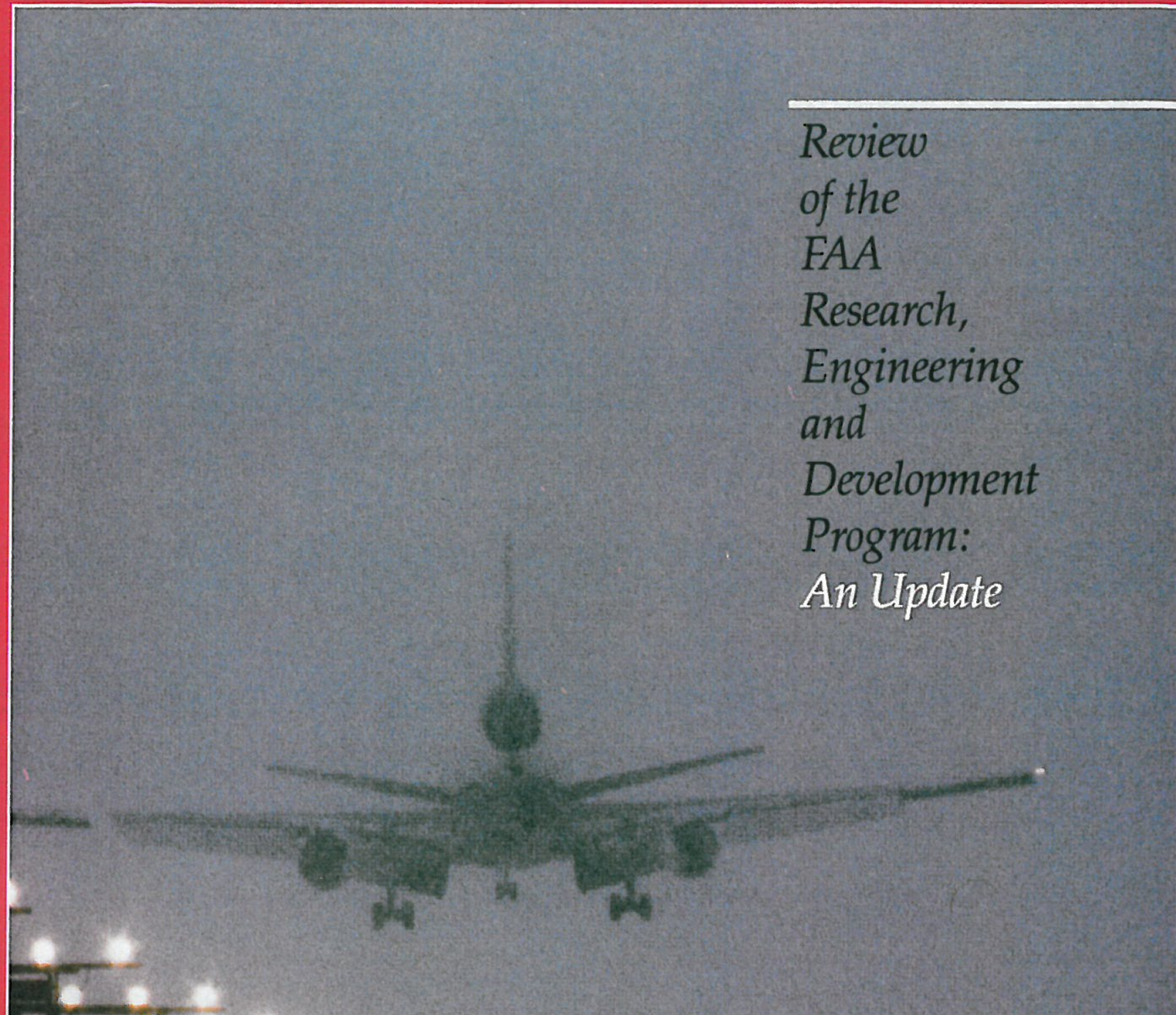
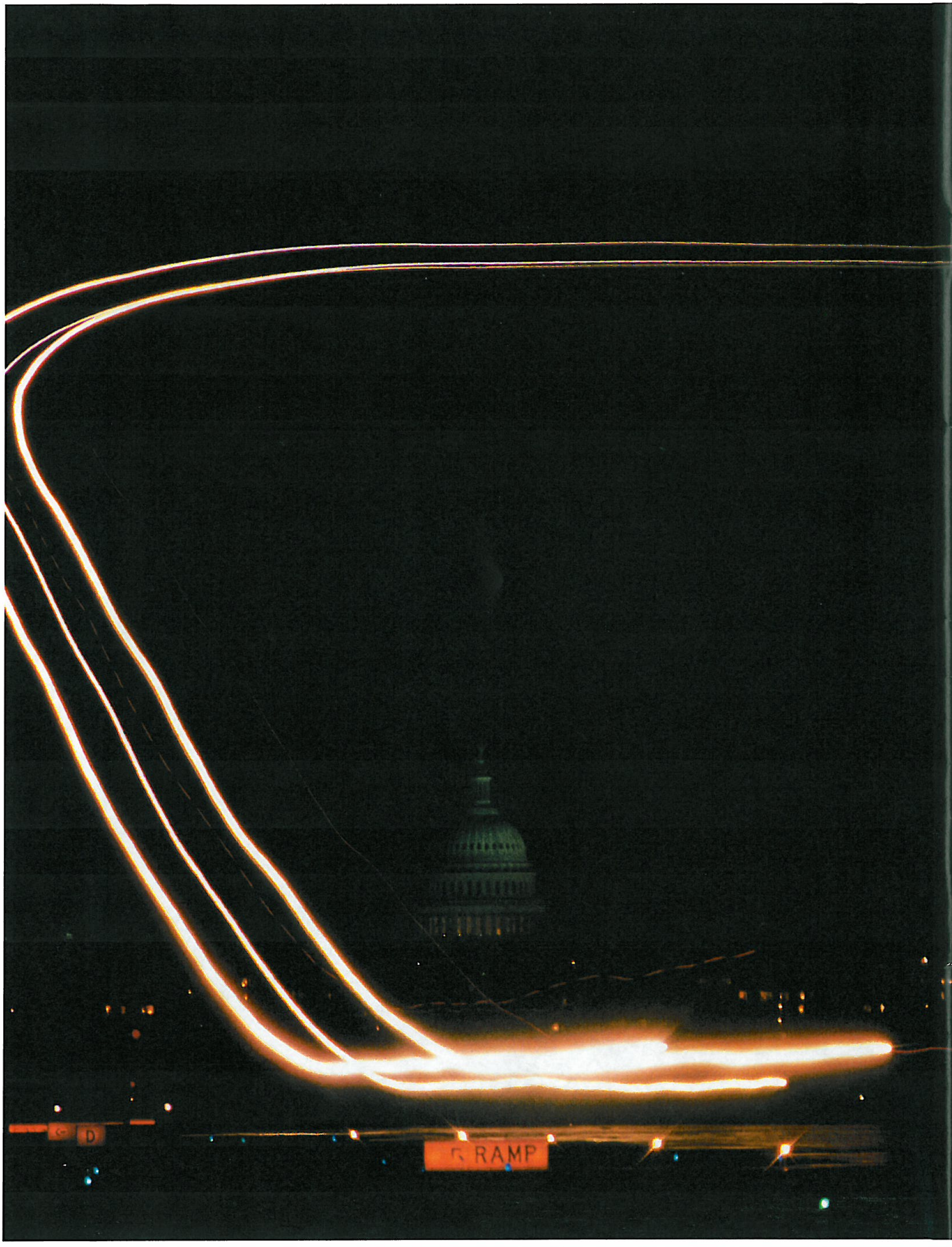
Review of the FAA Research, Engineering and Development Program: An Update

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U.S. Leadership in Air Traffic Services

An Update of the Earlier Review of the FAA Research, Engineering and Development Program

R&D Plan Review Panel
of the FAA Research,
Engineering and
Development
Advisory Committee

January 1993
Washington, DC

Additional copies of this report or the original report of November 1991 may be obtained from:

Federal Aviation Administration
Office of the Associate Administrator for System Engineering and Development, Attn: ASD-6
800 Independence Avenue, S.W.
Washington, DC 20591 (202) 287-8543

R&D PLAN REVIEW PANEL
OF THE
FAA RESEARCH, ENGINEERING AND DEVELOPMENT
ADVISORY COMMITTEE

January 21, 1993

To: The Administrator of the Federal Aviation Administration

Early in 1991, FAA management concluded that an independent, outside assessment of the adequacy of the FAA's technology pursuits would be appropriate. A panel of the FAA Research, Engineering and Development Advisory Committee was established to undertake such a review and completed its work on November 25, 1991, submitting a report of its findings at that time.

A number of actions have been taken by the FAA in response to the above report, and in October 1992 the review panel was requested to reconstitute itself for the purpose of conducting an updated assessment. The findings of that further examination are presented herein.

For many decades U.S. air transportation has set the standard of quality for the world. Today, that position of leadership is being severely challenged. Particular concerns lie in the areas of capacity (delays), security, and safety improvement. Progress in each of these areas is heavily technology dependent.

It is the conclusion of the Panel that significant improvements have been made by the FAA in its organization and in its process for managing research, engineering and development tasks. In addition, progress has been made in finding accelerated and innovative ways to build new systems using commercial technologies, and a road map for future air traffic management systems has been created. However, the number of FAA personnel with the necessary technical expertise to meet future requirements remains too small, and the overall research and development underpinning of the nation's future air traffic management system continues to be severely underfunded. As a consequence, limitations on the nation's aviation infrastructure can be expected to become increasingly debilitating in the years ahead.

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Summary

FAA Research and Development (R&D) is not funded adequately to deal with the increasing demands on the nation's air traffic management system. Now is the time to revitalize the R&D efforts which will provide the foundation for modernization in the future.

The international aviation system has been built on innovations created for the most part in the United States, brought to reality by imaginative research and development efforts. Virtually every meaningful FAA modernization effort to date has had its roots in research and development conducted in the preceding 10 to 15 years.

The United States today stands in serious risk of losing world leadership in aviation and suffering the loss in competitiveness, jobs and convenience which that portends. Underpinning the current leadership position, built over the larger part of a century, is the nation's air traffic infrastructure — a responsibility of the FAA. Both adequate funding and a larger forward-looking cadre of FAA personnel will be required if America is to maintain this position of leadership.

Boeing Flight Line

Air Traffic Management Leadership

The U.S. has played a prominent role in the development of air transportation ever since the Wright Brothers invented the first practical airplane in 1903, and the U.S. has benefited commensurately. World War I expedited the early technological development of the airplane and in the years between World War I and World War II the U.S. fostered civil applications by emplacing an air navigation and control system across much of the country. This system, initially consisting of no more than fires and rotating flashing lights, in some cases emitting Morse Code signals, served to navigate early aircraft to and from open-field landing sites. Just prior to World War II, rudimentary weather and instrument flying capabilities were incorporated, permitting relatively safe, controlled air commerce — often government underwritten via such programs as air mail transport.

With the technological advancements achieved in aircraft design and the greatly increased air traffic demand during the Second World War, more sophisticated air traffic control systems and procedures became necessary. The Civil Aeronautics Board, the Civil Aeronautics Authority, and, today, the Federal Aviation Administration, over the years established the world's standards for aviation certification together with the operational procedures that enabled the rapid, safe and economical growth of the world's aviation infrastructure as we know it today. It was the U.S. standards for aircraft, systems and procedures that propelled the world into the jet transport age. But this age is now nearly 40 years old.

During the intervening years the U.S. economy benefited significantly from its world leadership position in aviation — not only from the sale of civil aircraft and from airline operations, but also from ground support, airport facilities, air traffic control technology, radars and aircraft-based avionics systems, to mention but a few sources of revenue.

In 1989 it was estimated that aviation related activities accounted for almost 5.5 percent of the nation's gross national product (GNP). Direct annual impact was estimated at $165 billion, enabling the employment of two million persons. The total economic activity attributable to aviation, including induced activities, brought total economic impact to about $552 billion and provided for the employment of some eight million persons (Figure 1).

In 1991, the U.S. aviation industry experienced a favorable balance of trade of $29 billion which, together with other aerospace activities, comprised the single largest positive contribution to the trade balance. Analyses of the airline industry have suggested that some 40 major industrial groups tracked by the Bureau of Economic Analysis are impacted by purchases by the airlines. These economic sectors range from specialty metals and metal fabrication to a host of agricultural groupings, and include most of the major service sectors in the U.S. economy. The economic health of the airlines has been found to influence many other components of the U.S. economy.

Annual U.S. passenger enplanements now approach 500 million, or the equivalent of twice the entire population of the U.S. flying each year — or the population of Detroit flying every day of the year.

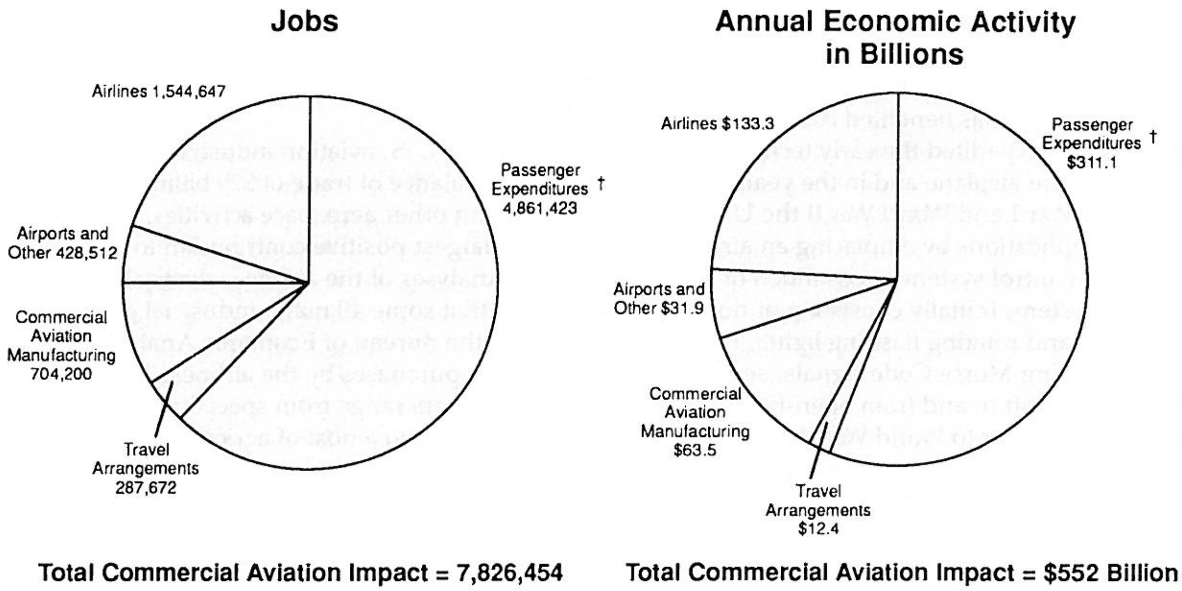
Evolving business and manufacturing practices increasingly rely on rapid and reliable transportation for documenting transactions, providing parts for just-in-time production and shipping end-products. The value to the economy of the incremental improvements in air transport capacity and reliability needed to keep pace with expected growth in demand may well dwarf this industry's current contribution to the GNP.

In spite of the past accomplishments of U.S. aviation, this, the final decade of aviation's first century, finds most U.S. airlines in dire financial circumstances; segments of general aviation manufacturing generally driven abroad,[1] commercial aircraft manufacturers hard pressed by foreign government-supported producers; and an air traffic management system verging on saturation and potentially vulnerable to intentional disruption.

It is this latter system, the air traffic management system, which is of immediate

[1]In a speech delivered on December 9, 1992, the Administrator of NASA remarked, "The U.S. market share for commuter aircraft is almost zero, and the situation in general aviation is equally frightening. The typical light plane is 25 years old with 40-year-old technology." He went on to say that, "Sales of general aviation aircraft have crashed from 18,000 aircraft in 1979, to 3,000 in 1984, to less than 1,000 today. In 1980, there were 29 U.S. manufacturers of certified piston aircraft and 15 foreign manufacturers. Today the numbers are reversed — only 9 U.S. firms and 29 foreign. Manufacture of single engine planes in this country is almost dead. And the number of manufacturing jobs in general aviation fell from 40,000 to 21,000 in the last decade."

Figure 1. Annual Economic Impact of Commercial Aviation* (1989)



* Includes "multiplier" effect based on the U.S. Department of Commerce input/output model
† Excludes air ticket

Source: The Economic Impact of Civil Aviation on the U.S. Economy, Partnership for Improved Air Travel, June 1990, (Wilbur Smith Associates).

concern in this review — in part because of the enormous bearing it has on other elements of U.S. prosperity. Without an adequate air traffic system, the U.S. will inevitably lose aviation leadership, U.S. passengers will suffer debilitating delays, and airline operators will have little opportunity to recoup investments initially intended to maintain competitiveness in the global marketplace. Similarly, there will be reduced opportunity for U.S. aircraft manufacturers to develop and build new aircraft if existing fleets are limited in their usefulness.

Air Traffic Management Concerns

In view of the considerable impact of air transportation on America's competitiveness and therefore its quality of life, it is significant that three major concerns persist which could seriously impair the future utility of air transport. These concerns relate to system capacity, security, and safety.

System Capacity

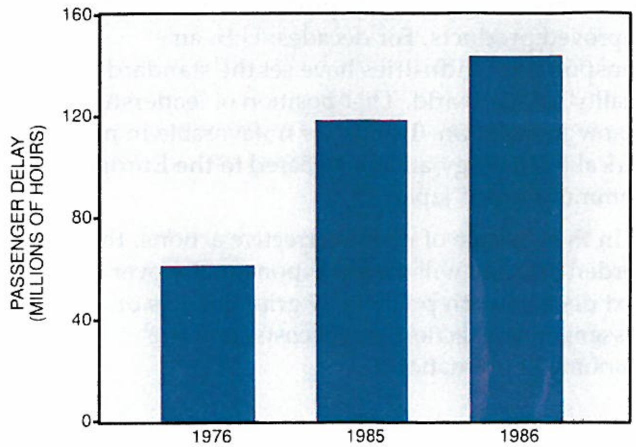
According to both airline and FAA statistics, a major source of cost to airlines is delays. Delays per operation increased by 38 percent between 1976 and 1986. A changed reporting system in use since 1987 precludes direct comparison with earlier data; however, even with airlines allowing more schedule time over established routes and increased aircraft speed, delay per operation continues to rise.

Delays continued to increase until the decline in operations between 1990 and 1991, a temporary drop attributable to the Gulf War and the economic recession. This transitory decline in operations did not, however, produce a comparable drop in average flight delay, further indicating an erosion of system capacity. The continuing routine imposition of flow control programs significantly increases costs to airlines and ultimately their passengers and shippers. It is estimated that air traffic control delays cost airlines alone $1.5 billion per year in direct operating costs (fuel, crews, etc.).

But the principal cost of airline delay is borne by airline customers through economic costs and inefficient use of their time. The FAA has estimated that almost 150 million passenger hours were wasted in 1986 due to delays; a figure that more than doubled over the 1976-1986 time period (Figure 2). While dollar values assignable to passenger time are highly subjective, the total cost most likely exceeds $3 billion annually. The costs to industry may be even greater since the cost of missed appointments, delayed production and late orders are reflected in lost business, lost wages, and degraded quality of service.

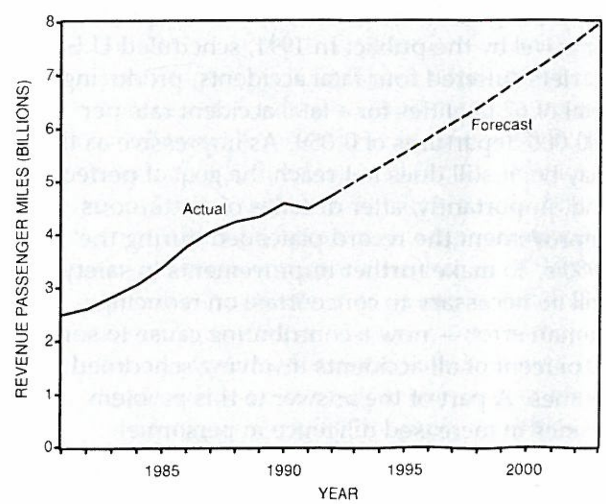
There is little doubt that increased demand for air travel will substantially increase delays in the future unless significant further improvements in the air traffic control system are undertaken. It is estimated that over the next 10 years the total number of passengers carried annually by U.S. commercial air carriers will increase from 480 million to about 750 million, with an accompanying increase in revenue passenger miles of about 300 billion over the current 473 billion (Figure 3). During this same time period the number of departures can be expected to increase from 6.3 million to about 8 million annually. Further, none of these figures includes general aviation or pure-cargo transport.

Figure 2. Annual Passenger Delay Nationwide



Source: Airline Delay, FAA Standardized Delay Reporting System.
Note: Comparable data not collected subsequent to 1986.

Figure 3. U.S. Commercial Airlines (Domestic) Revenue Passenger Miles



Source: The Annual Report of the U.S. Scheduled Airlines, Air Transport Association of America, June 1992.

In summary, most of the priority personal travel and business and manufacturing practices of our nation are geared directly to the capacity and quality of air transportation service. In the past decade, air traffic capacity has neared saturation under all but the most favorable operating conditions, and in many respects quality has deteriorated. Capacity and reliability of service are critical factors in determining quality of transportation as judged by the customer. Both of these factors are to a considerable extent technology driven.

While the cold war has ended, the U.S. is now being challenged in global marketplaces by competitors backed by powerful private-public sector compacts which are working at the frontiers of advanced technology to produce continuously improved products. For decades, U.S. air transportation industries have set the standard of quality for the world. That position of leadership is now in question. Trends are unfavorable in many critical technology areas compared to the European Community and Japan.

In the absence of major corrective actions, the burden of delay will mount exponentially over the next decade, with predictably grim impacts on passenger satisfaction, travel costs, and the economy of the nation.

Safety

In spite of the pressures for increased capacity, the U.S. air traffic management system rightfully retains safety as its first priority. A better air traffic system is a safer system.

The outstanding safety record compiled over the years greatly contributes to the acceptance of air travel by the public. In 1991, scheduled U.S. air carriers suffered four fatal accidents, producing a total of 62 fatalities for a fatal accident rate per 100,000 departures of 0.059. As impressive as this may be, it still does not reach the goal of perfection and, importantly, after decades of continuous improvement the record plateaued during the 1980's. To make further improvements in safety it will be necessary to concentrate on reducing human error — now a contributing cause to some 70 percent of all accidents involving scheduled airlines. A part of the answer to this problem resides in increased diligence in personnel selection and training, but perhaps an even greater gain is to be achieved from engineering designs that are more human-error tolerant than is the case today and that can ameliorate the problems of complacency, inattention and occasional boredom on the part of flight and ground personnel.

Security

While major confrontation by world powers now seems more remote than in recent decades, it is likely that regional and nationalistic frictions will increase the number of world locations subjected to violence. Such behavior, coupled with modern technology, will place even greater demands on the security requirements associated with air travel — as suggested by the recent downing of relief aircraft in Somalia and in Bosnia by shoulder-fired anti-aircraft missiles. Although nationalistic and ethnic conflicts will probably continue to have an impact on U.S. carriers operating abroad, the added possibility of domestic acts of terrorism cannot be ignored. While airline and airport security programs have consumed considerable resources before and since Pan Am 103 and the Gulf War, they have done so with only modest government funding and few mandated programs, largely at the expense of other urgent priorities and with only limited regard for the potential threat.

Perhaps most important is the need to evaluate future threats so that a better match is achieved between evolving risks and the development and application of new "countermeasure" technologies. Much remains to be done to assess threats realistically and to create technology or procedures to deal with sophisticated adversaries. In recent years, the U.S. aviation system has not been severely tested — a circumstance which will not necessarily prevail in the future.

Role of Research, Engineering and Development

The solutions to the problems which will adversely impact air travel in the decade ahead include many facets, among which are training and procedures. But without innovative application of new technological developments, travel delays are likely to increase greatly, safety to enjoy no further improvement, and security to be perilously dependent upon the non-emergence of more challenging threats. Future U.S. air transportation leadership resides largely in technology yet to be developed and harnessed. This conclusion becomes all the more compelling if environmental and economic considerations are to preclude significant expansion of the nation's airport system. The scheduled opening of Denver International Airport in 1993 will mark the first opening of a major new airport in the United States in 19 years.

There is no lack of technological opportunity to increase system capacity. A number of important technology applications are already available for incorporation into the nation's air transportation system. They include accurate navigation throughout the world using space-based capabilities such as the U.S. Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS) originally constructed by the Soviet Union. Similarly, satellite communications promise increased safety and efficiency: one U.S. airline has estimated fuel savings of $100,000 annually for each of its Boeing 747-400s, due solely to the enhanced ability to adapt transoceanic routing to changing weather and traffic conditions. Digital data communications should permit increased automation and reduce potential for human error, both on the ground and in the cockpit, and thereby improve safety. The revolution in computers will also lead to further enhancement of system capacity and safety. Advanced weather prediction techniques offer the promise of reductions in the 60 percent of delays now attributable to weather, much as new Doppler radars have enhanced flight safety by detecting microbursts. Wake vortex detection and amelioration can significantly increase runway utilization.

The list of promising benefits is almost endless and is indispensable to future safety, security, and the avoidance of system saturation and delay.

Fundamental research in industry and elsewhere in government is generating still more advanced technologies, many of which offer promise in resolving remaining air transportation concerns. These technologies include advanced electronics, artificial intelligence, advanced computers and other information technologies, digital telecommunications, materials, secure communications, and many more. The FAA needs the internal capability to exploit as well as contribute to the generation of this new technology if it is to enhance the performance of the nation's air transportation system.

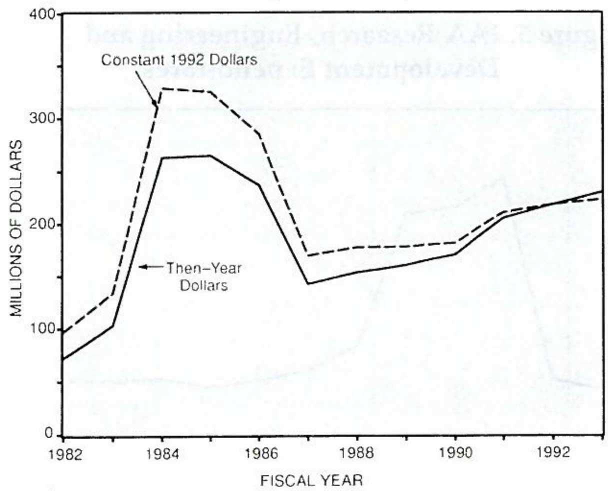
Adequacy of Research, Engineering and Development

For a number of years, the nation's civil air traffic infrastructure, safety, and certification process have all benefited substantially from technological investments made by the Department of Defense and NASA. Considerable opportunity still exists for the FAA to harvest prior achievements of this work, particularly in the space arena. But with the major reductions now taking place in defense spending, and even with increased emphasis on dual-use (military-civil) technology, the military can be expected to diminish as a major source of new air traffic-related technology. NASA, for virtually the first time in over 15 years, is also facing a declining budget in real purchasing power. Thus a greater part of the burden for the creation of essential technology to underpin the nation's future airways system will fall to the FAA itself. The Panel is concerned that the nation is, and has for years, been seriously underinvesting in the technological foundation of the airways system.

Since 1987, federal non-defense R&D outlays have increased by 79 percent, approaching 40 percent of the federal R&D budget. In contrast, FAA Research, Engineering and Development spending, measured in constant purchasing power, has remained at generally the same level of about $200 million per year for 7 years. Funding for this purpose is today substantially below the funding level at the peak year FY84 (Figure 4), although even in that year the preponderance of funding was associated with acquiring updated equipment rather than research in support of bringing further innovative technology to the field. Thus, the total budget for the FAA's R&D program tends to mask the level of effort associated with developing and implementing *new* air traffic management technology.

While the pace of funding for safety and security has been at an increased rate in recent years, the remaining areas of the FAA's R&D program, such as human factors, certification, and air traffic management have not been adequately supported. In the wake of the Pan Am Flight 103 terrorist sabotage and the Aloha Airlines airframe

Figure 4. FAA Research, Engineering and Development Expenditures



Source: FAA.

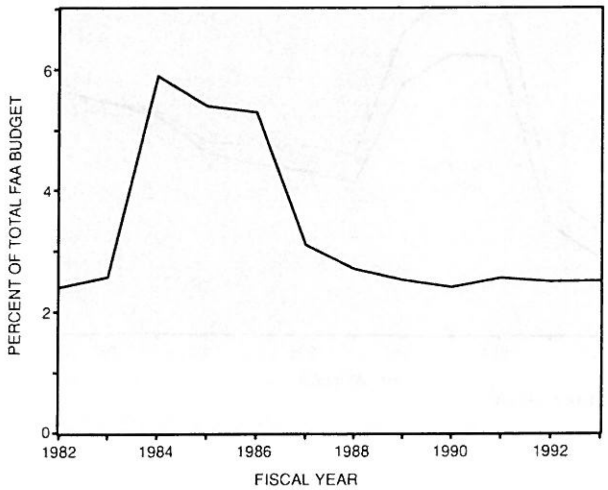
failure, steadily increasing emphasis justifiably has been placed on R&D in security and safety programs. But in an essentially level budget, this has resulted in an effective decrease in the resources available to conduct research in the area of air traffic management — notwithstanding the crucial needs identified above.

The FAA must replace the concept of air traffic control with a concept of air traffic *management*, focusing new energy on efforts to reduce delay — without compromising safety or security. Among the areas which require major additional effort are the achievement of the best balance of flow management and separation assurance; implementation of en route, terminal and airport surface automation; optimum integration of air traffic management and aircraft flight management systems; enhancement of system capacity in instrument flight conditions to a level essentially equivalent to those in visual conditions; provision of improved weather services; and the reduction of the impact of wake vortices.

In comparison with other high quality, technologically dependent organizations, whether governmental or commercial, the FAA investment in the creation of technology is at or near the lowest level of any comparable organization in the statistics examined by the Panel.

Even as a fraction of the FAA's own total budget, overall technology investment has steadily eroded, today amounting to only about 2.5 percent (Figure 5).

Figure 5. FAA Research, Engineering and Development Expenditures



Source: FAA.

Recommendation

The R&D Plan Review Panel, having reexamined its earlier findings (Appendix I), observes only increased urgency behind the majority of the recommendations previously offered. It does, however, note progress on the part of the FAA, particularly in increased organizational receptiveness toward major technological advancements — such as the use of satellites for navigation and communication. Further, improvements have been introduced into the FAA's planning for the pursuit of solution-oriented new technology and the implementation of that technology.

Nonetheless, the fact remains that the current level of investment in technology by the FAA, in both people resources and financial resources, is inadequate to deal with highly likely future demands on the nation's air traffic system. The risks and consequences of not making the necessary improvements can be expected to have serious long-term adverse impacts on the nation's economy.

The Panel, having reviewed the content of the FAA R&D Plan, believes that a level of funding of approximately $500 million annually must be allocated to the Research, Engineering and Development program by the mid-1990's if the work needed to underpin system safety, capacity and security — and, therefore, U.S. competitiveness — is to be pursued. A single recommendation is offered herein:

> ***Recommendation:*** That annual funding of the FAA research, engineering and development activity be increased stepwise to $500 million by FY96.

The above figure, although very significant, is relatively modest in comparison with the amount of FAA funds allocated to current operations or to other government R&D expenditures. The consequences of not making the needed investment are likely to be eclipsed by costs incurred by airlines, passengers and government (taxpayers) from future air traffic system inadequacies and by concomitant erosion of U.S. aviation leadership.

Appendices

I. Recommendations of Original Review

II. Panel Membership

Appendix I Recommendations of Original Review

Recommendation 1: The Panel recommends that the safe achievement of additional airspace and airport system capacity be assigned as the highest priority within the FAA research, engineering and development activity.

Recommendation 2: The Panel recommends that, in view of the conviction that historical funding levels are not adequate to execute the proposed research and development program, additional financial resources be programmed based upon a re-examination of likely costs of each individual project.

Recommendation 3: The Panel recommends that the FAA take steps to enhance competitiveness in acquiring and retaining highly qualified technical personnel, including fully utilizing recently approved government-wide personnel legislation; and that it establish centers of excellence at selected universities to address FAA-related issues and train a cadre of future leaders.

Recommendation 4: The Panel recommends that the process for establishing requirements and justifications for the technology program draw heavily upon the FAA's operating organizations and users' stated needs, but that the research and development organization also be encouraged to pursue promising technology possibilities and innovations even though they may not yet have the support of users or operating services.

Recommendation 5: The Panel recommends that the FAA's system engineering methodology be used and strengthened to translate user needs and technological opportunities into goals and to flowdown requirements, establish programs, assess results, provide integration across program areas, and serve as the basis for the allocation of technology funds.

Recommendation 6: The Panel recommends that the national simulation capability be funded on an expedited basis and used to streamline the transition of new technologies and concepts into the nation's air traffic system.

Recommendation 7: The Panel recommends that the FAA's current activities for prototyping of critical new technologies be strengthened through the provision of greater budgetary support, broader integration and increased management attention so as to expedite the fielding of new ideas.

Recommendation 8: The Panel recommends that the project manager exercise principal authority in the execution of technology programs, with the support of a qualified contracting officer, and that contracts for technology development recognize the uncertainty inherent in such activity and utilize contract instruments which appropriately balance risks between the government and its suppliers.

Recommendation 9: The Panel recommends that the latitude to determine which early technological pursuits are worthy of funding not be narrowly reposited in a few senior management individuals but rather be widely diffused throughout industry, academia, government and not-for-profit organizations through the provision of modest sums of discretionary funding to be used to encourage innovation.

Recommendation 10: The Panel recommends that the FAA plan the augmented program recommended herein with the maximum appropriate intra-governmental, academic and industrial cooperation to maximize and leverage the synergistic benefits of each of their capabilities.

Recommendation 11: The Panel recommends that a process be created which accelerates the introduction into the field of system improvements funded in the Research, Engineering and Development Plan and that all projects be supported by an implementation plan (contingent upon the success of the development effort).

Recommendation 12: The Panel recommends that an expanded portion of the funding now being devoted to security be allocated to basic research in that area, and that efforts addressing the security of data systems be considerably enhanced.

Recommendation 13: The Panel recommends that increased effort be devoted to the early application of spaceborne elements in support of the air traffic control system and to the solution of remaining integrity issues and procedure development pertaining thereto.

Recommendation 14: The Panel recommends that the FAA ensure that activities are closely coordinated in the critical human factors area and that projects described in the National Plan for

Aviation Human Factors as having FAA prime responsibility be included in the FAA Research, Engineering and Development Plan and appropriately budgeted.

Recommendation 15: The Panel recommends that the section on innovative and cooperative research be deleted as a separate topical section in the FAA Research, Engineering and Development Plan and be emphasized throughout the entire body of the Plan.

Appendix II Panel Membership

Chairman:

Norman R. Augustine Mr. Augustine is Chairman and Chief Executive Officer of the Martin Marietta Corporation and a member of the FAA Research, Engineering and Development Advisory Committee. He holds a BSE and an MSE in Aeronautical Engineering from Princeton University, where he wrote his thesis on vertical take-off aircraft, and holds five honorary doctorate degrees. He is a former chairman of the Aeronautics Panel of the Air Force Scientific Advisory Board, the NASA Space Systems Research and Technology Advisory Committee, and the Defense Science Board. He has served as Under Secretary of the Army, Assistant Secretary of the Army for Research and Development, and Assistant Director of Defense Research and Engineering. He is a member of the National Academy of Engineering, a Fellow of the Institute of Electrical and Electronic Engineers, and an Honorary Fellow and past president of the American Institute of Aeronautics and Astronautics.

R,E&D Advisory Committee Members:

Robert R. Everett Mr. Everett, a pioneer in the development of digital computers, received his BS degree from Duke University (1942) and his MS from the Massachusetts Institute of Technology (1943), both in Electrical Engineering. In 1945, he became associated with Jay W. Forrester in the development of electronic digital computers. Mr. Everett joined the newly organized MITRE Corporation in 1958, rose to President and Chief Executive Officer, and is currently on MITRE's Board of Trustees. He serves as a member of numerous boards and as Chairman of the FAA's Research, Engineering and Development Committee. He has received numerous awards and honors, including the 1990 Air Traffic Control Association's George W. Kriske Memorial Award for his contributions to air traffic control.

J. Lynn Helms Mr. Helms entered the Navy cadet program while in college during WWII, and was commissioned a Second Lieutenant in the U.S. Marine Corps in 1945. After retirement he held positions in industry of General Manager, Vice President, Group Vice President and President. He was Chairman and CEO of Piper Aircraft Corporation prior to retirement in 1980. He was nominated by President Reagan for Administrator, Federal Aviation Administration and filled that role until resigning in 1984. Mr. Helms now works as an International Consultant in the fields of strategic planning, acquisition and divestiture, high technology program evaluation and international finance.

Jonathan Howe Mr. Howe is a partner in the Washington, DC law firm of Zuckert, Scoutt & Rasenberger. Prior to joining the law firm, Mr. Howe served as President of the National Business Aircraft Association (NBAA). Mr. Howe came to NBAA from the FAA where he held several positions including Deputy Chief Counsel and Director of the FAA's Southern Region. He has been an active pilot for more than 30 years and served until recently as chairman of the FAA's Aviation Rulemaking Advisory Committee. He is currently a member of the Office of Technology Assessment (OTA) Aviation Advisory Committee, and is a member of a GAO panel examining aircraft certification. Among his numerous honors and awards is a Presidential Meritorious Award from President Carter. Mr. Howe served on Recertification Teams for both 1974 and 1979 DC10 accidents. He is a member of several local, state, and federal bar associations, and is a recognized teacher, lecturer and published author in aviation law. He attended Denstone College in England; graduated from Yale University with a BA degree, cum laude, in 1960, and from Yale Law School in 1963.

John McCarthy Dr. McCarthy is the Director of the Research Applications Program at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, where he directs the research associated with aviation weather hazards. Dr. McCarthy participates on the FAA Research, Engineering and Development Advisory Committee and the National Airspace System Design Review Team. He is past chairman of various committees of the American Meteorological Society, the American Institute of Aeronautics and Astronautics, the FAA, and the National Weather Service. He is a former Professor of Meteorology, University of Oklahoma (1973-1980). He holds a BA in Physics from Grinnell, MS in Meteorology from the University of Oklahoma, and a PhD in Geophysical Sciences from the University of Chicago.

John L. McLucas Dr. McLucas is Chairman of the Board of External Tanks Corporation, Avion Systems, Inc. He is a member of the boards of DARTRAIL, Orbital Sciences Corp, and Boeing's Technical Advisory Council. He is also chairman of International Space University, International Space Year Associates, and a member of various boards and committees of the Corporation for Atmospheric Research, U.S. Space Foundation, FAA, and the National Academy of Engineering and the Academy Committee on Science and Engineering Public Policy. He was Administrator of the FAA (1975-77); Secretary and Under Secretary of the U.S. Air Force (1969-75); and Assistant Secretary General of NATO for Science (1964-66). Dr. McLucas is the author of Space Commerce, published in 1991 by Harvard University.

John E. O'Brien Mr. O'Brien is the Director of the Air Line Pilots Association's Engineering and Air Safety Department. His career with ALPA began in 1972. In 1975, he was promoted to Deputy Director Operations, in 1978 he was promoted to Manager of Engineering and Operations; and in 1982 was promoted to his present position. Prior to coming to ALPA, he spent seven years with Pan American Airlines, two years with the airline division and five years with the aerospace services division. In addition to flying for Pan American, he was a project engineer on a study of margins for space shuttle design operations and safety. He received an MBA from Stetson University and a BSAS from Embry-Riddle Aeronautical University.

John W. Olcott Mr. Olcott is currently President of the National Business Aircraft Association (NBAA). He previously held the position of Vice President and Group Publisher within the McGraw-Hill Aviation Week Group, responsible for *Business and Commercial Aviation, AC Flyer* and the McGraw-Hill Aviation Week Groups' Show Dailies. He has fixed wing experience, is qualified on helicopters and auto gyros, and has been licensed as a flight instructor since 1956. He received his BS and MS degrees in Aeronautical Engineering from Princeton University and an MBA from Rutgers. In the early 1970's he was the principal investigator for a number of NASA-sponsored research programs. He has served as a Flight Research Specialist for Princeton University and was assigned to the Indian Institute of Technology in Kanpur, India. He is a member of numerous boards and committees, including the FAA's Research, Engineering and Development Advisory Committee, and served as chairman of the General Aviation Safety Panel (GASP).

Richard Paul Brigadier General Richard R. Paul, Deputy Chief of Staff for Science and Technology, Headquarters Air Force Materiel Command, Wright-Patterson Air Force Base, Ohio, directs the Air Force's annual $1.5 billion Science and Technology Program. He earned a bachelor's degree in electrical engineering from the University of Missouri at Rolla in 1966 and a master's degree in electrical engineering through the Air Fore Institute of Technology in 1971. He completed Air Command and Staff College, Naval War College, and the Defense Systems Management College. In 1988 General Paul became commander of what is now the Wright Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base. He directed a 3,200-person laboratory complex that discovered, developed and transitioned leading-edge technologies in materials, aero propulsion and power, solid state electronics, avionics, conventional armament, flight dynamics, signature reduction, cockpit integration, and manufacturing. He assumed his current position in July 1992. The general's military awards and decorations include the Legion of Merit with oak leaf cluster, Defense Meritorious Service Medal, Meritorious Service Medal with oak leaf cluster and Air Force Commendation Medal.

Siegbert B. Poritzky Mr. Poritzky is responsible for aviation technical matters of the Airports Association Council International-North America (AACI-NA). He joined the organization (then called AOCI) after 11 years with the Federal Aviation Administration. Prior to FAA, he worked for the Air Transport Association of America, Aeronautical Radio, Inc., the Civil Aeronautics Administration, the McDonnell Aircraft Corporation, and Trans World Airlines. He served as the U.S. member of the International Civil Aviation Organization's Special Committee on Future Air Navigation Systems. He is a member of the FAA Administrator's Research & Development Advisory Committee, chairman of the FAA Aviation System Capacity Advisory Committee Subcommittee on Capacity, Technology, and Airspace and Airport Surface Automation, and is on the Board of RTCA.

Robert Rosen Dr. Rosen is currently the Associate Director for Program Development at the NASA Ames Research Center. Prior to this, he was NASA's Deputy Associate Administrator for

Aeronautics and Space Technologies. He has served on the National Critical Technologies Panel, the FAA R,E&D Advisory Committee, and the Science and Industry Advisory Committee of the National Renewable Energy Laboratory. Dr. Rosen has held positions in industry at Rocketdyne and McDonnell Douglas, and holds BS, MS, ME, and PhD degrees. He has published over 25 technical papers in fluid dynamics and aerodynamics and has received numerous achievement awards, including the Presidential Rank of Meritorious Civil Servant and NASA's Outstanding Leadership Medal.

Jack E. Snell Dr. Snell, Deputy Director of the Building and Fire Research Laboratory, heads the fire research program at the National Institute of Standards and Technology (NIST). He has a BSE in aeronautical engineering from Princeton, a MSE degree in operations research and a PhD in transportation systems engineering from Northwestern University. He has airline and USAF(SAC) aircraft maintenance engineering experience. He is U.S. Chair of the U.S.-Japan Panel on Fire Research and Safety, on the Board of Directors of the National Fire Protection Association, chairs its Toxicity Advisory Committee, is a member of Society of Fire Protection Engineers, American Society of Testing Materials Committee E5, and a Fellow of the American Society of Mechanical Engineers.

Technical Consultants:

Albert P. Albrecht For the past 49 years, Mr. Albrecht has been active in the Aerospace community on both sides of the government-industry interface. Most of this activity has been related to Technology and Air Traffic Control (ATC). As the FAA Associate Administrator for Engineering and Development and later for Development and Logistics, Mr. Albrecht has been a major participant in the ATC development and acquisition programs. In industry, Mr. Albrecht pioneered the use of radar for ATC, developed automation and navigation concepts, and led the development of military GCA applications. Mr. Albrecht is a former member of NASA's Aeronautics Advisory Committee, a member of the Aerospace America Advisory Board, a joint author of the Electronic Designers Handbook, a Fellow of the Institute of Electrical and Electronic Engineers and a Fellow of the American Institute of Aeronautics and Astronautics.

Antonio A. Cantu Dr. Cantu received a BS degree in Chemistry and a PhD. in Chemical Physics from the University of Texas at Austin. After post-doctoral work at the University of Alberta, Edmonton, he began his career in the application of science and technology to law enforcement in 1972. He has been with the Bureau of Alcohol, Tobacco, and Firearms (ATF), the Federal Bureau of Investigation (FBI), and for the past five years with the U.S. Secret Service. His duties include threat assessments, explosive detection, hazardous material countermeasures, and forensic science. Dr. Cantu is involved in several interagency committees concerned with science and technology and terrorism.

John J. Fearnsides As Director of the FAA-sponsored Federally Funded Research & Development Center, Dr. Fearnsides leads MITRE's aviation and air traffic control R&D for the Federal Aviation Administration (FAA) and foreign governments. He also directs all of MITRE's weather-related R&D for the FAA, the National Weather Service, the National Oceanographic and Atmospheric Administration and the Federal Highway Administration. Prior to joining MITRE, Dr. Fearnsides served at the U.S. Department of Transportation holding positions of Deputy Under Secretary, Chief Scientist, Acting Assistant Secretary for Policy, and Acting Administrator of the Research and Special Programs Administration. Dr. Fearnsides has PhD, MS and BS degrees in Electrical Engineering. He has served on several National Academy of Sciences panels on transportation, and as Adjunct Professor, Engineering and Public Policy at Carnegie-Mellon University.

J. Roger Fleming Mr. Fleming joined the Air Transport Association in January 1966, served in several different capacities in the ATA Operations, Engineering and Air Traffic Management Divisions, and in December 1992 was appointed Senior Vice President - Operations & Services. Mr. Fleming serves as industry spokesman and directs ATA programs supporting U.S. scheduled air carrier objectives in matters related to aviation safety, flight operations, engineering and maintenance, and ATC system development. He has been responsible for airline industry assessments of and support for FAA's Research, Engineering and Development programs and related projects. He is also involved with FAA and airlines in planning the transition to space-based communications, navigation, and surveillance functions.

C. A. Fowler Mr. Fowler's career at MIT Radiation Lab, AIL, Department of Defense, Raytheon and MITRE includes: participant in the development of the GCA radar landing system; project engineer for the first radar air traffic control system and the first radar for civilian air traffic control; and contributor to the development and production of other radars and electronic systems. He is a Fellow of the Institute of Electrical and Electronic Engineers, the American Institute of Aeronautics and Astronautics, and the American Association for the Advancement of Science; a member of the National Academy of Engineering and the Association of Old Crows; a member and past Chairman of the Defense Science Board and the Defense Intelligence Agency Advisory Board; and a former member of the Air Force Scientific Advisory Board. He has published widely in his fields of expertise.

John F. Zugschwert Mr. Zugschwert is a 30-year veteran of military service. He served 11 years at the Pentagon, where he addressed aviation research and development. He is a member of the Army and Defense Science Boards specifically addressing aviation programs. He is also a pilot with over 3,000 hours of fixed and rotary wing flying time, and multi-engine, instrument, weapons systems qualifications and night vision technology experience. Mr. Zugschwert has experience flying the XV-15 tilt rotor, Apache, and AHIP advanced combat helicopters, and the NOTAR helicopter. He is engaged in establishing the Vertical Flight Program Office at the FAA and the NASA vertical flight program, and is presently Vice President, Washington Operations, for Bell Helicopter Textron, Inc.

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