Boeing Company also has helicopter development divisions in both Philadelphia, Pennsylvania and Mesa, Arizona (formerly McDonnell Douglas). As the market for aircraft and missiles shrinks the associated work force will shrink. Further, consolidation has reduced the number of organizational entities available to support aeronautics R&T.

AERONAUTICS AS A “MATURE INDUSTRY”

The aeronautics industry, particularly the civil aeronautics industry, is frequently described as a “mature industry,” implying that it is characterized by diminishing technological opportunities and low returns on R&T investment. Although there are significant exceptions, most of the economic activity in aeronautics is conducted by large, well-established, “mature” companies. However, aeronautics technology is far from mature, if mature means there is limited opportunity

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for growth. Technological advances continue to produce important improvements in performance and affordability, even if those advances are not readily visible to the eye. For example, the C-17, C-141, and C-5 look very similar, but the advanced technologies incorporated in the structures and systems of the C-17 contribute to capabilities and operational performance unmatched by the older C-141 and C-5 (Figure 12). Aeronautics technology tends to be limited by ideas, not by basic physics. In the past, the U.S. aeronautics program has generated technical opportunities; with stabilized funding, the NASA and DOD aeronautics R&T program could be structured to *continue* generating technical opportunities.

Aeronautics R&T has many areas of great opportunity reflecting its R&T-intensive nature and use of inputs from other R&T-intensive industries. The application of information technology to aircraft controls, guidance and navigation, traffic management, and propulsion is only one example. The use of advanced metallic and composite materials is another. The industry also faces ample opportunities for far-reaching innovations in production management and methods. Like the pharmaceuticals industry, the top tier of firms in aeronautics is complemented by a very large number of smaller supplier firms, many of which are relatively recent entrants to the industry. In at least some supplier sectors, such as avionics, significant entry by new start-up firms has occurred and is bringing innovative vitality to the industry.

In short, the characterization of aeronautics as a mature industry says little if anything about the level of technological opportunities. In the judgment of this committee, there is little reason to anticipate that these opportunities will diminish in the near future. Indeed, the continued social demands for quieter, safer, and more environmentally friendly air transportation all require innovative responses.